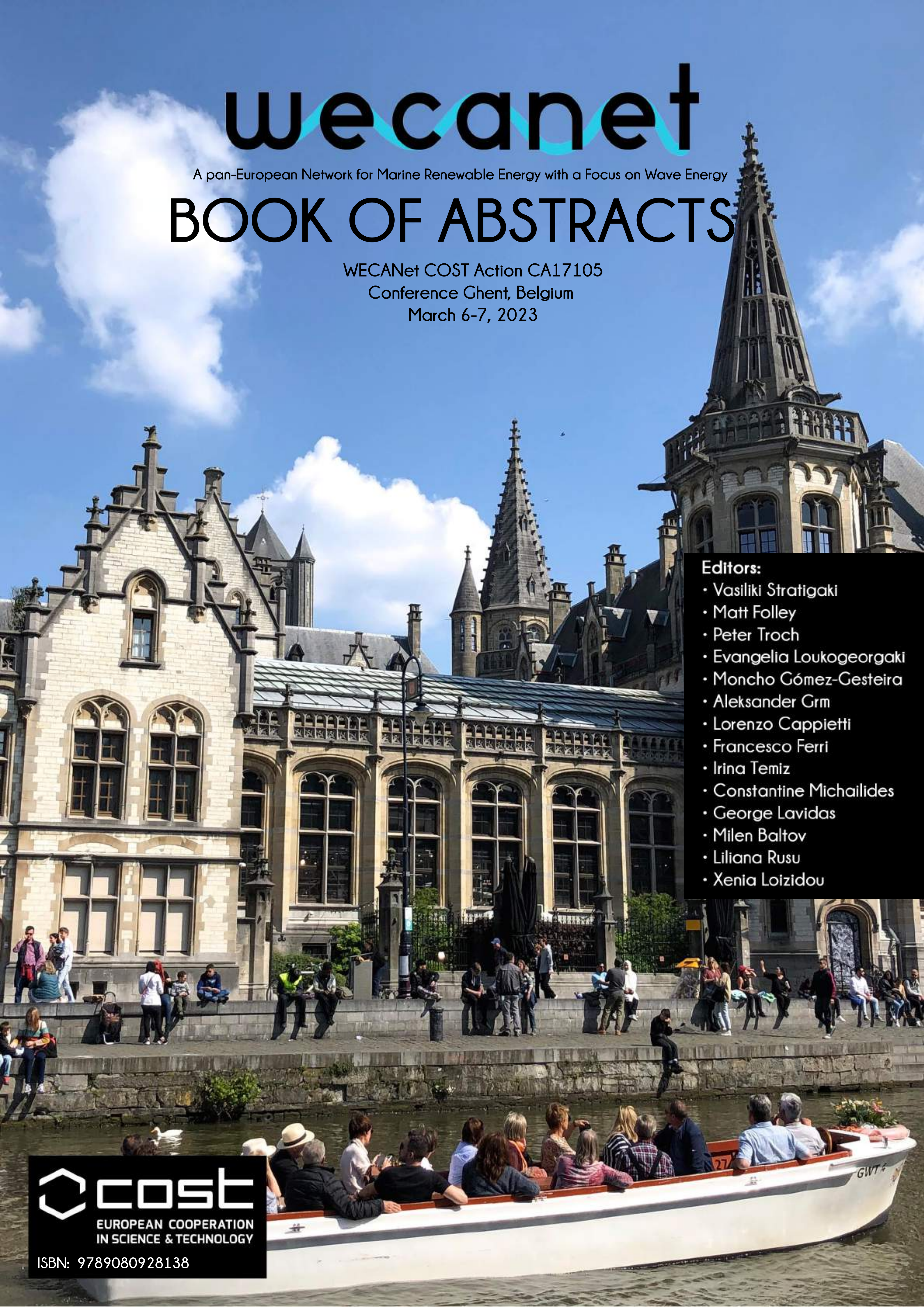

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A pan-European Network for Marine Renewable Energy with a Focus on Wave Energy

BOOK OF ABSTRACTS

WECANet COST Action CA17105
Conference Ghent, Belgium
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- Vasiliki Stratigaki
- Matt Folley
- Peter Troch
- Evangelia Loukogeorgaki
- Moncho Gómez-Gesteira
- Aleksander Grm
- Lorenzo Cappietti
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About the WECANet European COST Action CA17105

The pressure of climate change and the growing energy demand has increased interest in marine renewable energy resources, such as wave energy which can be harvested through Wave Energy Converter (WECs) Arrays.

However, the wave energy industry is currently at a significant juncture in its development, facing a number of challenges which require that research re-focusses onto a techno-economic perspective, where the economics considers the full life-cycle costs of the technology. It also requires development of WECs suitable for niche markets, because in Europe there are inequalities regarding wave energy resources, wave energy companies, national programmes and investments. As a result, in Europe there are leading and non-leading countries in wave energy technology. The sector also needs to increase confidence of potential investors by reducing (non-)technological risks. This can be achieved through an interdisciplinary approach by involving engineers, economists, environmental scientists, lawyers, regulators and policy experts. Consequently, the wave energy sector needs to receive the necessary attention compared to other more advanced and commercial ocean energy technologies (e.g. tidal and offshore wind).

The formation of the first pan-European Network on an interdisciplinary marine wave energy approach will contribute to large-scale WEC array deployment by dealing with the current bottlenecks. The WECANet (Wave Energy Converter Array Network) European COST Action, introduced in September 2018, aims at a collaborative approach, as it provides a strong networking platform that also creates the space for dialogue between all stakeholders in wave energy. An important characteristic of the WECANet Action is that participation is open to all parties active in the development of wave energy. Previous activities organised by WECANet core group members have resulted in a number of joint European projects and scientific publications. WECANet's main target is the equal research, training, networking, collaboration and funding opportunities for all researchers and professionals, regardless of age, gender and country in order to obtain understanding of the main challenges governing the development of the wave energy sector. Currently, 31 partner countries are active in WECANet.

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Abstracts

Abstracts for Working Group 1:

Numerical hydrodynamic modelling for WECs, WEC arrays/farms and wave energy resources

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Hydroelastic analysis of floating shell elements

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Large moored offshore floating structures (OFSs), employed for offshore wave energy technologies such as Pelamis (Yemm et al., 2012), are mainly exposed to large environmental loads which induce hydroelastic response and structural deformations. Therefore, accurate numerical modelling is essential to assess their serviceability and survivability; this can be only achieved by resolving non-linearities in the fluid domain, and the hydroelastic response in the solid domain. To address knowledge gaps related to high fidelity simulations, a numerical platform is developed to simulate floating shell elements based on the coupling of smoothed particle hydrodynamic (SPH) solver DualSPHysics and the finite element analysis (FEA) module Project Chrono.

The existing coupling of the numerical solvers facilitates the fluid-structure interaction (FSI) of solely rigid floating bodies. In the presented research, the capabilities of the coupling are extended by discretizing the floating structure into multiple interconnected rigid bodies, representing a regular grid mesh surface. The fluid particle forces acting on the rigid bodies are transferred to the Project Chrono library and are applied to a shell element floating in space (Figure 1), with a user defined mesh grid. This novel approach allows us to accurately simulate the hydroelastic response and the corresponding internal structural stresses of OFSs using Project Chrono. To maintain a synchronized hydroelastic response between the structural solver and the fluid solver, the rigid bodies are interconnected with flexible links based on the rigid finite element method (Wittbrodt et al., 2006). With this 3D formulation the flexible links compensate for the structural stiffness of a shell element to all rotational degrees of freedom.

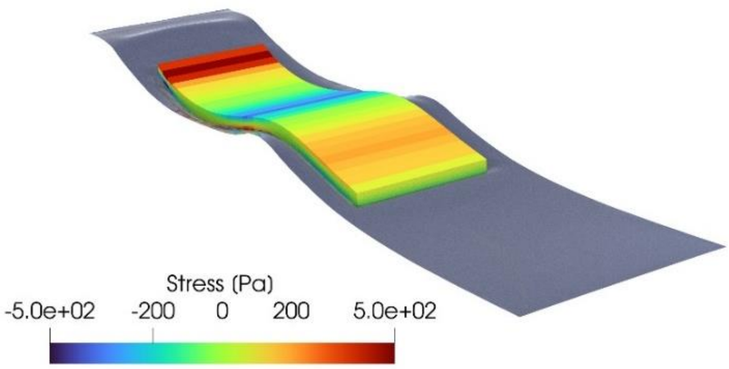

Figure 1: Project Chrono visualization of shell element floating in space under environmental loads derived from DualSPHysics

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The first author, Rafail Ioannou, would like to acknowledge his PhD Aspirant Research Fellowship by the Research Foundation Flanders, Belgium (FWO) (application number 1184622N).

The Impact of RCP8.5 Climate Change Scenario on the Atlantic Coast of the Iberian Peninsula

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The long-term shifts in the temperature and patterns of weather on earth have attracted the attention of researchers in different fields of science. Studies on the use of wave energy sources are no exception. Hence, the present study aims to investigate the effect of climate change on the wave energy resource of the Atlantic coast of the Iberian Peninsula. In order to evaluate the potential changes along the study area, a high-resolution and long-term assessment is needed. Version 41.31A of SWAN, an open-source nearshore wave modeling tool, is used. The numerical wave model was forced with wind data from the climate projections obtained for the RCP8.5 carbon emission scenario. The study spans two 20-year time slides: 20 years from 1979 to 1998 and 20 years from 2081 to 2100. The model's inputs include a high-resolution unstructured mesh using GEBCO's 400m x 400m high-resolution bathymetry data. The wind projection data was obtained from CMIP5's scenario RCP8.5 produced by Euro-Mediterranean Center on Climate Changes in Italy. The boundary conditions for the model were extracted from MRI-CGCM3 global wave projection model developed by the Meteorological Research Institute CGCM in Japan. Initially, the SWAN model was forced by ERA5 wind and wave reanalysis data. Afterward, the model was calibrated and validated against wave buoy measurements at 10 different locations. Finally, the climate projection model was run with the previously calibrated SWAN model.

The results obtained show, in general, negative trends, with the greatest changes in the northwest, with spatial and temporal annual mean changes of -0.12 m for the significant wave height, -0.14 s for the energy period, and -4.7 kW/m for theoretical wave power throughout the study area. The smallest changes are observed in the southwest area. In addition, the maximum annual changes observed in the northwest of the study area are -0.27 m for the significant wave height, -0.41 s for the energy period, and -15.05 kW/m for the wave power.

Acknowledgments
The authors acknowledge funding in the form of a Ph.D. scholarship grant by the FCT, co-financed by the EU's ESF through the NORTE 2020 program, with reference 2021.04847.BD. This work was also supported by the project ATLANTIDA (NORTE-01-0145-FEDER-000040), supported by the North Portugal Regional Operational Programme (NORTE2020), under the PORTUGAL 2020 Partnership Agreement and through the European Regional Development Fund (ERDF).

Developing Spectral-Domain-Based Wave-to-Wire Model of Wave Energy Converters (Group 1)

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Wave-to-Wire models play a significant role in the development of wave energy converters (WECs) since they could provide insight into the whole operation process of the system, from the hydrodynamic stage to the power conversion stage. However, existing wave-to-wire models are formulated predominately based on the time-domain approach to cover relevant nonlinearities. However, it is known that time-domain modeling is associated with a large number of computational efforts. Considering the demand to perform considerable times of iterations of design and optimization, a computational-efficient model to cover the wave-to-wire responses would be appealing to the WEC community.

Spectral-Domain modeling presents adequate accuracy and requires limited computational loads. It has been developed to incorporate a series of nonlinear effects, such as wave force decoupling, viscous drag force, nonlinear hydrostatic force, PTO force saturation, etc [1-4]. Nevertheless, existing spectral-domain models were mainly established for predicting hydrodynamic responses, and it has rarely been applied to wave-to-wire analysis. Thus, the applicability remains unclear, especially in modeling the electrical responses of WECs. Therefore, it is of significance to develop and verify spectral-domain-based wave-to-wire modeling for WECs.

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Acknowledgements

Application of Smoothed Particles Hydrodynamics models for offshore wave energy converters

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For accelerating and reducing the cost of the development of wave energy converters (WECs), new innovative numerical approaches are required. Existing well-validated numerical methods based on potential flow models (PFM) are only suitable for the analysis of operational sea conditions. For accurate extreme conditions assessments, computational fluid dynamics methods (CFD) are normally used. However, conventional CFD methods based on Euler's equations have the disadvantage related to the difficulty of implementation for WECs given their requirement of setting up challenging moving meshes. On the other hand, novel Lagrangian CFD methods, based on smoothed particles hydrodynamics (SPH), allow representing floating WECs, also having uncommon motions and geometries, with minimum numerical modelling difficulties. Since SPH is a meshless method, using a finite number of particles for defining the fluid and rigid bodies, SPH appears to be very appealing to be used for WECs numerical analysis. In contrast, SPH methods lack verification studies against experimental or other convention approaches, such as PFMs for specific sea states and geometries. In this context, this study aims to apply SPH for the assessment of the motion and wave loads for two simplified WEC geometries using deep water waves. Therefore, in the present study optimal SPH configuration and parameters are investigated for simulating deep water waves and for estimating wave loads over the considered geometries. The work is part of a STSM carried out at the University of Vigo (Ourense Campus) and belongs to WP1. Preliminary results allowed identifying best configurations and a wave generating technique to produce deep water waves (e.g. Figure 1).

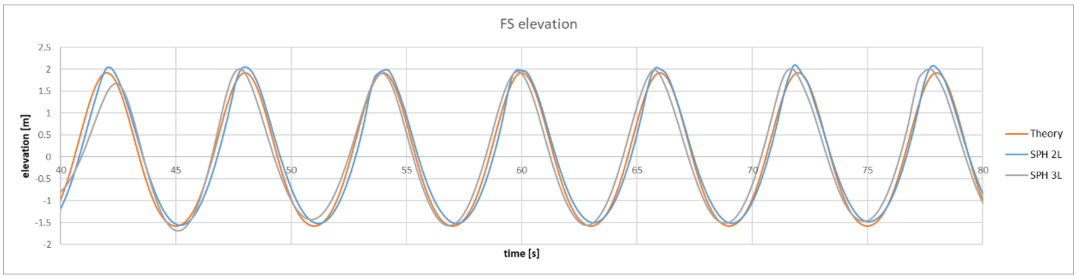

Figure 1. Free surface elevation from SPH for regular waves (T=6s, H=3.5m) compared to 2nd order theory.

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This work is also part of the project PORTOS – Ports Towards Energy Self-Sufficiency (EAPA 784/2018), co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund.

Seakeeping analysis of floating bodies using waves and current generation in DualSPHysics

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Technical advancements in the offshore wind industry have led to new Floating Offshore Wind Turbine (FOWT) concepts that can be assembled on shore and towed to the installation location. However, there is a lack of experimental and numerical seakeeping analysis of fully mounted turbines when they are towed from the construction location to site.

The objective of this work is to study of the capabilities of the Smoothed Particle Hydrodynamics (SPH)-based code DualSPHysics (Domínguez et al., 2021) to perform seakeeping analysis of floating bodies to later by applied for studying towing of FOWTs. The simulation of a body moving with a certain forward speed in waves requires very large domains, which involves a very high computational cost in DualSPHysics due to the nature of the SPH method. Therefore, a different approach is taken: the seakeeping problem is modelled applying a constant current with a negative magnitude equal to the forward speed while keeping the floating object fixed in the x-direction, with the consequent reduction of domain in that direction.

