Final report

Project details

Project title	OES Task 10 WEC Modelling Verification and Validation
Project identification (program abbrev. and file)	J.nr. 64017-05197
Name of the programme which has funded the project	EUDP17:
Project managing company/institution (name and address)	Rambøll Danmark A/S, Hannemanns Allé 53, 2300 Copenhagen S
Project partners	Aalborg Universitet DTU Mekanik Floating Power Plant.
CVR (central business register)	DK REG. NO. 35128417
Date for submission	29. 03. 2017.

1 Contents

2 Short description of project objective and results English

The International Energy Agency (IEA) Technology Collaboration Programme (TPC) for Ocean Energy Systems (OES) initiated OES Task 10 with focus on Modelling, Verification and Validation of Wave Energy Converters in 2016. The objective is to improve confidence in the numerical tools used in the design and prediction of power production from Wave Energy Converters.

The development of Wave Energy Converters relies on numerical simulations to optimize and evaluate their designs and provide the power performance estimates that feed into calculations of the Levelized Cost of Energy (LCOE). The reliability and accuracy of the numerical tools used is therefore of paramount importance.

Within the scope of the current phase of the project, answers have been obtained to the original problem statement. Specifically, confidence has been gained in the numerical models and a first step made towards quantitative identification of model accuracy.

Calculations based on linear and weakly-nonlinear potential flow theory provide fast and reliable results which are suitable for all phases of the design process. High-fidelity, fully nonlinear potential flow or CFD models can provide more accurate and detailed results in cases with steep waves and/or large-amplitude responses, but they require careful and diligent set-up and validation to be reliable.

The main unexpected result of the project was the level of difficulty that exists in obtaining high-quality experimental data which is suitable for distinguishing the accuracy of the different numerical models.

3 Kort beskrivelse af projektets målsætning og resultater Dansk

Det Internationale Energiagentur (IEA) Technology Collaboration Program (TPC) for Ocean Energy Systems (OES) indledte OES Task 10 med fokus på modellering, verifikation og validering af bølgeenergimaskiner i 2016. Målet er at skabe tillid til de numeriske værktøjer, der anvendes i design og beregning af elproduktion fra bølgeenergimaskiner.

Udviklingen af bølgeenergimaskiner benytter numeriske simuleringer for at optimere og evaluere deres design og beregne den årlige energiproduktion, der indgår i beregninger af Levelized Cost of Energy (LCOE). Pålideligheden og nøjagtigheden af de anvendte numeriske værktøjer er derfor af afgørende betydning.

Inden for rammerne af projektets nuværende fase er den oprindelige problemerklæring blevet besvaret positivt. Der er opnået tillid til at de numeriske modeller testet giver samme resultat og med et første estimat af kvantitativ modelnøjagtighed.

Beregninger baseret på lineær og svagt ikke-lineær potentiel teori giver hurtige og pålidelige resultater, som er velegnede til alle faser af designprocessen. High-fidelity, fuldt ikke-lineære potentiel-flow eller CFD-modeller kan give mere præcise og detaljerede resultater i tilfælde med stejle bølger og/eller store gensvarsamplituder, men de kræver omhyggelighed og påpasselig opsætning og validering for at være pålidelige.

Et uventede resultat i løbet af projektet var at data fra eksisterende førsteklasses eksperimentelle modelforsøg, alligevel viste sig mangelfulde i valideringsprocessen i forhold til at vurdere nøjagtigheden af de forskellige numeriske modeller.

4 Executive summary

The International Energy Agency (IEA) Technology Collaboration Programme for Ocean Energy Systems (OES) initiated OES Task 10 with focus on Modelling, Verification and Validation of Wave Energy Converters (WECs) in 2016. The objective is to improve confidence in the numerical tools used in the design and prediction of power production from Wave Energy Converters.

The development of Wave Energy Converters relies on numerical simulations to optimize and evaluate their designs and provide the power performance estimates that feed into calculations of the Levelized Cost of Energy (LCOE). The reliability and accuracy of the numerical tools used is therefore of paramount importance.

This EUDP project was approved in March 2017 for a period of 3 years and results were presented at webinars and workshops in the project period. The partners have also prepared and submitted conference and journal papers.

The testcase performed as part of OES Task 10 are important generic reference cases for numerical modelling of WECs.

- The theoretical heaving sphere formed WEC
- The experimental heaving Mask Basin float
- The KRISO OWC
- Dedicated experimental sphere verification

This international collaboration under the OES project builds on results obtained by experts from different member states. The task on Numerical modelling of WECs is established as a permanent task that will continue if the participating members can find the resources to carry out the work.

Within the scope of the current phase of the project, answers have been obtained to the original problem statement. Specifically, confidence has been gained in the numerical models and a first step towards quantitative identification of model accuracy has been made. The main unexpected result of the project was the level of difficulty that exists in obtaining high-quality experimental data which is suitable for distinguishing the accuracy of the different numerical models.

The conclusions drawn from this project can be summarized as follows:

1. Calculations based on weakly-nonlinear potential flow theory provide fast and reliable results for the design process with regard to operational conditions.
2. High-fidelity, fully nonlinear potential flow or CFD models can provide more accurate and detailed results in cases with steep waves and/or large-amplitude responses, but they require careful and diligent set-up and validation to be reliable.
3. Most existing model-test data is not suitable for distinguishing the relative accuracy of different numerical models, due to large uncertainties in the generated incident waves and/or the measured device responses. There is a need for dedicated, high-quality benchmark experimental data with well-defined uncertainties.

5 Project objectives

Ocean Energy Systems (OES) is a Technology Collaboration Programmes (TCPs) under the International Energy Agency (IEA). OES was founded in 2001 by Denmark, the United Kingdom, and Portugal, and now includes 25 member countries.

The OES Task 10 on WEC modelling verification and validation was identified by 13 experts from 7 countries attending the workshop in 2016 as a task that was very suitable for international co-operation, with the overall goal to assess the accuracy of the numerical models used, and to improve confidence in these codes. The task is like offshore wind validation/verification projects (OC3-OC5 conducted within IEA Wind Task 30).

The long-term objectives of the OES task 10 are:

1. To assess the accuracy and establish confidence in the use of numerical WEC models

2. To validate a range of validity of existing computational modelling tools

3. To identify uncertainty related to simulation methodologies in order to:

   a. Reduce risk in technology development
   b. Improve WEC energy capture estimates
   c. Improve loading estimates
   d. Reduce uncertainty in LCOE models

4. Define future research and develop methods of verifying and validating the different types of numerical models required depending on the conditions:

- *Operational conditions* significant wave height Hs<5 meters*:* Validation of energy production and power take-off (PTO) optimization
- *Survival conditions* significant wave height Hs > 12 meters*: Validation of* structural and mooring system loads, and operation of the PTO and structural motion in extreme conditions

The OES task 10 started on a voluntary basis in a period in which the teams conducted numerical coding and calculations, included two webinars in which the preliminary results were discussed. At the Workshop held in March 2017 it was agreed to prepare a reference paper based on these results for the EWTEC conference 2017. To bring the work further the US, Sweden and the Danish participants had received national funding, and all other partners agreed to try find their own financial support.

Participation was and is open to all interested partners, and initially a total of 29 organizations from 13 countries joined the project. The participants include universities, research laboratories, commercial software developers, consultants and WEC developers. The numerical models range from linear and weakly nonlinear potential flow models, through fully nonlinear potential-flow models, and fluid dynamics (CFD) solvers.

The work in the OES WEC modelling task is, so far, mainly focused on operational conditions, concentrating on a range of regular wave cases and long-term irregular sea states, so there was a risk that the focus was too narrow and leaves out extreme loading cases. During the project complimentary work is being undertaken in the Collaborative Computational Project in Wave Structure Interaction, in which members from the wider wave structure interaction community have been participating in blind comparative studies involving the interaction of focused wave events with various surface-piercing structures. Also, the network WECANET has emerged under which simulations and experiments are undertaken. The OES Task 10 has chosen the strategy to co-operate with these emerging groups of similar interest and benefit from these additional efforts undertaken – and so far, this strategy has been successful.