The waves and current case are generated using the newly implemented inlet/outlet boundary conditions (Tafuni et al., 2018). DualSPHysics open boundaries consist of buffer layers near the open regions where waves can be generated and absorbed by imposing orbital velocities, surface elevation and pressure. To avoid wave reflection and to ensure a proper wave absorption at the outlet, a damping zone matching the current velocity has been imposed close to the outlet boundary. Figure 1 shows initial results of the two validation test cases that will be studied within this research: towing of the OrthoSpar FOWT (Büttner et al., 2022) (left) and sailing in shallow waters of the DTC Container Carrier at the towing tank of Flanders Hydraulics (van Zwijnsvoorde et al., 2019) (right).

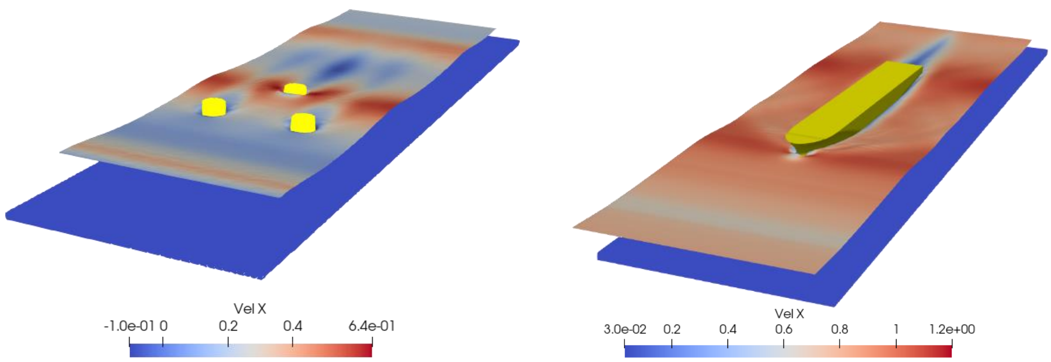

Figure 2. Sea-keeping analysis of the OrthoSpar FOWT Turbine (left) and the DTC Container Carrier (right) in DualSPHysics.

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A CFD study on the interaction between wave motion and fixed bottom-detached breakwaters

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Climate change and energy crisis are fueling wide concern. Coastal areas are prone to the effects of sea level rise and flood events occurrence as a result of extreme weather. These phenomena also drive coastal erosion, and the related lack of alternative dwelling space presents coastal communities with even higher density urban structures [1–2]. The use of floating structures, such as the Very Large Floating Structure (VLFS) [3-4], is a potential solution to expand human's activity space and to cope with the sea level rise with a resilient approach. To date, most of the research activities have been focused on floating structures with small draft, located in intermediate or shallow waters of naturally protected marine areas. Expanding the human's activity space toward the more exposed offshore marine areas is a big challenge both in term of scientific and technological issues.

In this study, a fixed bottom-detached box-type breakwater with large draft is investigated, with the aim to limit the wave motion in a protected offshore marine area, with a focus on extreme wave conditions. The wave-structure interaction has been studied by Computational Fluid Dynamics (CFD). First, a 2D numerical wave tank has been developed and validated, then the interaction between the wave motion and the fixed bottom-detached box-type breakwater has been investigated. This work will present the implementation and validation of the numerical wave tank and the features of the wave-structure interaction based on the CFD results. A discussion on the sensitivity of the transmission coefficient to the structure main's design parameters is provided. Furthermore, existing predictive formulations for design usage are reviewed and their accuracy in predicting the transmission coefficient, for this specific structure exhibiting a very large draft previous omitted, is evaluated. Limits of existing formulations are highlighted, and outlook of ongoing and future works are provided.

Keywords: Very Large Floating Structure (VLFS); Floating breakwater; Extreme weather; Numerical simulation; Transmission coefficient.

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A Comparative Study on BEM Solvers for Wave Energy Converters

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WG1: Numerical hydrodynamic modelling for WECs and WEC arrays/farms

In order to estimate the power generated by Wave Energy Converters (WECs), an accurate modelling of wave-structure interactions is essential. The Boundary Element Method (BEM) based on the linear potential flow theory has yielded accurate results at low computational costs when compared to the more complex Computational Fluid Dynamics (CFD) methods. Hydrodynamic Analysis of Marine Structures (HAMS), a recently developed open-source BEM frequency domain solver, was originally created for large marine structures. HAMS offers unique advantages with its efficient removal of irregular frequencies and low computational costs owing to its parallelization. Our recent work [1] compares hydrodynamic quantities (hydrodynamic coefficients, exciting forces and RAOs) and computational costs between HAMS, the commercial solver WAMIT, and the open-source solver NEMOH for a cylindrical Point Absorber (PA) and an Oscillating Surge WEC (OSWEC).

For the case of the PA, the results showed that the HAMS hydrodynamic results HAMS are closer with those obtained using WAMIT contrary to NEMOH. Furthermore, HAMS is able to suppress irregular frequencies efficiently similar to WAMIT. As for computational costs, HAMS is faster than NEMOH (x21) and WAMIT (x2), when no irregular frequencies are suppressed and comparable to WAMIT when irregular frequencies are suppressed. For the case of the OSWEC, both NEMOH and HAMS hydrodynamic results are close to those of WAMIT. On the other hand, HAMS is faster than NEMOH (x21) and WAMIT (x3). Within the domain of open-source solvers for wave-structure interactions, HAMS offers some unique advantages as compared to NEMOH and it is seen to be comparable to the industry standard WAMIT. HAMS has the potential to become one of the more valuable options to meet the numerical challenges within the field of ocean engineering, particularly the possibility of low computational effort with good accuracy.

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wecanet a pan-european network for marine renewable energy

Different approaches to analyze the impact of climate change on future wave energy exploitation

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Compared to other marine renewable energies (offshore wind or tidal power), wave energy is at a lower level of technological development, and the research effort aimed at studying how climate change can affect the wave energy resource and exploitation is much less than that dedicated, for example, to offshore wind energy. Apart from the inherent factors that hinder the development of this source of energy, such as the non-existence of a market-leading type of capturing device, uncertainties about the available future resource also hamper its growth. In this sense, researchers with experience in wave energy resources from different countries and research centers, have exchanged and shared information, experience, and data related to wave energy resources in different regions of the world under the impact of future climate change. This exchange among experts has allowed an exhaustive analysis of the current state of the research in the assessment of future wave energy resources, highlighting the different methodologies and approaches applied in these studies. These procedures include the evaluation of the best future atmospheric data to drive wave models, the different downscaling techniques to evaluate the resource in large regions with high spatial resolution, and the analysis of the future variability of the energy resource and its future exploitability in a certain region taking into account different types of devices. Additionally, the current state of the art of previous studies dealing with future wave energy resources for different locations worldwide is described. This study aims to describe in detail the difficulties encountered when approaching the analysis of the future variability of wave energy due to inherent uncertainties associated with climate change and describes the efficiency of current wave energy converters under future climate conditions. The collaborative work developed has generated synergies during the last few years in such a way that many of their studies are intermingled in common articles that are framed within the objectives of different WGs in Wecanet. The participants in this study hope to maintain their collaboration and even extend it to other research groups working in the same field, creating synergies that allow them to share both the experience and difficulties in analyzing wave energy resources worldwide.

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Extension of the Open-source Solver HAMS to Multi-bodies

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Boundary Element Method (BEM) based on linear potential flow theory has been widely utilized for modelling the wave-structure interaction, since it offers good accuracy at low computational costs. WAMIT (commercial) and Nemoh (open-source) are two of the most popular BEM solvers within the domain of wave energy. Hydrodynamic Analysis of Marine Structures (HAMS) is a recently developed open-source solver, originally released in 2019, which offers unique advantages through its efficient removal of irregular frequencies and lower computational costs (a comparison between WAMIT, Nemoh and HAMS highlighting these aspects has been recently performed in [1]); however its current version enables only the analysis of a single floating structure.

Motivated by this, the focus of this research is to extend the capability of the open-source BEM solver HAMS to analyze multi-body interactions including diffraction and radiation, so as to make it capable of studying wave farms. The COST Action CA17015 Short Term Scientific Mission (STSM) was granted to the first author to incorporate the algorithms for solving the diffraction and radiation problem for multi-body interaction within the framework of BEM in order to derive the hydrodynamic quantities (hydrodynamic coefficient and exciting forces). The code has been validated by comparing results with those obtained from the commercial software WAMIT for different geometries, including spherical and cylindrical ones, for infinite depth cases with varying incident wave angles and layout of bodies.

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Perspectives for the exploitation of satellite observations for resource assessment

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Reliability, high information content and accuracy are the key elements for identifying a suitable data source for studying the states of the sea. Knowledge of wave characteristics is essential not only in offshore renewable energy but also in port design, navigation safety, and environmental change assessment. By implementing numerical models (e.g. SWAN, acronym of Simulating Waves Nearshore), calibrated and validated with in-situ measurements and satellite observations, robust hindcast time series are inferable. The absence of time gaps ensures the reliability of the modelled data; high information content is guaranteed by the high number of deducible output parameters; accuracy can be verified by comparison with in-situ measurements and satellite observations. The aforementioned numerical approach is widely used, and its advantages and limitations are known to the scientific community. However, there are some gaps and challenges in the current common practice, which are briefly discussed and attempted to address as it follows.

Satellite wave data varies accordingly to the instrument installed on board and their operating mode. This differentiation results in substantial variability in spatial resolution and data accuracy. Only satellite missions, with the same instruments and a similar operating mode, are considered for calibrating and validating numerical models in common practice. In this way, the entire dataset of satellite observations is not exploited, and many data are excluded. Alternatively, satellite data equipped with the same instrument, after editing, homogenization and filtering, are compared with the numerical data; however, such information have a rough spatial resolution (around 7 km x 7 km). Investigating a novelty methodology for exploiting satellite observations would allow exploring the potential of such information. The results associated with this activity would provide support in different areas of the WECANet COST Action CA17105 Working Groups, defining a methodology to identify the best sites for the exploitation of wave energy (WG1), and providing reference cases numerical data, evaluating the literature and identifying guidelines for WEC projects (WG1, WG3 and WG4).

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Dynamics of Point Absorbers Connected to Floating Platforms

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Along the challenges currently being faced by the wave energy industry, there are the ones related to the mathematical and numerical modelling of Wave Energy Converters (WECs) and WEC arrays. The most various levels of physical complexity may be reflected on the dynamics of such wave harvesting systems. Oftentimes, the term 'nonlinear' is employed, because the mathematical modelling brings dynamic equations to be solved that are indeed nonlinear in nature, however, these nonlinearities may arise in different parts of the system, e.g. from the wave excitation pressure field on the WEC, to the mooring system dynamics or the Power-Take Off (PTO) dynamics.

In the case of point absorbers, for instance, the coupling between different wave converters, or between wave converters and a central floating platform, is normally performed by means of arm connections and hinge connections. In that case, the appearance of nonlinear geometric constraints is unavoidable. The existence of several interconnected floating bodies characterizes a multi-degrees-of-freedom hydrodynamic system, while the existence of geometric constraints between the different bodies reduce the total amount of degrees-of-freedom in the cost of adding nonlinear geometric constraints. It is a challenge to model, both mathematical and numerically, the exact multi-degrees-of-freedom coupled dynamics of such mechanical systems.

That said, the ongoing research development brings a method based on generalized coordinates (see [1 – 3]) that generates a robust first-order dynamic matrix for the simulation of multi-body hydrodynamic systems as the ones abovementioned. The method requires complete knowledge on the geometries of the system and a few assumptions, namely to perform a robust linearization of the geometric constraints. The method may be illustrated with two case studies: i) Interconnection between 2 point absorbers (a first simplified scenario), and ii) Connection between several WECs to a central floating platform and hydraulic PTO (realistic scenario).

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Numerical modeling of non-conventional coastal protection solutions

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Numerical models are considered a valuable tool to simulate the nonlinear interaction of waves with complex coastal structures and the dynamics of wave energy converters. REEF3D is an open-source hydrodynamics code developed by NTNU for coastal, marine and hydraulic engineering flows, able to solve hydro and morphodynamics problems. However, it is of paramount importance to validate the results of such model with experimental data from physical model tests.

Esposende sandspit, in the north of Portugal, protects the city of Esposende, some recreational areas and a large saltmarsh with high ecological and cultural value from storms. With the ongoing erosion, continued overwashing and weakening of sediment sources, this sandspit is becoming ill-fitted to withstand coastal storm risks [1]. Hence, two non-conventional solutions were proposed and studied experimentally on a geometric scale of 1/80: one composed of nearshore detached living breakwaters and the other consisting of an offshore wave energy park (an array of 2x10 WaveRoller devices). The living breakwaters were the solution selected to be first simulated using REEF3D since the wave park was considered computationally more demanding and hence unfeasible for the duration of this STSM. During the experimental tests, the evolution of the free surface elevation was recorded by strategically positioned wave probes as well as the bathymetry evolution in the sandspit and adjacent area using a laser scanner. To set up the numerical model, the same experimental conditions of bathymetry, waves and tides were applied. The numerical schemes and discretization were adapted and the coordinates of the wave probes were inputted numerically. A 15-minute scenario was simulated computationally (equivalent to more than 6 days). The validation of the numerical model was done by comparing the experimental results with the numerical ones.

The main goal of this work (working group 1) was to learn how to handle and to develop the numerical model in REEF3D, so that in the future this effort and knowledge can be used to build another model for the second solution – offshore wave energy park. This will allow the comparison and identification of the solution that best solves, hydrodynamically, the case study problems. Another future purpose is to be able to fully validate the numerical models taking into account the fluvial and morphodynamics component.

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Use of IGA methods in WEC numerical modelling

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In the numerical modelling of WECs systems exists, there are several approaches to obtain different relevant data. One of the important problems is the dynamics of the WEC. A WEC can be a submerged or floating device. In our case, we focus on the floating device.

The Iso-Geometric Analysis (IGA) method [1,2] uses NURBS basis functions to represent the solution, and NURBS is also used to represent the geometry/domain. The same basis function space representing the geometry and the solution allows for unified numerical analysis. The body geometry, in this case, is also the computational mesh for the body. For free surface problems, the free surface can also be represented by the NURBS basis when solving nonlinear problems. For linear problems, the free surface is computed and represented by the NURBS basis.

The order of the functions can be specified by the user so that the solutions can be represented accurately. In the case of a linear wave theory model, the solution for the surface elevation also clearly shows the nonlinear effects [3]. The numerical method for flows embedded in the IGA formulation can be coupled with the shell structure naturally as well [4].

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Coupling methodologies to enable more effective numerical simulations of wave energy converter farms

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As the level of maturity of WEC technologies increases and some prototypes reach real sea deployment, the design of WEC farms becomes urgent. The main aspects currently investigated are the maximization of the power output and the impact of the farm in the surrounding marine area. Those two aspects are strictly related but act at different scales of the farm site.

For numerical simulations, the trend of coupling methodologies is to deal with multi-scale characteristics of a farm in order to reduce the computational cost [1]. Several examples are available, coupling solvers of different fidelity, and decomposing the domain around each single device or around the entire array. In [2], the near-field around the array is solved using potential theory, which is used also in the propagation phase in the far-field. Alternatively, a high-fidelity solver is used in a small domain around the device and the solution is propagated further away with lower fidelity solvers, as in [3]. When the level of fidelity is the same between the coupled solvers, the communication is straightforward; otherwise, a difficulty might arise in converting the solution without losing accuracy. On the other hand, multi-fidelity simulations allow higher accuracy around the device, where the complexity is relevant.

Exactly as the simulations for the single device, the different numerical techniques respond to different needs and should be chosen accordingly. Therefore, there is a need for benchmarking as well as sharing the knowledge about the various numerical simulations of WEC farms.