The project has developed according to the scheduled plan. The detailed description and choice of the test cases were selected along the way by the participating experts of the OES Task 10 group and based on their actual interests and needs. This approach has been successful and necessary as many of the participating partners carried out the work without funding.

Problems facing the project that were not expected have been related to the quality of experimental data selected for verification. The participants found even selecting high quality test data at relatively large scale – imposed a challenge when it came to detail. This could be simple issues such as calibration errors, synchronisation of time series of different measured quantities etc. Surprisingly, there were also more fundamental problems in obtaining an accurate description of the undisturbed incident wave in some experiments. Such problems could lead to delays in deliverables, but at the same time comfort could be found in the fact that the simulated results compared well between the partners – which lead us to challenge to accuracy of the experimental measurements.

6 Project results and dissemination of results

The Project has been structured in 6 Work Packages

WP 1 Project management and co-ordination of the OES Task 10

WP 2 Verification and validation practice and metrics

WP 3 Baseline cases for experimental comparison

WP 4 Simulation results analysis

WP 5 Dedicated experimental test data for model validation

WP 6 Dissemination

WP 1 Project management and co-ordination of the OES Task 10

Ramboll has been the lead partner in management, coordination and correspondence with the project partners, EUDP and OES-IEA and the international expert group.

This has included
1. Preparation of cost statements and progress reports to the EUDP
2. Face to face meetings between the project partners
3. Webinars between the Danish and international group
4. Workshops for all interested parties

WP 2 Verification and validation practice and metrics

This WP focused on a code verification study and setting up procedures for data submission, analysis and comparison. NREL shared lessons learned from offshore wind validation/verification projects (OC3-OC5 conducted within IEA Wind Task 30). An important lesson "start simple" was integrated into the approach of the OES Task 10 group.

As a result, a floating sphere was selected as the verification test body. Methodologies was developed for specifications of the WEC system, including the dimensions, mass properties, and system parameters for each of the simulation tests to be performed during this study. The methodology followed involved the following steps:

1. Description of geometries and layout

2. Specification of Hydrodynamic Coefficients

3. Specifications of variables and simulation cases:

   - Hydrostatic test: Geometry, mass, mass-distribution and external loads
   - Heave decay test: Initial displacement, and PTO setting
   - Regular waves: Wave period and wave height
   - Irregular waves: Spectrum type, significant wave height and period

The data was uploaded and stored on an NREL share-point site made available for the project. This database was used for benchmark model verification and test cases for comparison, as well as code-to-code comparisons.

Participating Organizations
National Renewable Energy Lab
Sandia National Labs, Ramboll, EC Nantes,
MARIN, University College Cork
Tecnalia, Cascadia Coast Research
Kriso, Aalborg University
EDRMedeso, Wave Venture
WaveEC, Floating Power Plant
Hawaii Natural Energy Institute
Glosten, DTU, INNOSEA
Plymouth University, KTH
Queen's University Belfast, ANSYS
BCAM, Dynamic Systems Analysis

Table 1. Participating Organizations.

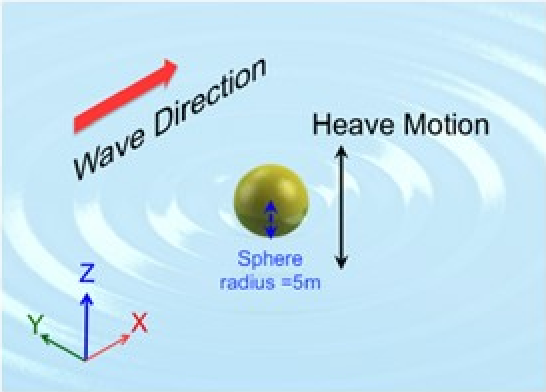

Figure 1 Illustration of the heaving sphere experiment and partners involved

The results of the floating sphere simulations are described in the conference papers for:

- 12th European Wave and Tidal Energy Conference EWTEC, Ireland 2017.
- The 3rd International Conference on Renewable Energies Offshore, Portugal 2018.

The first paper serves as a joint reference paper for the group.

All results are stored at the NREL open point share files and access can be obtained by contacting by email NREL.: https://openpoint.nrel.gov/sites/IEA_WECVV/SitePages/Home.aspx

WP 3 Baseline cases for experimental comparison

The first baseline case using existing experimental data for validation was the surface-piercing float as shown in Figure 2. The Float was used in a testing campaign led by Sandia National Laboratories, in the US. The waterline diameter is 1.8 m, with a total weight of 880 kg. The float has cylindrical sides and a conical shape below waterline. The hydrodynamic coefficients of the float were computed using WAMIT and supplied to the participants.

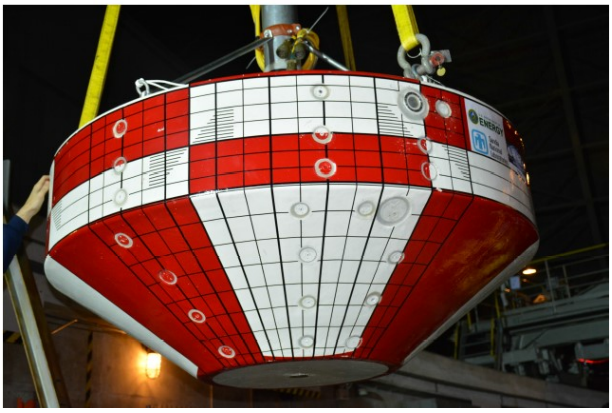

Figure 2 Sandia float used for experimental verification

For model validation difficulties were encountered related to the inherent uncertainties of the wave data in relation to the position of the float. Linear models appear to be in good agreement with weakly and fully nonlinear models, for this case.

The results from the Sandia test simulations were presented and discussed at webinars and included in the journal paper in J. Mar. Sci. Eng. 2019. The journal paper is open access and can be found at: https://www.mdpi.com/2077-1312/7/11/379

Following the heaving float test case, the group discussed which type of WEC would be suitable as the next test case. The decision was made to focus on an Oscillating Water Column (OWC) type of Wave Energy Conversion system which has been built as prototypes in several countries.

Experimental data from relatively large-scale OWC tests performed by the Korea Research Institute of Ship & Ocean Engineering (KRISO), was offered to the OES Task 10 group, as a basis for Verification and Validation of numerical models. Fig. 3 shows the OWC experimental model.

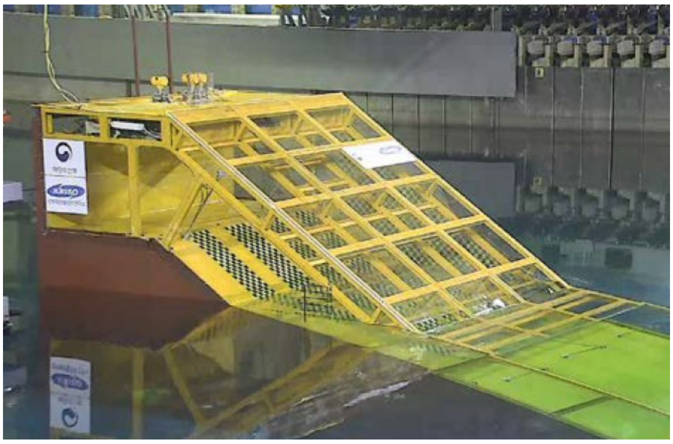

Figure 3 The experimental setup for the KRISO OWC model verification

The experiment was conducted in the 3.2 m deep ocean basin of KRISO which is 56 m long and 30 m wide. In this experiment tests in regular waves with various periods and heights were used. A beach type wave absorber was located at the far end of the basin to dissipate the generated waves.

The results of the simulations and comparison with experiments were presented and discussed at webinars and at the workshop in November 2019. The test-data from KRISO turned out to have relatively large uncertainty with regards to the accuracy by which it had been collected and calibrated and post processed. This resulted in some delay and the final processing is ongoing. Also this experience highlighted the need for dedicated benchmark experimental programs (see WP5).