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Advanced optimization algorithms towards the optimization of the E-Motions wave energy converter

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Physical and numerical modelling studies are pivotal towards understanding and developing Wave Energy Converters (WECs), but require significant resources and effort. Consequently, only a limited number of variable combinations from the global solution space are usually analyzed. To assess alternative WEC design solutions in an efficient manner, data-driven algorithms have been adapted to numerous case studies, from wave time series gap filling [1] to hull shape optimization [2]. Within the scope of WECANet's 8th STSMs call, a joint collaboration between the Host – The University of Edinburgh – and the Home – FEUP – institutions was established. The main goal involved selecting and applying AI-based algorithms to the case study of E-Motions, supported by data from previous physical and numerical modelling studies. Therefore, this algorithmic approach is mainly applicable to the scope of WG1, although it involves and affects topics inherent to other work groups. During the first week of the STSM, the Grant Holder got acquainted with the optimization algorithms and defined, with the Host Institution's support, the application procedures to the E-Motions device. To that end, a triage of the experimental and numerical input data was carried out. During the second week, the most suitable algorithmic tools for the E-Motions case study were selected, configured and applied.

Genetic Algorithms and Particle Swarm Optimization were the selected methods, and the respective fitness functions and settings were configured through the Matlab Optimization Toolbox. Several functions were considered with the aim of minimizing the root mean square error between the estimated and expected average power outputs, based on floating body/PTO motions/velocities and, later, wave parameters. It was found that the PSO tended to be more easily defined, converged faster and provided more accurate results than the GAs, although the range of options of GAs is greater.

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Improved soil-cable interaction mooring simulations

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Moorings of floating oil and gas (O&G) structures exhibit surprisingly large failure rates. In the O&G industry this problem is simply handled by redundancy in the design. It is unlikely that marine renewables - in order to obtain a competitive levelized cost of energy (LCOE) – can afford such redundancy in the mooring design. ISLINGTON has the overall objective to reduce uncertainties in estimated fatigue damage of mooring cables due to soil-cable interaction in the touch down zone (TDZ); and subsequently lower the economic cost of mooring systems for marine renewables. To achieve this objective, the following research actions will be carried out:

1. Improving the numerical modelling of the cable-soil interaction in the TDZ for mooring cables by allowing for time-dependent-granular soil dynamics. This will be done by creating an Application Programming Interface (API) inside a granular particle soil solver to allow a two-way coupling to a mooring cable solver providing position and motion of the mooring cable.
2. Generating open-access experimental data for mooring line trenching to be used for validation. This will be done by forced oscillations of a cable in a wave flume with sandy bottom and log the development of the trenching under different forcing.
3. Numerical investigation of the effect of trenching on fatigue of mooring cables. This will be done for standard test cases such as the IAE Task 30: OC3-OC6 test cases. Additionally, the influence of time-dependent soil-cable interaction on snap loads development will be numerically investigated.

The resulting numerical code will increase the accuracy of numerical simulations, providing researchers and designers with a better insight of tension evolution and fatigue processes in the TDZ. The novel experimental data-set would provide open access validation data that would enable the validation of new numerical approaches on mooring line dynamics and soil interaction in the community.

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PROJECTIONS OF BALTIC SEA WAVE ENERGY RESOURCES ACCORDING TO SHARED SOCIOECONOMIC PATHWAYS (SSP) SCENARIOS

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The increasing demand for electricity accelerates the interest of society in new types of renewable energy sources. Recently, a lot of attention has been focused on the investigations of wave energy potential. Studies revealed that the world's ocean contains twice as much energy as is currently being consumed. Moreover, it is important to know not only the current situation of wave energy application possibilities but also how these resources may change in the future. Various hydrodynamic models are being applied for wave simulation that requires large computing resources. The statistical relations between wave height and wind speed in a reference period can be the solution for a more simple prediction of wave energy resources. Therefore, the main goal of this research was to project the wave energy flux of the Baltic Sea in the 21st century according to SSP climate scenarios using the determined relations between wave height and wind speed.

The observational data of wind speed and wave height near Klaipėda (south-eastern part of the Baltic Sea) for the reference period of 1995-2014 was used in this study. The projections of the wave height (H, m) and wave energy flux (WEF, kW/m) in the near (2025-2044) and far (2081-2100) future were based on the wind data ensemble according to three GCMs (BCC-CSM2-MR, EC-Earth3-Veg-LR, INM-CM4-8) and four SSP climate scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5). It was determined that the average wave height reached 0.6 m, and the WEF contained 3.1 kW/m in the Baltic Sea nearshore at Klaipėda during the reference period. The gradual increase from 1.1% to 10.2% in WEF values was found according to SSP1-2.6 and SSP5-8.5 respectively for the near future comparing with the reference period. In the far future, the tendencies showed a bit different character because the highest relative increase in the projected WEF values was found according to SSP1-2.6 (11.9%) and SSP5-8.5 (9.1%) while WEF values by other scenarios were almost unchanged. Such differences in WEF between scenarios and periods could be caused by the size of the grid cells of GCMs that in some cases covered not only the sea surface but also some part of the land. Therefore, further studies should involve the output of regional climate models with the finer grid cells. It would enable the potential partners from LT, LV, EE, PL, DE, DK, SE and FI to expand the investigation on WEF projections for the entire Baltic Sea under the WECANet COST Action CA17105 WG1 umbrella.

Acknowledgements
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Evaluation of Various WEC technologies for Filyos, Southwestern Black Sea

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Long-term wave climate and wave energy potential studies in the Black Sea show that the Southwestern Black Sea is the most energetic coast of Turkey (Akpinar and Komurcu, 2012, Ayat, 2013, Ozbahceci et al. 2020). In this study, various existing wave energy converter technologies are evaluated to determine the most efficient one for Filyos coasts in the Southwestern Black Sea. For this purpose, firstly long-term wave climate is derived in the coastal zone of Filyos using a third-generation nearshore wave model, SWAN (Simulating Waves Nearshore), forced by the ERA5 offshore wave data, which is the newest re-analysis of the European Centre for Medium-Range Weather Forecasts (ECMWF). Before using ERA5 offshore wave data, they are calibrated by the wave data of the satellite radar altimeter. In-situ measured bathymetry data are used in the SWAN model. The wave bulk parameter values (significant wave height (H_{m0}), peak period (T_p), energy period (T_e)) predicted by the SWAN model are validated by assessing the error measures against the wave measurements at Filyos, one of the limited numbers of nearshore wave measurement campaigns in the Black Sea. When the error measures are compared with the previous validation studies, the current study has lower bias and scatter index values than the previous studies. Especially wave period predictions are much better. Using validated 40 years of wave data, joint frequencies of the Hm0 versus T_p, and H_{m0} versus T_e and the energy period and are determined and the power matrix is calculated. The capacity factor, efficiency index, and capture width as indicators of the WEC's efficiency are calculated and compared for various WECs like SSG, WaveDragon, Oyster, Oceantec, Pelamis, Pontoon, Aquaboy and WaveBob.

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Studies concerning the expected impact of the marine energy farms in different coastal areas

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The objective of the present work is to present some studies concerning the expected nearshore impact of the marine energy farms in various coastal areas, together with a computational platform that facilitates these evaluations. A coupled modelling system (denoted as CSIAM - Computational System for Impact Assessment of the Marine energy farms) has been developed to account for the near and far field effects of the marine energy farms. This computational platform joins two numerical models, SWAN spectral model (acronym for Simulating Waves Nearshore) for waves and Surf model to assess the nearshore circulation patterns. This is an improved version of ISSM (the Interface for SWAN and Surf models), which has been validated in various coastal environments.

Different configuration designs have been considered, including one or two-line marine energy farms located at various distances from the shore. For these designs, several studies have been performed using the CSIAM computational platform in different nearshore areas and considering various databases for the analysis of the environmental matrix, targeting especially the Portuguese continental nearshore and coastal areas from the Mediterranean and the Black Seas. A special attention was paid to the coastal protection that can be provided by the marine energy farms and a significant case study discussed is related to Sacalin Peninsula, a biosphere reserve in the Black Sea. Since the marine energy farms based on wave energy converters extract the energy from the waves, an attenuation of the coastal processes is in general expected. This includes also the nearshore currents, which are an important factor in driving the coastal dynamics. Nevertheless, the results of the studies carried out show that in some cases the presences of the marine energy farms can increase the intensity of the longshore currents. This is because although the wave energy is absorbed, the wave direction might be significantly changed by the presence of the wave farm.

The most important conclusion coming from the studies developed is that the coastal impact of the marine energy farms is site-dependent and each nearshore area represents a distinct case study, even if there are very close geographical locations. Furthermore, while the effect of the farms operating very close to the shoreline is quite significant, this effect decreases very fast when going offshore. Finally, the results show also that the marine energy farms can represent in certain situations a viable solution for coastal protection.

Acknowledgement
This work was carried out in the framework of the research project DREAM (Dynamics of the REsources and technological Advance in harvesting Marine renewable energy), supported by the Romanian Executive Agency for Higher Education, Research, Development and Innovation Funding – UEFISCDI, grant number PN-III-P4-ID-PCE-2020-0008.

Numerical simulation of flexible wave energy converters: a coupling between DualSPHysics and Project Chrono

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One of the emerging technologies in the renewable marine energy market is the flexible wave energy converter (WEC) that promises unprecedented efficiency and the ability to simultaneously harness waves and currents [1]. Before upscaling this technology, the operability, survivability, and efficiency under different hydrodynamic conditions need to be further investigated. In this context, DualSPHysics (DSPH) presents itself as a numerical platform able to resolve the wave-current-flexible structure interactions. By employing the latest coupling between DSPH and the FEA module of project chrono [2], the deflections of the flexible wave energy converter are resolved using the Euler-Bernoulli beam element. This approach not only accounts for the flexural rigidity of the WEC but also simulates, through the damping model, the resistance resulting from the mechanical and electrical generation components.

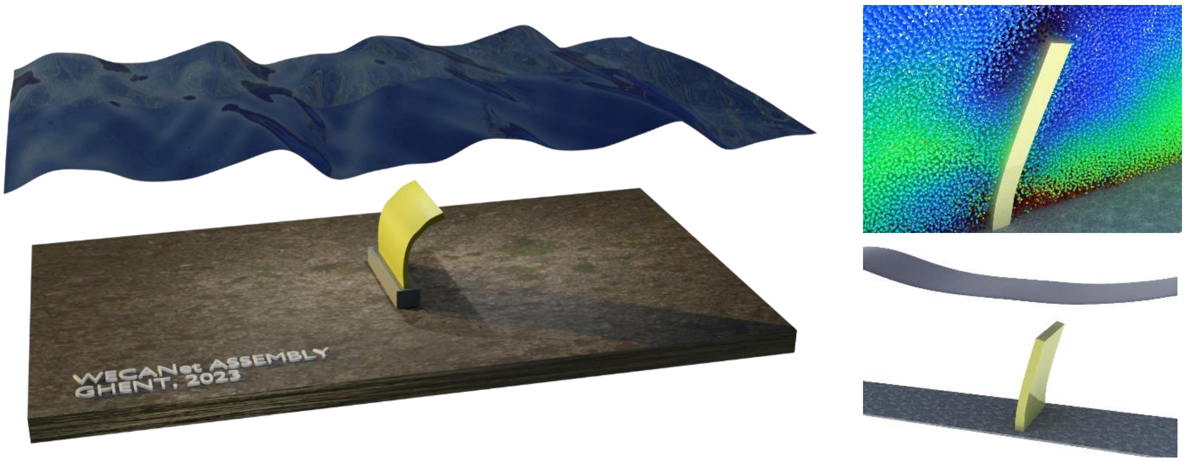

Figure 1: Left panel: artist impression of a flexible WEC deflecting under the action of an oscillatory flow; right panel: deflected WEC in the DualSPHysics domain, the flexible WEC is shown in yellow and resolved using the Euler-Bernoulli element.

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Assessment of the climate change effects on the wave energy resources in the Mediterranean Sea

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The increasing investments in marine renewable energy also bring to attention the need to evaluate the potential effects of climate change on these resources. According to the European Green Deal, an important enhancement regarding harvesting the energy existing in marine environment (wind, wave, tide, etc) is expected in the European nearshore. Among renewable marine resources, wave energy has great potential for exploitation, being abundant and widely available, but so far there has been no significant progress in developing large-scale projects to extract this renewable energy in an effective way. An important role in the amount of wave energy that can be harvested is finding the locations with the greatest resources and to identify the most appropriate devices for the sea state conditions in that area.

In this general context, and taking into consideration that the marine environment is strongly affected by the climate change, the present work aims to evaluate the expected wave power dynamics in the coastal environment of the Mediterranean Sea. This can be done using the results provided by numerical models implemented in the target area. Thus, to assess the dynamics of wave power in the context of 21st-century climate changes, a wave modeling system based on the SWAN (Simulating WAves Nearshore) model was implemented in the Mediterranean Sea while as a, only the wind fields are considered. Since the driving factor for the wave model are the wind data, high-resolution wind fields provided by the Regional Climate Models (RCMs) are used for the historical and future periods, considering wind fields simulated under RCP4.5 (Representative Concentration Pathway) for future periods simulations. SWAN simulations over an extended period covering the past period (historical period) were performed and the results include the wave power components. Based on them the wave power is computed and then compared to the values (mean, maximum, etc) resulting from the projections made for the future. The most important differences will be also evaluated.

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Present and future functionalities of DualSPHysics code to simulate wave energy converter systems: design and implementation through coupling techniques

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Numerical modelling plays an important role in supporting the design stages of Wave Energy Converters (WECs) and arrays of WECs. Specifically, Computational Fluid Dynamics (CFD) models are numerical tools widely used to deal with the most important aspects when WECs are under investigation, such as the study of their efficiency and survivability. Generally, WECs are complex devices that may be attached to the seabed using mooring lines and comprise mechanical systems to reproduce the Power Take-Off (PTO) employed to convert the energy from waves. However, the use of a single model might be not enough to simulate the wave-WEC interactions, the tensions in the mooring lines and the complex mechanisms involved in the PTOs. In this work, a CFD-based solver named DualSPHysics [1], which implements the meshless Smoothed Particle Hydrodynamics (SPH) method, is used to analyse the hydrodynamic response of different devices under the action of waves. The SPH method is suitable to simulate free-surface problems, complex moving boundaries and fluid-driven objects under the action of extreme waves. In addition, the open-source DualSPHysics code is coupled with other solvers to address the simulation of WECs and their functionalities. Thus, DualSPHysics provides a two-way coupling with a mooring line dynamic solver named MoorDyn+ [2] to simulate moored floating devices. On the other hand, to reproduce the PTO of the WECs, DualSPHysics includes a two-way coupling with a multiphysics library called Project Chrono [3], which allows the solid-solid interaction and multibody dynamics where mechanical constraints can be applied such as linear spring damper actuators or joints. Therefore, this work aims to show the capabilities of a co-operative framework involving three different solvers (DualSPHysics-Chrono-MoorDyn+) to numerically reproduce the response of different concepts of WECs and to address more challenging scenarios.

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OES Task 10 Numerical modeling and verification of systems to convert Wave Energy

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Mid November 2019 the OES Task 10 received WECANET support for young researchers attending for the OES Task 10 one day workshop in Amsterdam, https://www.wecanet.eu/oes-task-10-workshop. The workshop was held with the focus on verification of numerical modeling tools used for wave energy projects, comparing results between different project partners and with experimental results.