WP 4 Simulation results analysis

The principles for simulations and analyses also followed a structure developed as part of the project. The Specification of output data format for Post-processing and Analysis was provided in the writeup, in connection with each numerical testcase.

All participants submitted their results from simulating the response over each experimental condition. This included: their model of the incident wave forcing; the motion response of the device; forces on the device, including Power Take Off (PTO) forces; and the absorbed power. All simulated data was then analysed and compared the experimental data both directly (as time-series) and statistically in terms of amplitude components.

The results of the OES Task 10 participants show in general good agreement between the different numerical models. Although the comparison with experiments was in general reasonable, due to the uncertainties in the experimental measurements, it was not possible to draw firm conclusions about the relative accuracy of the different models. Thus, the objectives of the project were successfully achieved, and clear recommendations for future work have been identified.

The numerical results show that the power absorption of a device can theoretically be increased by means of a negative spring, which alters the system's resonance frequency – this provides incentives to conduct additional numerical simulations of controlled WEC systems, which will require realistic control strategies with a description of the adopted method and complete specification of the PTO/mooring equipment.

The calculation of annual energy production from waves depends on both the distribution of the wave conditions and the WEC, the importance of which is discussed in the paper for the International Conference on Renewable Energies Offshore, Portugal 2018.

WP 5 Dedicated experimental test data for model validation

As a first step towards the goal of high-quality benchmark experimental data with well-defined uncertainties, a dedicated experimental program was initiated as part of this EUDP project. An aluminum sphere of 300mm in diameter was constructed to extremely high tolerances, both in terms of its geometry and its mass properties. A dedicated drop-test mechanism was also built and confirmed to produce a high-accuracy impulsive release of the body to produce decay test data at various initial drop heights. Measurement of the motion was confirmed to be accurate to well below 1mm. This data made it possible to characterize the accuracy of numerical simulations carried out in the first phase of the project as shown in Figure 4. Since the original calculations were made at a much larger scale than the experiments, the CFD simulations were re-run at the correct scale to finalize the comparison. This presentation of this work in a journal paper is in progress.

The experimental setup and experimental procedure include

- The fabrication of the sphere
- Placement, weight and ballast
- Experimental setup
- Instrumentation to measure motion in 3D and radiated waves at 3 positions
- Data files and plots

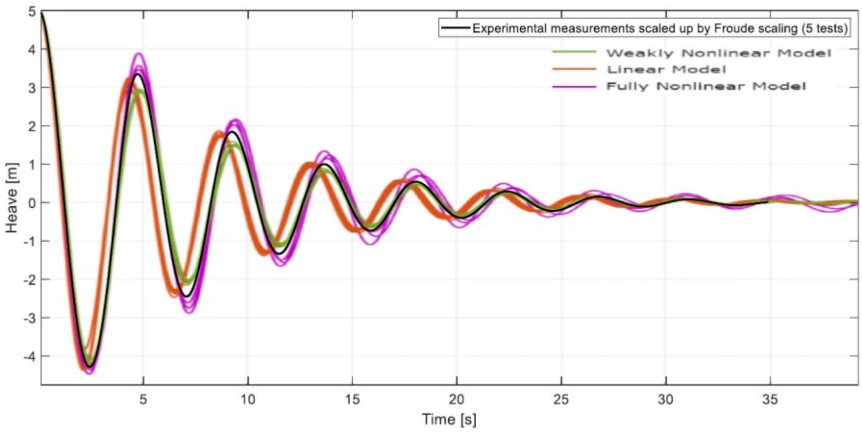

Figure 4 The black line is the dedicated experiment performed at the end of the EUDP project compared to the numerical simulations at the beginning of the project using linear theory, weakly-nonlinear and fully-nonlinear calculations.

WP 6 Dissemination

The OES TCP is providing the OES Task 10 WEB page: https://www.ocean-energy-systems.org/oes-projects/wave-energy-converters-modelling-verification-and-validation/

A summary of OES task 10 is included in the OES annual reports from 2017, 2018 and 2019. https://www.ocean-energy-systems.org/publications/oes-annual-reports/

Additionally, the OES Exco 2019 has asked for a proposal to deliver a high-quality report to be submitted to the OES in 2020 -2021. A proposal has been submitted to the OES in January 2020. The proposed report will focus on the long-term goal to establish confidence in the use of numerical WEC models in design and power production calculations.