In 2019 the OES Task 10 project focused was on the:

1. Numerical simulation of fixed experimental OWC (Kriso)
2. Experimental simulation heaving sphere free decay oscillation

The OES Task 10 project has since this workshop continued, but due to COVID the follow on workshops was replaced by webinars in a virtual meeting setup. The OES Task 10 has during 2020, 21 and 22 continued working on different testcases for extracting wave energy. These studies focused on the fixed DTU OWC system with side opening and further development of the experimental dataset for the sphere fixed in waves and radiation forces on the moving sphere in still water. The OES Task 10 project partners attend from different countries around the world and their participation and work is in some cases funded by national funding programmes or as part of other ongoing relevant projects. The project datasets and simulations are stored at the NREL share-point in USA. The project is coordinated by the Danish participants from Ramboll, in collaboration with DTU, AAU and FPP has been supported by the EUDP in two rounds until end March 2023.

The plan is to continue the OES Task 10 and develop additional experimental data sets from wave energy systems tested in wave basins/flumes and towing tanks that can be used for validation and assessment of the related uncertainties.

This abstract is submitted to provide the opportunity to present, discuss and received feedback on the continuation of the OES Task 10 project at the WECANet Conference in Ghent, March 2023.

References:

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

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Modelling of a two-WEC array with Smoothed Particle Hydrodynamics

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In order for Wave Energy Converters (WECs) to become economically viable, they have to be installed in large numbers grouped together in WEC arrays [1]. Existing research focusing on WEC modelling in SPH considers isolated WECs only, whereas the novelty of this research lies in the simulation of a two WEC-array. The two WECs are heaving truncated cylindrical buoys, positioned close to each other to maximize the WEC-WEC interactions due to the radiated and diffracted wave field of each WEC. In the presented research radiation tests are performed of a two WEC-array in DualSPHysics (DSPH) [2], after which numerical results are validated with experimental data from [3,4]. During the first radiation test a chirp-up noise signal force is imposed on one of the WECs (WEC A) in the wave basin without waves, while the other WEC (WEC B) is kept fixed. The velocity of WEC A, the force acting on WEC B and the free surface elevation (FSE) between both WECs were measured in DSPH and validated with experimental results. These measurements allow the calculation of the complex impedance matrix. In a second radiation test, a force is imposed on both WECs, while their velocities and the FSE between both WECs were measured (Figure 1). The motor, gearbox and rack and pinion friction system of the WEC are numerically implemented using the friction model provided by the DPSH - Project Chrono coupling library [5]. Friction compensation above a certain WEC velocity threshold, as applied in the experiments, was implemented in the DSPH – Project Chrono coupling code. After the radiation tests, the two WEC-array was simulated in regular and irregular waves, with implementation of a global control strategy. This showed that the WEC array had a higher individual average absorbed power than an isolated WEC.

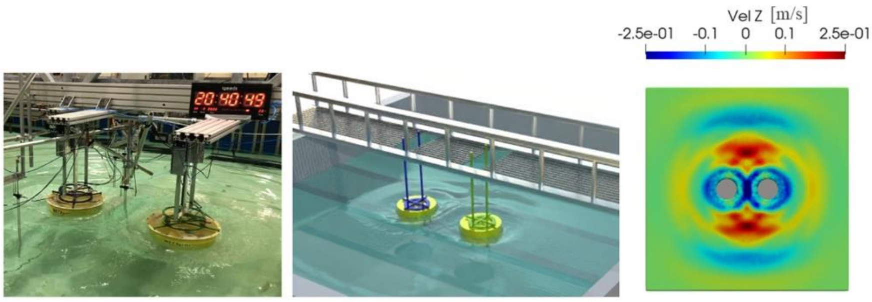

Figure 3: Snapshot of radiation test in experiment (left), DualSPHysics (middle), and vertical fluid velocity in DualSPHysics (right).

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Effect of Tsunami on A Floating Wave Energy Converter

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The fluctuating prices of fossil fuels and their harmful effects on the environment are driving the need for renewable energy such as wind, wave, and solar. Wave energy has a higher energy density and higher daytime availability than well-known renewable sources like wind and solar energy. Currently, a wide range of wave energy converter (WEC) technologies is used to produce wave energy. Some of these are fixed structures, while others are floating structures. Floating type WECs like floating point absorbers, attenuators, floating oscillating water columns, and floating overtopping WECs are generally installed in deeper waters due to their higher energy capacity. However, an attenuator type of WEC is designed to be installed in shallower water to protect the coast from erosion at the same time.

A tsunami is a series of large waves caused by earthquakes, landslides, or volcanic eruptions under the sea. In the Aegean Sea, the densely populated coastal areas have been exposed to several tsunamis in the past, some of which were devastating. The most well-known tsunami in the region is the 1956 Amorgos event (Mw 7.8), which caused runup heights of up to 25 m (Dogan et al., 2021). More recently, a strong earthquake (Mw = 6.6) of normal faulting striking about E-W occurred on October 30, 2020, between offshore Seferihisar (Izmir, Turkey) and Samos Island (Greece). The earthquake generated a tsunami that affected an area on the Aegean Coast of Turkey, from Cesme Alacati in the northwestern part to the Gumuldur coast in the southeastern part. The tsunami caused a change in the sea water level, inundations, and severe damage to various coastal structures, especially floating docks, due to tsunami-induced currents (Ozbahceci et al., 2022).

In this study, the effect of tsunami-induced currents and water level changes on a floating attenuator-type WEC is investigated using a hydrodynamic numerical model based on potential flow theory and Morison's equations. Tsunami-induced water level changes and currents are obtained from high-resolution modeling of tsunami propagation by NAMI-DANCE (Yalciner et al., 2017). Water levels are transformed to power spectral densities, and the current speed and direction are converted to forces and given as inputs to the hydrodynamic model. Structure responses and the tensions in the mooring cables are calculated. Results show that tsunami-induced currents generate large motions and high tensions that should be calculated during the design stage.

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Assessing Loads of Arrays of Heaving Wave Energy Converters in front of Wall-type Breakwaters under Normal Operating Conditions

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Arrays of heaving Wave Energy Converters (WECs) deployed at near-shore locations may be integrated with existing wall-type (vertical) breakwaters, contributing to the efficient use of the marine space, the reduction of costs and the advancement of WECs' maturity. Relevant studies (e.g. [1]) have developed methodologies to determine optimum layouts of heaving WECs arrays in front of a vertical wall, so that the array's power absorption ability is maximized. However, under a holistic design approach optimum solutions should be also examined for structural integrity related issues.

In this context, we have recently assessed [2] the loads applied on oblate spheroidal heaving WECs of optimally-arranged linear arrays in front of a wall-type breakwater under normal operating conditions. The arrays maximize the annual absorbed energy at 3 near-shore sites in the Aegean Sea, Greece, while the WECs are attached on the breakwater via connections restraining all rigid-body modes except heave. Loads are quantified with a spectral analysis, where the required transfer functions are obtained from a frequency-based hydrodynamic model that solves the relevant diffraction/radiation problem, and load contours are calculated. The results (surge and sway restraining loads) indicate that the local wave climate affects strongly the load contours' shape; yet, it does not introduce major differences on the global load peaks for all the WECs. A comparison with equally-spaced arrays reveals that positive contributions on structural integrity related issues can be identified for specific devices of the optimum arrays. The present results could form the basis for a short- or long-term fatigue damage analysis, while nonlinear numerical models and/or appropriate experiments are required to assess loads under extreme wave conditions for specific survival modes.

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Suitability of Wave Energy Converters to future winter sea conditions in Northwestern Spain

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Marine renewable energies can play a key role in mitigating climate change by reducing the dependency on fossil fuels. In particular, it is expected that wave energy will experience rapid growth in the upcoming decades. Knowing how the wave climate will change in the future is the first step to reach sufficient maturity in the wave energy sector. In addition, it is necessary to analyze the suitability of the wave energy converters (WECs) to the new sea conditions, for later be able to study their survival in simulations and their subsequent experimental validation. The present study aims to evaluate the capability of four different WECs—a WaveRoller type device (WRTD), Atargis, AquaBuoy and Pelamis—to extract wave energy on the Northwest coast of Spain, which is the area with the highest wave energy potential in the Iberian Peninsula.

The analysis was carried out by means of the high-resolution (450 m) wave data obtained from the Simulating Waves Nearshore (SWAN) model over the near future winters (2026-2045). Four parameters were analyzed: the energy output (PE), the power load factor (ε), the normalized capture width (NCw) and the operational time (OT). According to these parameters, among the devices that can work for intermediate-deep waters in the area, Atargis would be the best option (PE=1400±56 kW, ε=55.4±2.2%, NCw=35.5±4.1% and OT=84.5±3.3%), AquaBuoy would be an intermediate option (PE=89±9 kW, ε=35.7±3.4%, NCw=22.0±0.9% and OT=95.1±1.2%) and Pelamis would be the worst option due to its large size (PE=163±19 kW, ε=21.7±2.6%, NCw=1.6±0.1% and OT =76.7±1.0%). In addition, the WRTD would also be a good option for shallow nearshore areas with PE=427±248 kW, ε=12.8±7.4%, NCw=48.9±9.6% and OT =88.7±18.9%. A combination of Atargis and WRTDs is proposed to make up the future wave energy farms on the Northwestern Spain coast.

The analysis of the wave energy resource for the future and the assessment of the WECs suitability to the future sea conditions allow framing the present study within the Working Group 1 objectives. The authors hope this study will be the initial bridge between research and wave energy farms implementation in the NW Spain in the coming decades and will serve as an example for further research in other regions.

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Validation of a CFD Model for a Fixed OWC Type WEC Using Large-Scale Experiments

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Although wave energy is one of the most promising marine energy resources in terms of the scale of the resource efforts to commercialize wave energy conversion technology have not been conclusive. An oscillating water column (OWC) is a wave energy converter that is made of a semi-submerged chamber and works on the principle of free surface water oscillation causing the air in the chamber to flow in and out through a turbine to generate electrical energy. OWC stands out for its simplicity and low maintenance cost (Pawitan et al., 2019). During recent decades, many analytical, numerical, and experimental studies have been done to investigate the performance of the OWC. CFD models validated by small-scale physical model experiments are commonly used tools to develop and assess the effectiveness of an OWC. However, high-scale effects have been recognized concerning air compressibility in small-scale experiments on the Oscillating Water Column (OWC) type WEC (Simonetti et al., 2017).

In this study, ANSYS-Fluent CFD software is used to model a fixed OWC-type WEC. The Fluent solves Reynolds-averaged Navier–Stokes (RANS) governing equations. Development of the CFD model involves the numerical domain setup, wave generation, and the hydrodynamic and pneumatic modeling of the interaction of the waves with OWC. Fig 1. shows the numerical domain with waves and OWC. A validation study is performed with a large-scale model of a conventional OWC-type WEC designed and built at LABIMA-UNIFI, shipped, and tested in the FZK Large Wave Flume. The experiments were designed at a Froude scale of approximately 1:5 relative to a prototype. The flume is 307 m long, 7.0 m deep and 5.0 m wide (Ozbahceci and Cappietti, 2021). The comparison of water surface elevation in the flume and across the OWC model shows that there is a good agreement between the numerical model and the experimental studies. Air velocities in the air duct at the central chamber and air and water-induced pressures at the left and the right chambers will also be compared for validation.

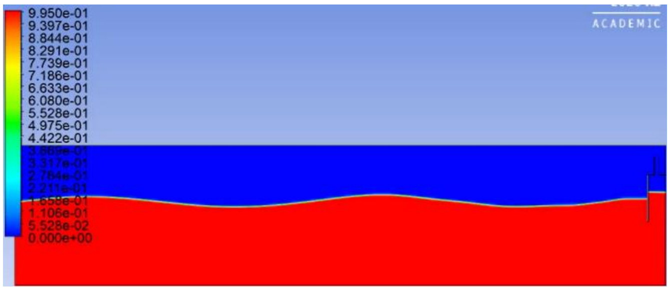

Fig.1. The numerical domain with waves and OWC

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Abstracts for Working Group 2:

Experimental hydrodynamic modelling and testing of WECs, WEC arrays/farms, PTO systems, and field data

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Characteristics of the Coastal & Ocean Basin in Ostend, Belgium

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The Coastal & Ocean Basin (COB) is located in the Flanders Maritime Laboratory on the Ostend Science Park, Belgium. The COB and its associated testing services are designed to facilitate the needs of the offshore/marine renewable, coastal and offshore engineering community and offers the opportunity to companies and government agencies to test scale models under action of waves and currents, to develop innovative designs. The exploitation is managed by the consortium Ghent University, KU Leuven and Flanders Hydraulics Research. The COB is a state-of-the-art wave tank, composed of a large concrete structure (30 m x 30 m x 2.3 m – L x W x H) filled with water in which multidirectional waves of 1st and 2nd order are generated by a L-shaped, piston type wavemaker, equipped with active absorption. Extreme directional wave conditions with a wave height up until

Figure 1: Flanders Maritime Laboratory (left) and first waves in the Coastal & Ocean Basin (right)

0.55m can be generated. Soon currents are added using advanced propeller systems with maximum current velocities of 0.4 m/s. COB's unique selling point is the combined wave and current generation in any relative angle with each other. The basin water depth is variable until 1.4 m. A central pit allows for experiments, at a depth of 4 m. Filling and emptying the basin to its maximum capacity is achieved in 1 h hour by 6 pumps with each 400 m³/s discharge. The achieved floor flatness of +/- 2.5 mm accuracy and the passive absorbing beach minimizes unwanted disturbances of waves and currents. Measurements of water surface elevation using resistive type wave probes and current velocities using ADV instruments, as well as loading (piezo-electric pressure sensors and strain gauge load cells) are logged using a National Instruments data logger system. Recently, QUALISYS was added to the measurement portfolio, providing a state-of-the-art 6 DOF multibody motion tracking system (with 20 cameras above and under water), especially relevant for floating offshore renewable energy devices. Currently the new wavemaker is being tested and the COB will be operational in April 2023.

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Experimental modelling of WEC arrays.

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In order to estimate the accuracy and precision of numerical models, it is always required to have a validation reference.

In recent years, with the exponential growth of computation power, more and more people rely on so-called high-fidelity models, such as RANS, LES, or SPH to estimate the response of wave energy converters and, in general, of floating structures. Unfortunately, the term high-fidelity model does not always imply high accuracy and precision, since the (often very) large number of input parameters can make the model configuration difficult.

In recent years, different initiatives were put in place aiming at the identification of numerical model accuracy through a set of case studies. In particular, the OES-Task10 has been running a number of experiments followed by blind numerical model validations for several single-body wave energy converters. While the methodologies proved to be efficient, with a large participation of the community, the cases under study were all focused on single-body devices.

Since the sector is approaching the pre-commercial stage, it is important to prove the capabilities of numerical models not only for isolated devices, but also for farm configurations.

Figure 1. Experimental set-up

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Considering the limited case of experimental modelling of farms of wave energy converters, only a few datasets are available online. With the support of the WECANet framework, it was possible to run an experimental campaign to simulate different arrays of wave energy converters at the Coastal and Offshore Wave Basin at Aalborg university.

Seven array configurations were tested during the campaign: from 2 to 5 devices, with different inter-array distances and spatial distribution.
The array's single unit is a 1:20 model of a single Wavestar converter, already used as part of the WECCOMP project.

The machines are fully controllable via a Simulink real-time application, from which position, velocity, acceleration, and PTO force were acquired for each device. In addition, surface elevation, excitation force, and wave paddle motion were recorded to be used in numerical validation.
Data and relates article are submitted with the title: An open-source experimental dataset for arrays of wave energy conversion systems, and will be available on Zenodo.

Experimental study of flapping hydrofoil for marine propulsion with a focus on wave height / frequency effect

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Facing the urgent issue of global warming, the world has acted to gradually shift from fossil fuels and unsustainable development to renewable energy dominance and sustainability in order to achieve the Net Zero goal by 2050. Wave energy, a type of green resource that is widely distributed in ocean areas, has been of interest to researchers and engineers. A traditional application for wave energy is to extract and convert it to electricity using wave energy converters (WECs).

Studies reveal that a floating or submerged body undergoes 6 DOF motion in response to waves, and a foil that flaps (a combination of heave and pitch motion) in a fluid has been shown to generate propulsion. As a result, a submerged hydrofoil undergoing heave and pitch motion is thought to have the ability to extract energy from waves and convert it into propulsive force, indicating its potential to be used in marine vessels as a replacement for rotational propellers. A wave-propelled marine vessel driven by submerged hydrofoils is less noisy and environmentally friendly, offering another way to directly apply wave energy.

Inspired by the concept of converting wave energy into thrust (Isshiki, 1982) and following the experimental setup for hydrofoil testing (Isshiki and Murakami, 1983), the present study experimentally investigates the dynamic behaviour of submerged hydrofoils and the marine propulsion they generate by varying wave parameters such as frequency (f) and height (W_h). The hydrofoil was constrained to heave and pitch motion only and was fixed to a linearly movable carriage over the wave tank using a PVC pipe of a certain length. A pair of heave and pitch stiffness springs were used to provide restoring forces for the heave and pitch motion. It was observed that the thrust generated by the hydrofoil and the hydrofoil's moving speed are directly proportional to W_h. The wave frequency significantly affects the time series of collected forces and the hydrofoil's moving process.

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The 2021-2022 WECANet-RoRo experimental activities

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The interactions between Wave Energy Converters (WECs) and wave motion lead to very complex fluid dynamics phenomena. The experimental modelling seems to be the most powerful scientific approach to explore such complex dynamics up to its full extent. However, laboratory effects may cause inaccuracy in the experimental measurements. Study such inaccuracy, figuring out the main causes and acting to control its magnitude is of pivotal importance to produce good-quality data. The execution of an experimental interlaboratory campaign, where the same WEC model is tested, seems to be the most viable methodological approach to i) assess the reproducibility of experiments with WECs, and ii) develop a reliable database for validating advanced numerical models. Under WECANet, a Round-Robin test campaign, namely WECANet-RoRo, was proposed in 2019 a group of three partners was formed, the experimental activity was designed, and Oscillating Water Column (OWC) WEC laboratory model was built (Cappietti, 2019). Afterward, in the years 2021 and 2022, the OWC-WEC model was bring to and tested in the laboratories of the three WECNet-RoRo partners at: i) Florence University; ii) Porto University; iii) Ghent University. In this work, the experimental activities conducted in the three infrastructures are presented and a preliminary intercomparison of measurements is shown. Moreover, the structure of the acquired database is described and the development of an interface of open access to the experimental database is presented. This work aims at promoting the formation of a community of users of WECANet-RoRo for scientific purposes such as, to cite just an example, for numerical model benchmarking.

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Acknowledgements

WECANet-RoRo is supported by the COST Action CA17105, through funding the Short-Term Scientific Missions of team members that moved across the participating experimental infrastructures.

Hardware-in-the-loop (HiL) evaluation of energy maximizing controllers for wave energy systems

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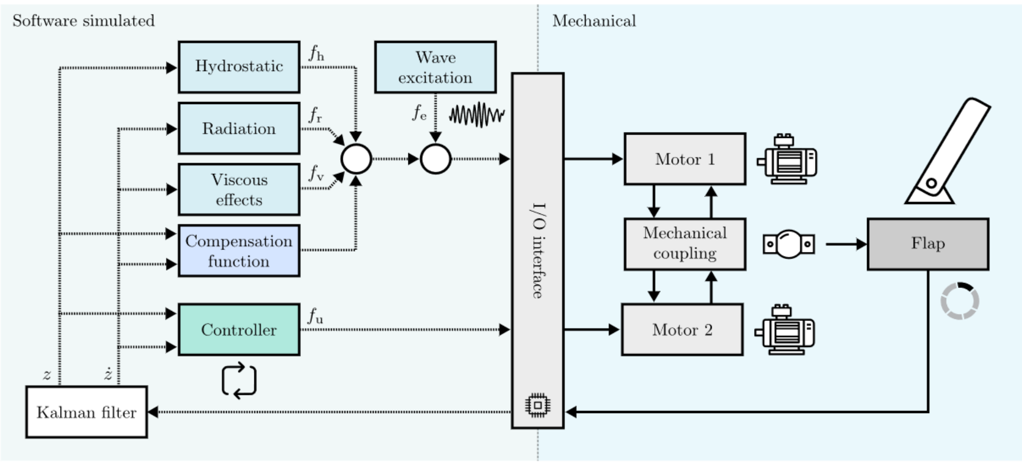
Real-time control has been identified as an important technology in bringing wave energy to economic competitiveness, with the capability to increase power production by a factor of 2-3, with proportionate decrease in LCoE. However, it is important that prospective control algorithms, and excitation force estimators[1], be carefully evaluated in a realistic scenario. HiL systems have the capability to evaluate the energy maximizing performance, adherence to PTO constraints (position, force), and real-time capability.



Two HiL systems have been commissioned at COER, one for generic translational systems (e.g. 1 DoF in heave) and one for rotational (e.g. oscillating wave surge converters, cyclorotors), which have been employed to evaluate a variety of WEC control algorithms[2]. One crucial aspect is that, since the hydrodynamic wave/device interactions are idealized (i.e. the known hydrodynamic model is implemented in software), it is important to evaluate the sensitivity of model-based WEC controllers to errors in the hydrodynamic model, since different WEC control structures have been shown to be somewhat sensitive to various hydrodynamic modelling errors[3].

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Wave energy converter power take-off with active oil-hydraulic accumulator

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The oil-hydraulic power take-off (PTO) device converts the reciprocating movement of the wave energy converter (WEC) prime mover to the rotation of the generator shaft. Moreover, the PTO may be classified as constant or variable-pressure type, if accumulators are used or not, respectively (Hanson, 2013; Penalba, 2017). The constant-pressure type has significant advantage in terms of conversion efficiency, however, increases the complexity of adjusting the PTO damping forces, thus decreasing the WEC energy harvesting performance (Jusoh, 2019).

A new concept of oil-hydraulic accumulator is proposed to improve the WEC harvesting performance. This accumulator consists of two standard accumulators with their gas chambers connected, so that the charging characteristics of the accumulator can be adjusted by compressing or decompressing the gas in the shared chambers. Thus, compared to the conventional PTO, the damping coefficient of this PTOs may be actively adapted to different sea states and ultimately improve the WEC harvesting performance. The ongoing work focuses on the numeric implementation of the concept and compares it with the conventional accumulator to evaluate whether it improves the performance of constant-pressure PTOs.

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Acknowledgements

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Site Selection and The Seismic Response of Large Monopiles for Hybrid Wind-Wave Energy Converters in the Aegean Sea (Türkiye)

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The fixed-bottom hybrid systems OWT/WEC are subjected to environmental loads such as horizontal cyclic loading due to wind and waves. These systems are exposed to earthquake loading and environmental loading in seismic areas. However, the response of the hybrid wind-wave energy converters under combined environmental and seismic loads has yet to be much studied in the literature.

The proposed research will implement for the hybrid systems in the Aegean Sea, Turkey, which is an active seismic area. It is comprising two main goals: (I) Investigating the potential offshore energy sites around Turkish coastlines in the Aegean Sea using multi-criteria decision-making tools; (II) Numerical analyses of hybrid wind-wave energy converters at two selected potential sites under environmental and seismic loading. The 3D finite element method will be carried out for the numerical analyses. Wavestar [1] point absorbers mounted around the monopile will be investigated as hybrid offshore energy systems OWT/WEC within the scope of this study. A diameter of $D = 10\,m$, a diameter-to-wall thickness ratio $D/t = 100$, and an embedded length of $L = 50\,m$ will consider for the numerical simulation of the monopile. The pile head deformation and rotation accumulation and the excess pore water accumulation around the monopile will investigate under seismic and environmental loadings.

This proposed study provides a site recommendation for OWT/WEC systems in the Aegean Sea, Turkey. Within the framework of the numerical simulation study, the seismic response of large-diameter monopiles for hybrid offshore energy systems will assess.

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Experimental Modelling of a Row of Two WECfarm Wave Energy Converters

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As a follow-up of the test campaign with a single, isolated 'WECfarm' WEC [1-2], a test campaign with a two-WEC array is performed in February 2022 at the Aalborg University (AAU) wave basin. Experimental system identification (SID) tests are performed to obtain an accurate dynamic model of the WEC array, in order to design power maximizing control strategies [3]. A radiation test for each WEC individually, with the other WEC lifted, allows to determine the intrinsic impedance of each WEC, obtained as the ratio of the frequency response function (FRF) of the PTO force chirp signal on the FRF of the WEC velocity. The impedance matrix for the two-WEC array is determined with a PTO force chirp signal input on one WEC, with the other WEC locked at the still water level. The velocity on the first WEC is measured, while the excitation force on the second WEC is measured. This test is repeated for the other WEC, to obtain the complete impedance matrix. Accordingly, a causal impedance matching Proportional (corresponding to resistive control) and Proportional-Integral (corresponding to reactive control) controller are designed, implemented in the MATLAB-Simulink real-time control environment, and tested for a selection of four sea states. Figure 1 shows the two-WEC row experimental setup at the AAU wave basin, with both WECs equidistant to the wave generation system. Three test cases are considered: (a) both WECs individually, isolated, (b) the two-WEC array with an independent controller taking no hydrodynamic interaction into account, considering only the diagonal of the impedance matrix, and (c) the two-WEC array with a global controller taking hydrodynamic interaction into account, considering the complete impedance matrix. The absorbed power and q interaction factor metric are used to evaluate the power absorption performance of the two-WEC array relatively to the single, isolated WECs. Constructive and destructive interaction effects are identified, which are dependent on the wavelength of the incoming waves and the distance between the two WECs. The obtained dataset has been used to validate a high-fidelity numerical model based on Smoothed Particle Hydrodynamics (SPH) [4].

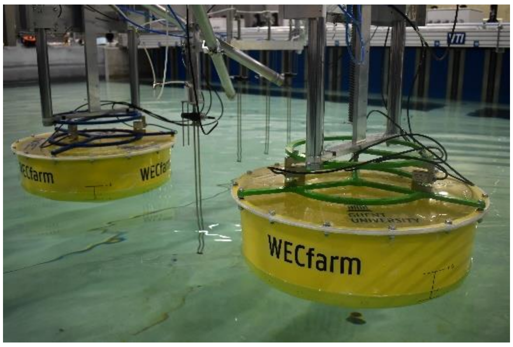

Figure 1: Experimental setup with the WECfarm two-WEC array at the AAU wave basin.

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Acknowledgements

The first author, Timothy Vervaet, would like to acknowledge his PhD Aspirant Research Fellowship by the Research Foundation Flanders, Belgium (FWO) (application number 11A6919N). Funding for constructing the experimental set up has been awarded by an ‘FWO Research Grant’ application granted to dr. Vasiliki Stratigaki (Reference code FWO-KAN-DPA376).

Experimental modelling of a WECfarm five-WEC array at the Coastal and Ocean Basin, Ostend

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In order to validate the results of (non-linear) numerical models on WEC arrays, there is an urgent need for realistic and reliable data in the wave energy converter (WEC) community. Therefore the 'WECfarm' project was initiated, aiming to address this research gap. The 'WECfarm' setup consists of an array of five generic WECs of the heaving point absorber type. The designed 'WECfarm' WEC is equipped with a permanent magnet synchronous motor acting as the power take-off (PTO), allowing the WEC to be actively and accurately controlled [1]. Real-time control and data acquisition are made possible through a Speedgoat Performance real-time target machine, which allows more advanced WEC array control strategies to be implemented via the MATLAB-Simulink environment [1]. Within the 'WECfarm' project, two experimental campaigns were already conducted. A single isolated WEC was tested in the wave basin at Aalborg University in April 2021. This was followed by a two-WEC array in February 2022 at the same wave basin. A five-WEC array will be tested at the new Coastal and Ocean Basin in Ostend, Belgium in 2023. The test campaign will be unique in several ways as it will cover the research gaps that were identified in [1]. A global control (GC) strategy is adopted meaning that the hydrodynamic model of the full array is taken into account when taking control decisions, instead of independent control which only considers the hydrodynamic model of each WEC individually. The WECs are closely spaced in the chosen array configuration in order to enhance hydrodynamic interaction to maximally benefit from GC. System identification tests will be executed to obtain a dynamic model of the WEC array, which is the basis for the control design. Both the resistive and reactive control strategy will be tested, corresponding to a causal impedance matching Proportional (P) and Proportional-Integral (PI) control, respectively. Finally, aside from regular and long-crested waves, tests will be run with extreme wave conditions, short-crested waves and focused waves.

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Development of tools and techniques for determining the impact of wave-tank aberrations on the estimation of wave energy converter performance

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Whilst numerical modelling is continuing to increase in fidelity and power, there will always be an essential role for wave-tank testing in the development of wave energy converters. This role typically includes the calibration/validation of numerical models being developed, as well as the generation of power matrices, the estimation of extreme loads, and the quantification of highly non-linear processes. Reasonably, it is generally assumed that the incident wave field that will be experienced in the sea will be spatially homogenous; unfortunately however, this is not the case when testing in a wave-tank due to internal reflections . Furthermore, there are countless other sources of unavoidable experimental aberration that will impact physical results obtained. These experimental uncertainties have the effect of increasing the challenge of numerical model calibration/validation as well as increasing uncertainty in the estimated performance of the wave energy converter.

There currently exists a range of tools and techniques that can be used for estimating the *random* uncertainty in wave-tank testing, which are generally accepted to be suitable for wave energy converters. However, accepted tools or techniques for the estimation of *systematic* uncertainties do not currently exist. The existence of systematic uncertainties has been evidenced by round-robin testing, which has illustrated that testing the same wave energy converter in different wave tanks typically results in different estimates of its performance. Although some of these differences may be traced to differences in operational procedures, others appear to be linked directly to the wave-tank characteristics and specifically its aberrations. Because wave energy converters are typically only tested in a single wave-tank this has a significant impact on the confidence in wave-tank data. Thus, enabling an estimate of the uncertainty due to wave-tank aberrations is a clear and necessary step in supporting the development of wave energy technologies.

It is proposed that a group is formed that will look to develop tools and techniques for estimating the impact that wave-tank aberrations may have on the estimation of wave energy converter performance from wave-tank testing. The tasks undertaken by this group would include developing both the statistical and numerical techniques for determining the impact of wave-tank aberrations as well as investigating their implementation in wave-tanks. A further objective of the group would be to produce a book on the physical modelling of wave energy converters (as a selection of individually authored chapters), in the same model that the numerical modelling of wave energy converters was produced by a similar group.

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Consideration of Stilling Wave Basin as an overtopping type device wave energy converter

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This research aims to ensure that a coastal protection structure where the promenade works as a Stilling Wave Basin (SWB) generates energy while it protects the coastline against flood. Wave-overtopping is a significant consideration for the safety of coastlines. There are several methods to decrease the amount of overtopping. One of the standard methods is increasing the crest height of the coastal protection structure, such as dikes, and seawalls. However, it is not always possible to implement this method approach due to recreational concerns. The crest top of a coastal protection structure, generally used as a promenade, works as an SWB within this concept. According to the study, SWB can be considered the reservoir of an Overtopping Device (OD) Wave Energy Converter (WEC). The amount of overtopped wave collected in SWB is discharged to the sea with the help of a drainage orifice. A hydraulic turbine is located inside this orifice, generating electrical energy from the potential energy of the collected overtopped water.