OES Task 10 results have been presented in connection with the OES EXCO.

The OES Task 10 participants have been collaborating virtually via 11 Webinars, and 3 Workshops where the Danish group and the international group could meet in person.

The Danish group have held four project meetings in Denmark and disseminated results at two Partnership meetings under the Danish Partnership for Wave Power.

Workshop 2016 09 05 Initial OES Task 10 Kick-off

Webinar 2017 01 17 Initial Sphere results

Webinar 2017 02 28 Core group

Workshop 2017 03 14

32nd Executive Committee Meeting April 2017, Principality of Monaco

Webinar 2017 09 19 Average power production

DK project meeting 2018 03 13 Ramboll, Copenhagen

Webinar 2018 03 18 Numerical to Existing Experimental Test Case (Mask Basin)

Webinar 2018 05 16 Presentation of initial results from the group

Webinar 2018 08 01 The results from the Radiation and diffraction tests

DK Partnership meeting 2018 09 11 Presentation

Webinar 2018 11 08 Final compilation a very uniform set of calculations

DK project meeting 2018 12 06 Ramboll, Copenhagen

Webinar 2019 01 17 Review of past and discussion of selection of new test case

DK project meeting 2019 04 30 Ramboll, Copenhagen

DK Partnership meeting 2019 04 30 Presentation

Webinar 2019 05 21 focused on OWC as tested at KRISO

DK project meeting 2019 08 27

Webinar 2019 09 25 Presentation and discussion of initial OWC simulations by NREL

37th Executive Committee Meeting September 2019, Dublin, Ireland

Workshop 2019 – 11 – (14-15) KRISO Simulation of Experiments

Webinar 2020 01 29 Presentation and summary of results from Workshop

6.1 The Project Milestones

M1. A report on the wave energy simulation model verification and validation metrics.

This report was prepared in the form of two conference papers, one for EWTEC 2017 and one for the RENEW 2018 presented in Lisbon. The papers include the results on the first comparison of WEC numerical models with a 1-DOF analytical case used for baseline verification of computational modelling tools.

1. Wendt, F.; Yu, Y.H.; Nielsen, K.; Ruehl, K.; Bunnik, T.; Touzon, I.; Nam, B.; Kim, J.; Kim, K.H.; Janson, C.; et al. International Energy Agency Ocean Energy Systems Task 10 Wave Energy Converter Modeling Verification and Validation. In Proceedings of the 12th European Wave and Tidal Energy Conference (EWTEC), Cork, Ireland, 27 August–1 September 2017.

2. Nielsen, K.; Wendt, F.; Yu, Y.; Ruehl, K.; Touzon, I.; Nam, B.; Kim, J.; Kim, K.; Crowley, S.; Sheng, W.; et al. OES Task 10 WEC heaving sphere performance modelling verification. In Proceedings of the 3rd International Conference on Renewable Energies Offshore (RENEW 2018), Lisbon, Portugal, 8–10 October 2018.

M2. A report on presentation and verification by comparison between numerical results and model-scale experimental results

The M2 report was prepared in the form of a journal paper including comparison of WEC numerical models with a 1 DOF analytical case used for baseline verification of computational modelling tools, presentation and comparison with experimental model scale verification.

3. Wendt F.; Nielsen, K; Bingham, H; Eskilsson, C; Kramer, M; Babarit, A; Bunnik, T, R Wendt, et al. Ocean Energy Systems Wave Energy Modelling Task: Modelling, Verification and Validation of Wave Energy Converters. In J. Mar. Sci. Eng. 2019

The journal paper can be found: https://www.mdpi.com/2077-1312/7/11/379

M3. A report on simulations developed for code-to-code comparison that gives a side-by-side comparison of the simulation results of selected generic WEC types such as cylinders, flaps and OWC.

The M3 report is in the preparation phase one on the results from the KRISO tests, due to delay in the experimental data from KRISO this report is still under preparation and will be lead by DTU.

M4. A report on code-to-experiment comparisons to verify and validate the side-by-side comparison of the data.

The M4 report is in the preparation phase and are expected to be published as a journal paper lead by AAU within a few months.

The main unexpected result of the project was the level of difficulty that exists in obtaining high-quality experimental data which is suitable for distinguishing the accuracy of the different numerical models. This highlights the need for dedicated benchmark experimental programs.

The results from several model teams simulating the same WEC are presented. The agreement of their simulations is discussed and the openness and confidence in the relevance of the models described. In addition, the possibility to calculate the power output from a specific WEC technology is described.

7 Utilization of project results

This international OES Task 10 project provided the opportunity to collaborate on numerical and experimental results from Wave Energy Conversion systems provided and obtained by experts from different member states. Established as a permanent task under OES-IEA Technology Collaboration Platform it is possible to continue and expand the work into the future. This gives a unique chance for the participants and members to have time to find the necessary resources to carry out the work. Within the scope of the current phase of the project, answers have been obtained to the original problem statement. Specifically, confidence has been gained in the numerical models and a first step towards quantitative identification of model accuracy has been made.

The main result of this study is the reliability of results of using linear, weakly nonlinear and fully nonlinear models in small and medium wave conditions. This is an important result and shows that linear models can be used instead of computationally costly nonlinear ones for most design purposes.

In this work, numerical modelling tools with different levels of fidelity have been used, in terms of capturing nonlinear hydrodynamic effects, to simulate two different heaving bodies and one OWC chamber. The code-to-code comparison revealed the significant impact of geometric nonlinearities on the simulation results. The weakly nonlinear models that consider the instantaneous wetted surface for hydrostatic and wave forcing forces can capture the impact of geometric nonlinearities on the response of the system. These nonlinear effects eventually impact the power performance predictions.

However, larger differences among the different models that consider strong nonlinearities was observed. Some of these differences can be attributed to the fact that CFD-type models require a lot more input from the user in terms of model definition (e.g., meshing, solver settings, and turbulence models). Some of the differences among the various high-fidelity CFD solutions are also related to the fact that different simplifications were applied to model the flow field (e.g. inviscid and irrotational flow versus URANS-type models). It should also be noted that, for cases including wave breaking, only URANS models can handle this correctly. Fully nonlinear potential flow methods show divergent behaviour, indicating that the assumption of potential flow is no longer valid. Linear and weakly nonlinear models can, however, be forced to compute solutions that are outside this range.

For the longer simulations that involve waves, especially irregular waves, only very few solutions with strong nonlinearities were supplied by the participants, due to the very large computational cost of URANS simulations. This highlights the limitations regarding the application of CFD tools to simulate a wide range of wave/design conditions. Simulating many wave conditions eventually yields a significant amount of work in terms of meshing, which adds to the inherently large computational costs of CFD models.

The utilization by partners of results of the project is mainly:

1. The participation in the OES validation of the numerical tools is by some partners used in marketing of their services and seen as helpful when it comes to marketing and acquiring new clients or projects.
2. The other aspect concerns developing more precise numerical methods and obtaining the insight to select between a portfolio of different numerical tools for certain calculations.
3. The established database of benchmark calculations and experimental measurements provides a good foundation for future projects to build upon.

Has your business plan been updated? Or a new business plan produced?

The project is not a normal EUDP project as it is part of the OES-IEA Technology Collaboration Platform. In this context the project results are shared and part of a longer process of consolidating and validating the performance of Wave Energy Converters.

There is a huge market potential in development, design, building and deployment of Wave Energy Converters which can support the objective of the overall energy policy of a carbon free renewable energy production. In order to tap into this potential, the wide number of competing ideas and WEC concepts must be validated and the technologies must converge. In this process the co-operation under OES Task 10 on numerical models validation can play a significant role.

As a result of this project, Ramboll is investigating a strategy for establishing a consulting business on Wave Energy. One aspect of this can be the development of a toolbox for Wave Energy Systems extending the existing numerical tools used for Oil & Gas consulting by the company.