OD WECs are investigated by small-scale physical model tests. The experiments are performed in the Wave-Current flume of the Maritime Engineering Laboratory (LABIMA) at Florence University (abbreviated as 'LABIMA-WCF') in Italy. The model is tested under irregular wave conditions for two different water depths. In total, one hundred twenty-six tests are performed for different geometric configurations of the SWB. Accumulated water in the basin is measured for each combination. The amount of energy generated by the hydraulic turbine has a relation with the volume of water in the basin. The number and the capacity of turbines will optimize according to the experimental and numerical data.

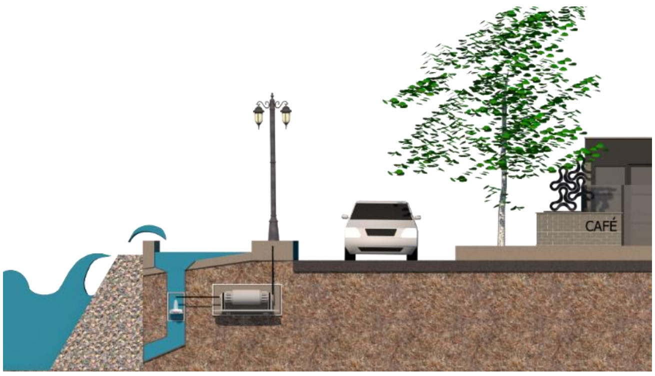

Figure 4: Sketch of the Overtopping Device WEC Concept

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Testing Scaled Model of an Overtopping Device (STSM)

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Sea level rise caused by global warming may lead to increased overtopping discharge. This results in coastal flooding, erosion, and damage to infrastructure and property. One potential solution to reduce the impacts of overtopping discharge is crest modification by considering stilling wave basins (SWB). They are designed to reduce the energy of waves when they reach the crest and store additional overtopping discharge in the basin. It is also possible to use the SWB as the basin of an Overtopping Device (OD) wave energy converter (WEC). This approach can not only reduce the amount of overtopping discharge but also generate renewable energy. This STSM is focused on the testing of SWB combined with OD-WEC.

The experiments are performed on the Wave-Current Flume1 of the LABIMA-UNIFI in Italy. Hydrodynamic conditions and geometric properties of the cost protection structures are scaled with 1/16 based on the case of Izmir Bay, Turkey. The scale model consists of three main parts: the simple caisson, rubble-mound armour protection, and superstructure parts (see Figure 1). The caisson is a 0.25 m wooden box, while rubble-mound armour consists of stones, with a total length of 0.72 m. The armour crest height is 0.25 m, ending with three stones width (0.22 m), and its front face slope is ½. The superstructure consists of a seaward storm wall (SSW), a landward storm wall (LSW), and a sloping promenade which will be the location of OD WEC. Two different wave heights and periods are considered for two different water depths at the toe (h_t). For SWB, 63 different combinations on the armoured caisson are considered. In addition, to analyze the SWB effect, five armoured caisson models without SWB and five different caisson models without armour protections with the same crest heights are considered for further comparisons.

In conclusion, 177 tests are performed with different combinations. The resulting overtopping discharge volumes are evaluated in terms of how the combination of SWB and OD-WEC ensures the safety of the coastal zone while also the wave energy potential.

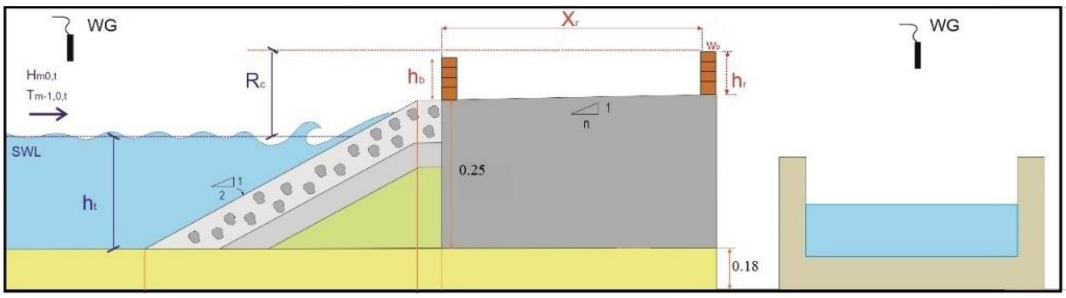

Figure 1. Experimental set in the LABIMA-WCF wave flume

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Climate change impacts on the wave energy in the North Atlantic

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To evaluate the potential for wave energy exploitation in the long term, the evolution of wave resource over the 21st century is studied in the context of a changing climate. The WW3 wave model is forced with wind and ice-cover data from an RCP8.5 EC-Earth system integration for two 30-year time slices. The first 30-year period, between 1980 and 2009, represents the present climate and the second, between 2070 and 2099, represents the climate in the end of the 21st century.

To estimate the accuracy of the results obtained with the WW3 simulations, mean and 95th percentile of Hs, Tp and Tm, are compared with corresponding empirical statistics taken from the ERA5 reanalysis for the same period. It is observed that although the spatial patterns of the empirical statistics are rather similar for most of the North Atlantic domain, there are some discrepancies between the empirical statistics of the two data sets.

The energy flux was extracted directly from WWIII simulations, the mean and 95th percentile for each 30-year was obtained. The energy flux shows a global decrease across the North Atlantic with exception of the area near Greenland. With respect with the extreme values of the energy flux, the area where an increase of energy is expected to be larger includes the Labrador Sea and the Atlantic for latitudes higher than 65ºN. This could be correlated to the growth in the frequency of extreme events, related with changes in the statistical distribution of wave parameters due to climate change.

The results obtained in the present work are found to be adequate and in agreement with other studie. In a forthcoming study, the climate changes in the energy flux will be assessed for different periods representative of future climate for the particular case of the Azores and Madeira Islands with wind fields downscaled from WRF atmospheric model.

Acknowledgements
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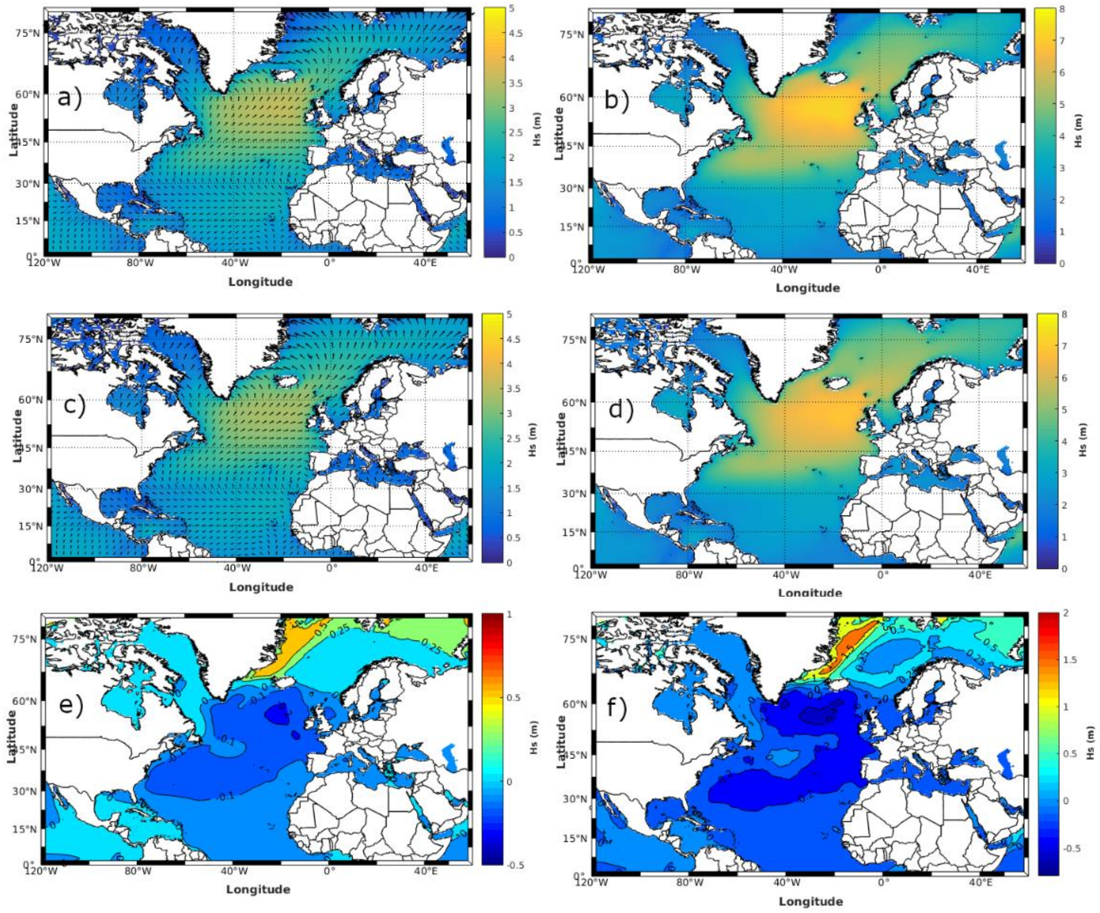

Figure 1- Mean (left panel) significant wave height (and mean direction) and 95th percentile (right panel) for present (top), future (middle) and difference between them (bottom).

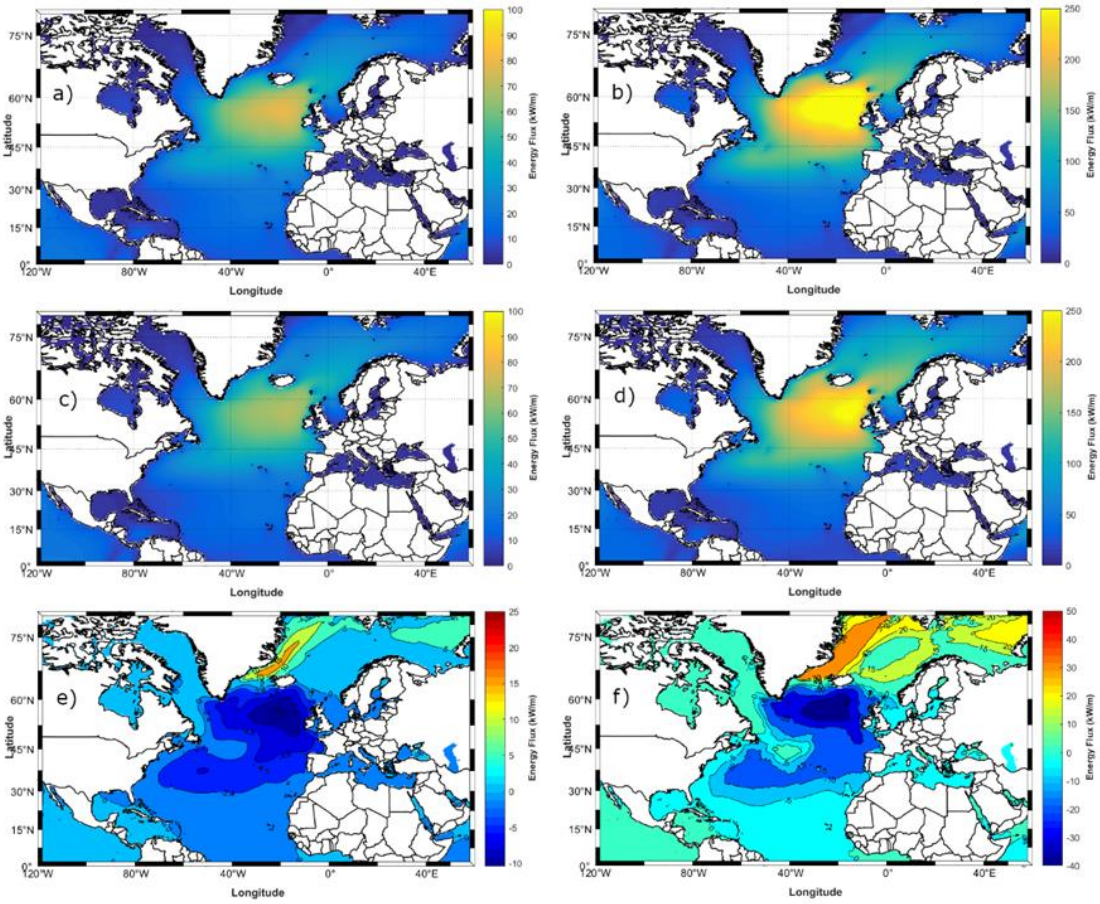

Figure 2- Right panel mean Energy Flux, left panel 95th percentile, for present (top), future (middle) and difference between them (bottom).

Experimental simulation of oil-hydraulic Power Take-Off systems for Wave Energy Converters

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The Centre for Marine Technology and Ocean Engineering (CENTEC) is dedicated to the development of a generic oil-hydraulic power take off (PTO) for wave energy converters (WECs). The generality of the PTO architecture is intended to allow mass production, thus industrial development and commercialization. More recently, CENTEC has designed and acquired a 5.5 KW Hardware In the Loop (HIL) simulation test rig to test and develop this PTO concept, but also to provide the research community an important and unique equipment for research and development.

Therefore, the short-term objective of this research is to increase the effectiveness of this PTO concept on the offshore renewable energy sector by consolidating partnerships with some of our partners and new ones that may be interested in joint applications for research funding calls. The medium-term objective is to expand the test rig to include more oil-hydraulic components and the long term one is to achieve higher technology readiness levels (TRLs).

The participation in the WECANet conference in the WG 2, topic "wave emulators to perform dry tests for PTO systems", may provide the opportunity to accomplish these objectives and finding support from experts on the field of HIL simulation. Moreover, CENTEC may provide testing services to entities with activities in the offshore renewable energies, either in person or remotely with the help of information and communication technologies. Thus, contributing for the building up of more competences, knowledge and qualified personnel on WEC and PTO HIL testing.

CENTEC is also available to participate in WG2 with the research dedicated to WECs assembled on Floating Offshore Wind Turbine (FOWT) platforms. More specifically, CENTEC is building an experimental model where an array of WECs is used to control the FOWT dynamic motions. The objective is to provide conditions for wind turbine power upscaling with a self-powered system.

Acknowledgements

This work has been supported by the project "Generic hydraulic power take-off system for wave energy converters" funded by FCT under contract PTDC/EMS-SIS-1145/2014, project "Experimental simulation of oil-hydraulic Power Take-Off systems for Wave Energy Converters" under contract PTDC/EME-REN/29044/2017 and "Variable geometry Wave Energy Conversion system for the floating platforms" under contract PTDC/EME-REN/0242/2020.

Abstracts for Working Group 3:

Technology of WECs and WEC arrays

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Dealing with problems in the supply chain of critical raw materials used in electrical generators applied in wave energy converters, with particular attention on the aspects of rare earth metals

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Working group: 3 – Technology of WECs and WEC
Working Group Topic: WEC / WEC arrays electrical aspects

Electrical generators are the main components of the greatest part of the WECs since these are converting the mechanical energy taken from the waves to electricity [1]. Nowadays, most of these are permanent magnet generators using high-energy rare earth permanent magnets.

The rare earth supply chain problems, which have become urgently important after the Covid outbreak and still-ongoing war, have attracted enormous economic and political interest from both the academic and corporate communities [2]. These challenges sparked intense R&D efforts to create electrical generators using more readily available ferrites, fewer rare earth permanent magnets, or variants without any permanent magnets. These investigations are concentrated on the creation of new topologies in addition to the optimized enhancement of the traditional generators (dc excited synchronous, doubly-fed, and squirrel cage induction ones). The research activities are targeting both rotational and linear generators to be used in WECs.

Finding novel and better topologies of low-speed permanent magnet linear electrical generators with optimally reduced rare earth permanent magnet amounts is an area of research that I am interested in and will be focusing on in the near future.

I should like to emphasize that I am open to new collaborations in this field in the frame of the WECANET project (but also outside it), inclusively for hosting in our laboratories young researchers.

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GUI tool for h-WEC device optimization and energy calculation

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Despite agreeing that wave energy is a very large resource, the research community is still struggling to make it competitive against other renewable energy sources. To reach that goal, research should focus on de-risking investment by providing reliable and accessible information on the performance of these technologies. This enables a techno-economic evaluation of the wave energy potential at a specific location that can lead to the successful implementation of wave energy harvesting.

The h-WEC, or hybrid-WEC, is a breakwater-integrated wave energy converter (WEC) that combines two wave energy harvesting concepts: the Oscillating Water Column (OWC) and the Overtopping Device (OTD). These are combined to achieve higher efficiencies for a broad range of wave and tidal conditions. To investigate the h-WEC performance for the chosen geometries, several experimental modelling tests were carried out at the wave basin of the Hydraulics Laboratory of the Department of Civil Engineering of the Faculty of Engineering of the University of Porto. These tests considered regular and irregular waves and tidal levels representative of the conditions at the Port of Leixões, Porto, Portugal. The device was integrated into a section of the planned extension of the North (rubble-mound) breakwater of the port. Three different OWC configurations were tested: two with different focusing walls designs and one that combined focusing walls with a dual-chamber OWC.

The data obtained from the tests was analyzed and processed using Empirical Mode Decomposition for smoothing and outliers were removed and replaced. The resonant frequencies of the different OWCs were determined, as well as the RAO for various frequencies. The data is then used to determine the best WEC configuration for the location. Moreover, a MATLAB-based application with a Graphical User Interface was created that allows to: *(i)* optimize the device's geometry for specific wave and tidal conditions, and *(ii)* determine the energy produced, income generated and GHG emissions reduction for the optimized geometry. This tool can greatly assist port authorities on carrying out a preliminary techno-economic assessment of the device for their port, thus enabling the successful deployment of wave energy. This work contributes to both Working Groups 2 and 3.

Acknowledgements

This research study was partially funded by the Ports Towards Energy Self-Sufficiency (PORTOS) project co-financed by the Interreg Atlantic Area Programme.

WECANet is a network of researchers and professionals from 31 countries, whose enthusiasm and commitment to the network activities are greatly acknowledged. More information about the WECANet members and their activities are available at: www.wecanet.eu; twitter: @wecanet.

Multitask wave energy converters

Multitask wave energy conversion systems

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The lack of energy is one of the greatest challenges for contemporary and future generations. The shortages of energy affect developed and developing countries. The problem is of significant importance for societies because the lack of energy is a serious development constraint for many regions and nations. Nowadays, alternative energy sources are believed to be the most attractive sources of energy worldwide.

The potential energy of ocean waves is estimated to be about 2.96 TW. It is a substantial resource of energy that may be converted into electrical energy. The perspective of rising global energy consumption and the unwanted side-effects of fossil fuel energy production brings even more importance to the issue of acquiring wave energy (Guo et al 2020, Zhou et al 2021). Despite the current low level of conversion, the studies regarding this topic and the development of numerous prototypes to capture this resource are extensive. This suggests that the optimal technology is yet to be determined and there exists a potential for advancements and innovations in this field.

A reliable technological solution for a profitable conversion of ocean wave energy is one of the most important challenges in the sector of renewable energy and environmental protection. A variety of devices have been proposed and tested but did not accomplish this goal. The main problem is that the available concepts are not efficient and economically attractive. There is a need for new ideas on how to bypass or mitigate this problem.

An attractive alternative for conventional devices is multi-task wave energy conversion systems (Sulisz 2013). These concepts provide opportunities for many regions and nations to solve the problem of the shortages of energy or fresh water, or to secure the protection of coastal and harbor areas by applying local resources and cost-effective environmentally-friendly technology.

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Concept analysis and design of wave energy conversion combined with energy storage

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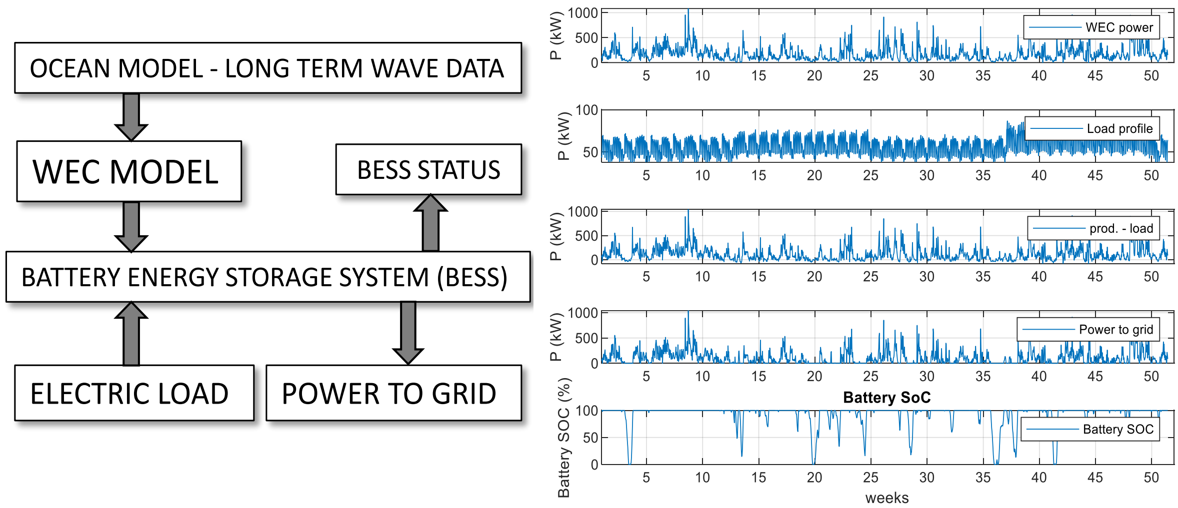
Despite the worldwide wave energy resource being significantly large, this resource is not yet used for electricity production as for other renewable energy resources, such as solar or wind energy. One of the main reasons for this situation is the difficulty in dealing with the high dynamic and random nature of ocean waves. For that reason, converting the mechanical energy of waves into stable electricity, in a cost-effective way, is the major present-day challenge. To overcome such a challenge customized wave-to-wire numerical models are required for the analysis of wave energy converters (WECs) power output. The present work focuses on the development of a time-domain numerical model that allows analyzing a system composed of a WEC coupled with an energy storage system (ESS) for providing constant power to direct end-users. Through the present model, irregular sea states, WEC's power absorption and stored energy are simulated. The model is used for sizing an energy storage unit coupled with a WEC. A simplified scenario relative to feeding a fraction of Portuguese power demand is set up for demonstration. The model is developed to be computationally efficient. Allows assessing long periods, e.g. of the order of 1 to 10 years, in few hours of calculations. This work locates in WP1 and WP3 and has been started within a STSM at the Norwegian University of Science and Technology.



Conceptual model (left) and example of model results (right).

Acknowledgements
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Emulator Test Rig for the Electrical Aspects of Wave Energy Converters

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Wave energy presents abundant potential for the generation of renewable and sustainable energy to expedite the transition to decarbonised power networks. The resource remains relatively untapped as compared to the contemporary wind and solar energy. Offshore renewable energy is gaining prominence for accommodating the increasing energy needs while simultaneously contributing towards materializing the reduced emissions targets.

Various forms of wave energy converters, with distinct mechanisms for absorbing the energy and converting it into electricity, have been proposed. A control system is typically used to direct the operation of the converter, with the objective of extracting the maximum power from the wave and ensuring the safe operation of the device. Grid interfaced wave energy converters need to satisfy power quality requirements imposed by grid codes to minimise the impact of their variable nature on the power network.

The proposed work concerns a wave energy emulator rig under development at the University of Malta. The heave motion of a point absorber is emulated to drive a rotary permanent magnet generator through a double clutch converter. The generator output is rectified and interfaced to the power network through a two-stage power converter. A battery storage system is planned to smoothen the power delivery to the network. The rig allows investigation of control algorithms for power take off and power conditioning strategies for network interfacing. The work aligns with the Electrical Aspects of WG3 and would benefit from collaboration with WG1.

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Grid integration of Marine Renewable Energy in large scale

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Working Group 3: Technology of WECs and WEC arrays – electrical aspects

Energy needs and onshore location scarcity have resulted in increasing number of marine renewable energy projects (offshore wind farms, floating PV, wave energy converters) as future energy harvesting projects. First large offshore wind farm projects assumed offshore platform, with power transformer, as point of common coupling (PCC) of all submarine cables from wind turbines [1].

Ambitious plans for intensive marine renewable energy deployment are imposing needs for development of "energy hub" which could act as energy crossroad and PCC of intermittent marine renewable production, likely. These "energy hubs" – "energy islands", either natural or artificial, should serve as hubs - or green power plants - that gather electricity from the surrounding offshore marine renewables and distribute it to the power grid onshore as well as directly to other countries [2].

It might be that control of vast variable production and interconnection power transmission could be convenient for power system operators with an energy hub with power storage, compensators, power electronics and transformer facilities. Consequently, dislocated offshore marine renewables, far from a shore, could be operated from relative vicinity (from energy islands) or indirectly by controlling an "energy hub" itself.

The energy island concept raises up new challenges for power system engineers in both construction and operational manner. It gives more opportunities for integration and operation of renewables, but imposes new power system stability challenges to integrate such energy bulk from an energy island into onshore power system by means of submarine cables. So, it could be a very challenging call for academia and power system experts for scientific works, analyses and studies related to these topics in near future.

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Energy-Maximising Control for Wave Energy Systems – High Performance, or Simplicity?

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Real-time control has been identified as an important technology in bringing wave energy to economic competitiveness, with the capability to increase power production by a factor of 2-3, with proportionate decrease in LCoE. However, not all wave energy developers are prepared to embrace the highest performing control algorithms, since they are generally quite mathematical in description and usually computationally onerous. Typically, the simplest spring/damper controllers are employed, with poor performance in broadbanded seas and physical constraints only being managed by conservative controller gain adjustment.

At the other end of the performance/complexity spectrum, MPC and MPC-like controllers [1] have the highest performance, and make full use of the operational PTO space, while respecting hard physical constraints. However, at each computation step, they must solve an on-line (constrained) optimization problem. Within this family of controllers, moment-based methods [2] have been shown to have high performance, can be extended to nonlinear WEC descriptions (still resulting in a convex optimisation problem), are computationally efficient, and have been demonstrated experimentally.

However, a collection of controllers, which require no on-line optimization, but have superior performance to spring/damper control, have recently emerged [3], with a number handling the physical PTO constraints efficiently. One such controller is the LiTe-Con+ controller [4], the performance of which has been recently demonstrated in tank tests. Indeed, a precursor to LiTe-Con+, the 'Simple and Effective (SE)' controller [5], has seen adoption by a number of WEC developers. Perhaps aiming for a lower point on the performance/complexity curve might result in overall better adoption of energy-maximising control technology?

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Technical, spatial, and financial analysis for the implementation of wave energy exploration in EU coastal regions.

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Persistent innovation in energy strategies and policies have been crucial to fulfil the proposed climate and energy targets in different EU regions in the past decades. Being Europe a continent highly constituted by coastal countries, increasing efforts have been focused on exploiting the marine resource and lead the strategies towards different ways of the blue economy.

Despite some renewable marine energy technologies, such as the offshore wind energy, have successfully reached a well-established commercial stage, the wave energy sector is suffering a slower growth. Several wave energy converter (WEC) technologies have been proposed since the second half of the past century. However, most of the wave energy converter projects stuck on R&D or prototype testing stages. To keep on pushing the wave energy technologies into further exploitation stages, continuous research is needed to identify suitable locations for the wave energy exploitation, considering the associated technical, spatial, and environmental constrains. Furthermore, site-specific optimization analysis is needed to determine the proper WEC array configurations that maximizes the energy harvest and minimizes the overall costs of installation and maintenance. Finally, financial metrics need to be associated to any proposed wave energy project to providing policy-makers and investors with meaningful information about the project viability and its possible contributions to the different nation's energy systems.

In the framework of the WG3 and WG4 topics, relevant future research involves evaluating the wave exploration possibilities in coastal European areas as a combination of wave resource analysis, marine spatial planning, technical projections of optimal WEC arrays, and the determination of site-specific economic and financial indexes. Geographical Information Systems and cutting-edge optimization algorithms are regarded as efficient tools for the pursuit of such wave energy exploitation potential analysis.

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Stability Analysis of Modern WEC Marine Semisubmersible In Waves

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The design of semi-submersible structures is a technical process that includes structural and stability analysis. All projects have to be tested and carefully analyzed before operation in real sea in order to ensure the project structural strength and stability for all operating conditions.
In this process, done mainly by the development and design departments, a number of requirements of stability are taken into account and they must be satisfied so that after the materialization of the project to achieve an optimal construction according to classification rules.
The semi-submersibles sector is developing fast and it plays a key role in offshore oil extraction industry due to good seakeeping performances. Most oil industry projects for waters deeper than 30 m are based on semi-submersibles and this type of structure is a remarkable expansion for maritime industry. Based on semi-submersible capabilities, semi-submersible is capable to carry in deeper waters different equipment for renewable energy extraction, like wind and wave energy converters. The resulted energy is needed to supply energy to near shore cities in a higher and higher percent, as requested by EU to all member countries.
This will be impossible without a stable and secure base structure able to carry energy converters in areas where the visual impact and the interference with the network of maritime transport is minimum and the amount of extracted energy could be maximum.
Projects assessment should be done for all ballast conditions and all sea states in order to ensure investors and shipyards to build and develop environmentally friendly technologies. This should be done accordingly to classification rules regarding intact and damage stability and this paper will present the Autoship stability and longitudinal strength evaluation of a three columns semi-stability that can be used in future offshore renewable energy.

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A Concept of Hybrid Wave and Wind Energy Converters

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The development of marine structures has been getting attention to harness renewable wave and wind energy. In this sense, a Floating Wind Turbine (FWT) can share its platform with Wave Energy Converters (WEC). This hybrid system can extract coupled wind-wave energy in order to transfer electrical power to the shared grid. Also, the WECs may reduce the oscillatory behavior of the FWT, induced by wind and waves. Therefore, we investigate the possibility of integrating WECs within the FWT's platform to achieve two main objectives: reduction of hybrid system oscillations and harvesting coupled energy. In this project, the use of Oscillating Water Columns (OWC), which are a type of WECs, will be investigated. In fact, the integrated OWC inside the FWT's platform opts to change the air pressure inside the capture chamber using a throttle valve control in order to reduce the system oscillations, especially the platform pitch and top tower fore-aft displacements. Also, both OWC's wells turbine and the wind turbine can extract hybrid energy using generators with designed intelligent controllers to transfer the electrical power to the grid. To do so, the hybrid system needs to be modeled and an intelligent hybrid controller should be designed to increase the electrical and mechanical efficiency of the system and to take advantage of the shared platform. Numerical modeling may be conducted under various sea states and midst turbulent wind inflow using SIMO-RIFLEX-AeroDyn, developed by MARINTEK and CeSOS/NTNU. Also, an experimental simulation will be done on a scale prototype of the hybrid FWT-WECs to validate the obtained numerical results.