Participation in this project has boosted the confidence in DTU-Mechanical's analysis tools for WECs and is expected to support the establishment of future projects in this area.

AAU has through the OES Task 10 project gained confidence in the linear methods used and has started to work with CFD tools; giving a complete toolbox for supporting WEC technology developers. The project has highlighted the need of better uncertainty quantification of experimental data.

During the project FPP has continued the development of multi-dof models for simulating dynamic WEC motions. The collaborative work in the project has supported this development. Also the possibility to compare model simulations to the heaving sphere experiments has proved to be an extremely valuable outcome of the project, which is used in the ongoing and future model developments.

There are in respect to numerical models no patents involved at this stage, on the contrary the use of open access simulations is encouraged. As an example, the WEC Sim software developed by NREL http://wec-sim.github.io/WEC-Sim/

8 Project conclusion and perspective

The future development of wave energy converters (WECs) will be increasingly reliant on numerical simulations to optimize and evaluate their designs and provide the power performance estimates that feed into the levelized cost of energy (LCOE) predictions. The reliability and accuracy of the numerical tools is therefore of paramount importance.

The "performance before readiness" path, put forward by Jochem Weber in 2012, argues that it is most economical to make the WEC optimization and major design choices early in the development process (at low TRL) to achieve a high technology performance level, which indicates a low LCOE, before building and deploying a costly WEC prototype at a higher technology readiness level. The history of WEC development has shown many cases of overpromising and companies that after the first deployment discovered a poor performance and too costly structure.

The "performance before readiness" path requires several optimization iterations using numerical tools and validations using small-scale physical tests, and thus confidence in the numerical tools must not be questioned.

There is a need for solid verification and validation of numerical codes used in wave energy applications, both in terms of how the overall level of fidelity depends on the hydrodynamic model, and how different choices within each sub-category affect the accuracy and reliability of the computed results. Investigation of these questions is the aim of the Ocean Energy Systems (OES) wave energy conversion modelling task on the verification and validation of simulation tools for wave energy systems.

The main conclusions drawn from this project can be summarized as follows:

1. Calculations based on weakly-nonlinear potential flow theory provide fast and reliable results for the design process with regard to operational conditions.
2. High-fidelity, fully nonlinear potential flow or CFD models can provide more accurate and detailed results in cases with steep waves and/or large-amplitude responses, but they require careful and diligent set-up and validation to be reliable.
3. Most existing model-test data is not suitable for distinguishing the relative accuracy of different numerical models, due to large uncertainties in the generated incident waves and/or the measured device responses. There is a need for dedicated, high-quality benchmark experimental data with well-defined uncertainties.

9 Annex

Add links to relevant documents, publications, home pages etc.

1. Wendt, F.; Yu, Y.H.; Nielsen, K.; Ruehl, K.; Bunnik, T.; Touzon, I.; Nam, B.; Kim, J.; Kim, K.H.; Janson, C.; et al. International Energy Agency Ocean Energy Systems Task 10 Wave Energy Converter Modeling Verification and Validation. In Proceedings of the 12th European Wave and Tidal Energy Conference (EWTEC), Cork, Ireland, 27 August–1 September 2017.

2. Nielsen, K.; Wendt, F.; Yu, Y.; Ruehl, K.; Touzon, I.; Nam, B.; Kim, J.; Kim, K.; Crowley, S.; Sheng, W.; et al. OES Task 10 WEC heaving sphere performance modelling verification. In Proceedings of the 3rd International Conference on Renewable Energies Offshore (RENEW 2018), Lisbon, Portugal, 8–10 October 2018.

3. Wendt F.; Nielsen, K; Bingham, H; Eskilsson, C; Kramer, M; Babarit, A; Bunnik, T, RWendt, et al. Ocean Energy Systems Wave Energy Modelling Task: Modelling, Verification and Validation of Wave Energy Converters. In J. Mar. Sci. Eng. 2019

In J. Mar. Sci. Eng. 2019: https://www.mdpi.com/2077-1312/7/11/379

Links OES WEB page: https://www.ocean-energy-systems.org/oes-projects/wave-energy-converters-modelling-verification-and-validation/