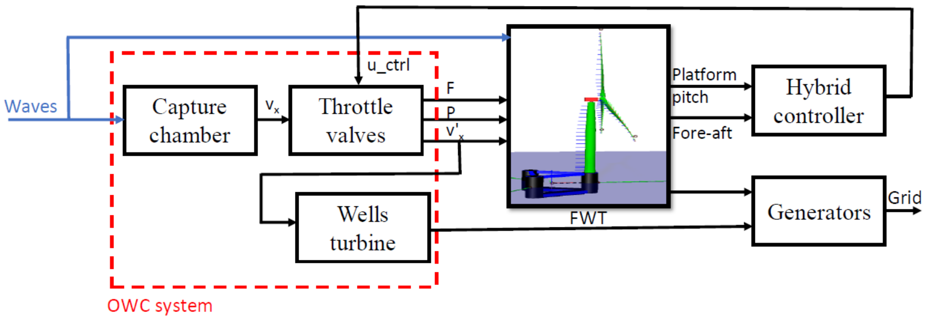

Figure 1: Hybrid FWT-WECs system

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Cost-benefit analysis of Grid Integration of Wave Power Farms on the Mediterranean (Adriatic) Islands' RES power microgrids

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Wave energy is of interest for regions with high as well as moderate wave power potential such as the Mediterranean (including Adriatic) coastlines and islands. The focus of our research is currently on the cost-benefit analysis of integrating a wave power farm with the power system of island in the modest wave power potential Mediterranean (Adriatic) Sea, combining the wave power with solar photovoltaics (PV) and/or onshore and offshore wind farm electricity generation consisting of small prosumer scale PV systems located on the island's households and other buildings combined possibly with island's power grid (energy community) scale PV or wind power farms and battery energy storage system (BESS) in so-called island's RES micro-grid. The power load profile of Mediterranean (Adriatic) islands is very specific where demand (consumption) substantially increases during the summer tourist season. The wave power technology implemented in our research is a point-absorbing wave energy converter (WEC) with a direct drive linear permanent-magnet synchronous generator power take-off device and the expected electricity generation is calculated for moderate island's micro-location wave heights (potentials). The main idea of this research is to determine the optimal number of WEC's and size of overall microgrid PV and BESS capacity where wave power farms (WPFs) will consist of up to enough (minimal) number of WECs for supplying low winter electricity demand with limited PV and BESS electricity supply. This optimization of island's microgrid size is based on cost-benefit analysis with technical goal to achieve grid net-zero and/or zero electricity exchange standard while reducing the intermittency of the power flow into the grid with minimum LCOE and shortest payback period. The preliminary results are published in [1] and will be published in relevant scientific papers in the future and hopefully will results in cooperation on future related international projects with members of WECANet projects.

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Electrical systems and grid connection of wave energy converters

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There is good potential in wave power and different types of wave energy converters (WEC) have been developed [1–3]. The WEC could for example be of the type overtopping systems, oscillating water columns (OWC), or wave activated (or oscillating) bodies [1, 2]. At WECANet, we can together analyze design and survivability aspects of different WECs to support future development. The WEC most studied at Uppsala University (UU) consists of a heaving buoy connected to a linear generator (LG) with permanent magnets (PM). The UU-WEC generates electricity as the translator in the LG moves in relation to the stator and this is a directly driven system. Due to the variable speed of the translator, the voltage and current from the WEC will vary in amplitude and frequency [3]. Therefore, the electric conversion system needs to be carefully designed before grid connection of the UU-WECs. One example is to convert the AC from one UU-WEC to DC, and then interconnect the system with several other WECs to a common DC-bus, and then convert back to a smooth AC which is then transformed to a suitable power level before grid connection [3]. Together in WECANet, there are opportunities to discuss, analyze, and design different types of strategies for grid connection of different types of WECs. There are also studies on WEC control strategies (such as latching or declutching), designed to e.g., enhance the power output or to support mechanical or electrical safety [4]. WECs could also be used directly for powering a specific system, such as a desalination plant for freshwater generation [5]. Future opportunities or limitations with control strategies and to use WECs for new applications can be discussed in WECANet. In WECANet, we can also talk about how marine renewable energy sources (RES) may require considerations on several aspects, including e.g., the power output from larger farms, power electronics, cables, control strategies, corrosion, environmental aspects, monitoring and so on. Some parts of the electrical system may be more costly or need more maintenance or installations at high costs, due to the marine environment. A techno-economic perspective is necessary to adopt, which we can discuss more in WECANet. There are opportunities to learn and share knowledge and ideas in this area. Thus, I am very interested in taking part in the collaborations in WECANet and to discuss and learn from other researchers, with basis in Working Group 3.

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Classification-based OWC Diagnosis Using Real Measured Data

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With the goals established by the European Strategic Energy Technology Plan (SET-Plan) to reduce the Levelised Cost of Energy (LCoE) to 200 EUR/MWh in 2025 and 150 EUR/MWh in 2030 for wave energy, the wave energy industry is facing a number of challenges, which require that research re-focus into the techno-economic perspectives. One way to meet the SET-plan targets is to advance the Technology Readiness Level of the existing Wave Energy Converters (WEC) [1]. However, another way to achieve these targets is to develop methods where the economics considers the full life-cycle costs of the technology. LCoE can be reduced through the improvement of the availability, capacity factor and Annual Energy Production (AEP) of a WEC farm. This may be achieved through good monitoring and maintenance strategies to maintain a good operation. In fact, maintenance has a strong impact on downtime during the lifetime of a plant, which lead to increase in availability, power production, capacity factor and AEP. Hence, reducing Operational Expenditure (OpEx) through Operational and Maintenance costs is an efficient approach to reduce the LCoE [2]. In this sense, and in line with the aims of WECANet's Working Group 3 (WG3), we investigate the possibility of reducing LCoE through the development of a classification-based Power Take-Off diagnosis using real measured data from WEC farms. This diagnostic technique will allow the future implementation of a predictive maintenance strategy, which can reduce OpEx by 18% and LCoE by 10%. The study case of Mutriku wave power plant is considered, where measured data will be processed using feature extraction methods (PCA, LDA, etc.) followed by a machine learning module (ANN, SVM, etc.) to classify the data and predict the health of the plant. Our work also investigates the development of control strategies of Oscillating Water Columns for enhanced wave energy generation.

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Optimization of Array Configurations of Wave Energy Converters Integrated in Near-shore Infrastructures

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The technology of Wave Energy Converters (WECs) has been developed remarkably during the past decade, aiming at delivering commercially competitive solutions that maximize efficiency, ensure survivability, reduce costs and minimize environmental impacts. WECs are in a reconsideration phase as far as design methods, tools and criteria. The optimum design at different levels (e.g. array configuration, shape, mechanical characteristics) has been highlighted as the main dominating factor for the successful future development of WECs in arrays by many researchers. Heaving type Point Absorbers (PAs) correspond to one of the most technologically advanced type of WECs, characterized mainly by operation simplicity and efficiency. Alternatively to offshore marine areas, PAs arrays can also be placed at near-shore locations and integrated in existing infrastructures (e.g. vertical/wall-type breakwaters) targeting to alternative uses of the corresponding marine facilities, the realization of cost-efficient solutions through costs sharing, and sustainability.

In our recent works [1, 2], we developed a robust optimization framework to determine the optimum layout configuration of an array of spheroidal heaving PAs in front of bottom-mounted vertical walls of finite-length under the action of long-crested irregular waves. The framework has been applied for arrays consisting of five PAs at five near-shore sites in the Aegean Sea, Greece, which are characterized by mild wave conditions. For all the examined cases the annual produced energy has been increased by an average (among all sites) 11.8% compared to the case of equally-spaced arrays, with PAs placed along a part of the total wall length, highlighting the importance of the inclusion of optimization related studies for the advancement of the WECs sector and their sustainable development.

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WEC grid integration – challenges and possibilities

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Although the theoretical potential of wave energy is over 20000 TWh/ year this renewable energy source is still the world's largest unexploited source of energy. However, in the last years there has been increased scientific interest in wave energy, the WECANet action is an example. The wave energy is intermittent, relatively unpredictable and highly variable, which rise concerns about the safe and reliable operation of the power grid. There are various issues associated with wave energy grid integration such as power output variability, control of power converters, hosting capacity, power quality issues, bidirectional power flow between the converter and the grid, optimal storage requirements etc. To enhance the grid integration of wave energy converters (WEC) it is necessary to explore extensively all of these issues.

Our past research has addressed some of these issues from multiple viewpoints. From the electricity grid viewpoint, we have studied the hosting capacity of power grids for distributed generation without energy storage and with electric vehicles that charge without specific coordination. To enable larger shares of renewable energy, we have also explored the possibility of using electric vehicles to regulate the frequency in microgrids and the possibility of using residential energy storage to reduce the impacts of buildings with PV on the distribution grid [1]. From the viewpoint of energy consumers, we have explored methods of energy sharing in energy communities, which ensure that all energy community members benefit from the energy sharing [2, 3]. Our future research will be in line to the WECANet WG3 programme. The hosting capacity of specific power grids for WEC will be studied. Another research activity will be to explore different methods of energy sharing in energy communities consisted of local electricity generation including WEC and flexible consumers. When the members of an energy community have flexible end-use appliances and loads, such as electric vehicles, they can also provide different ancillary services to the distribution grid, through coordinated smart charging of the electric vehicles.

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Optimization of a novel Wave Energy Converter through adaptable pitching and power-take-off techniques

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The digital transformation of Wave Energy Conversion (WEC) systems is vital for improving the technology through accurate monitoring and control of the devices which leads to cost-effective operation. This research focuses on the development of the digital twins of a dense array of floaters presented in [1], to optimize the design of the arrays.

Two different modelling techniques will be assessed, namely, the high-fidelity Computational Fluid Dynamic (CFD) and the mid-fidelity Multibody Dynamics (MBD). More specifically, a wide range of sea states will be used to compare the two methods and identify the range of sea states where MBD performs well while keeping the computational cost low. In parallel, a small-scale experimental set-up is being developed which will be used to validate the computational models even further.

Understanding the hydrodynamic interactions and mechanical interconnections between the array members is important to optimize and control the performance of the system. This will be achieved through adaptable pitching and power take-off (PTO) techniques. More specifically, an advanced control method will be established which will induce a resonant behavior either by adjusting the angle between the vertical axis of the floater and the free-surface of the water (pitching), or by adjusting the surface area of the pistons in the PTO system by using different combinations of several pistons. These design optimizations ensure the maximum wave power extraction possible.

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Multi axis WEC research using TALOS WEC as a case study

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The NHP-WEC project research investigates key aspects of Wave Energy Converter (WEC) technology and global deployment potential, that requires the integration of novel methodologies across optimisation, control, condition monitoring and resource forecasting. These advances will drive evidenced reductions in costs and hence provide confidence about the benefits of wave energy technology to developers and investors. TALOS WEC a multi axis point absorber style WEC completely enclosed with internal inertial mass using hydraulic cylinders or linear Generators PTO is used as a case study for this research. The design, development, deployment and operation of wave energy converters, such as the Lancaster University developed TALOS WEC concept and their potential commercial use, in arrays or hybrids with floating offshore wind, requires a holistic understanding of the marine environment. This research advances our knowledge and understanding of these extreme marine environments where these machines will be deployed, as well as improve operators' ability to control the machines when changes in conditions are forecast to improve their ability to generate electricity, and increase their ability to survive. The TALOS WEC research project is also a strong networking platform providing international collaboration with researchers from Europe, North America and Asia.

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A concept of linear DC generator moved by WEC

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There are important challenges that today's technology of wave energy faces to harness the ocean's energy as a continuous source of renewable energy. According to [1] a new idea of vessel`s anchoring in marinas and ports (SSM – Slow Stochastic Motion) is proposed as a simple WEC technology based on vessels (buoys) and Wells turbine.

Usually it is better in electricity generating to have continual dispose of mass flow of working fluid where synchronous generators are in function; for example, constant mass flow of water in hydroelectric power plants. Due to non-simultaneously motion of waves, variety of regulation problems occur in power generation. New proposed idea is a vessel anchoring in marinas and ports based on non-simultaneously motion of waves (SSM) conceived on large number of small volume plastic buoys. Cylindric buoys with permanent magnet inside the buoy as roller coat are mounted in tube as movable part of a linear DC generator. There are induction windings around each tube with possible vertical movement of permanent magnet. Sea waves independently move buoys up-down inside the vertical narrow tubes surrounded by described induction winding. Tubes can be constructed as a modular linear or even a modular aerial located DC generator. A PLC and electronic switches in each tube should be used to optimize electric output (different signs and value of output induced electricity). Dimensions of buoys and tubes should be optimized for wave conditions for defined location of port. Power electronic inverter device need to be used to get AC output electricity or DC electricity can be stored in batteries instead.

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Abstracts for Working Group 4:

Impacts and economics of wave energy and how they affect decision- and policy-making

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Sustainability Assessment of Wave Energy Converters: A Review

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Climate crisis and need of alternative renewable energy resources to fossil fuels, entailed the development of various ocean energy devices including wave energy converters (WECs). Besides the challenge of designing feasible devices in terms of energy production & costs, development of devices which are also feasible in terms of environmental & social impacts is important.

Life Cycle Assessment (LCA) is used both for validation of environmental sustainability of existing and emerging renewable energy technologies and WECs are not an exception. Two previous review studies on LCA of ocean energy technologies evaluate the existing literature (Paredes et al., 2019; Zhang et al., 2020). Based on this previous information, we planned a review study mainly focusing on LCA of WECs without including other marine renewables. With this review, we target to answer the following research questions (some of them previously answered but will be updated): **a)** How previous LCA studies are conducted? **b)** What are the goal & scope of the previous studies? **c)** What are the environmental hotspots of WEC designs? **d)** What are the limitations of the previous LCA studies and how can they be overcome? **e)** What are the research gaps identified with previous studies and with this work? **f)** Were the other pillars of sustainability (economic and social) evaluated? If yes, can we reach the answers for the same research questions defined for LCA? This information will be accompanied by our expertise and insights on the application of sustainability assessment methodologies for WECs as an emerging technology by the aim of informing the researchers developing new wave energy devices and raising the awareness of them on this issue.

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Combining Genetic Programming and Genetic Algorithm to improve the grid integration of offshore multi-source parks

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Marine (wave and tidal), PV, and Wind energy sources are envisioned to cover more than 65% of the 42,000 TWh electricity demand projected by 2050. That is why the importance of integrating multi-source parks, either onshore or offshore, with the onshore PV/Wind combination being the most commonly implemented model when referring to hybrid power parks [1,2].

However, integrating offshore multi-source parks into the PCC poses additional challenges compared to their onshore counterpart, and two key aspects are to be considered: on the one hand, the fact that pouring the maximum offshore energy into the grid can be detrimental to the mainland power systems when these are yet weak, and on the other hand, the overproduction of energy when demand gets lower can lead to over frequency problems with critical grid imbalances [1,2].

In this contribution, a novel combination of the basic principles of Genetic Programming [3] and Genetic Algorithm [2] for grid integration of purely offshore multi-source parks (OFPV/Wind/Wave) is proposed. The main contributions of the undertaken simulation model are reduced power losses at the PCC and steady seasonal variability of the combined capacity factor.

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Extended results of this research are published at: https://doi.org/10.3390/machines10121208.

Leveraging Copernicus products for better resource assessment and reduce cost and production uncertainties

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The reduction of the Levelized Cost of Electricity (LCoE), Capital Expenditure (CapEx), and Operational Expenditure (OpEx) is paramount for the industrial and economic success of wave energy conversion; the appropriate and easy-to-access knowledge of past, present, and future metocean information is an enabling factor for various stakeholders towards the achievement of such goals. At the Marine Offshore Renewable Energy Lab of Politecnico di Torino, two major routes are being followed, both leveraging Copernicus products to advance the state-of-the-art:

- The MORE-EST Wave and Wind Platform [1, 2]: a web-based platform to provide ease access to metocean data, maritime spatial planning constraints, and productivity, for a variety of stakeholders (not only developers, but also investors, policy makers, energy planners, etc.);
- MESPAC [3]: using Earth Observation satellites and time- and space-downscaling artificial intelligent algorithms for a higher resolution metocean information at a given site of interest.

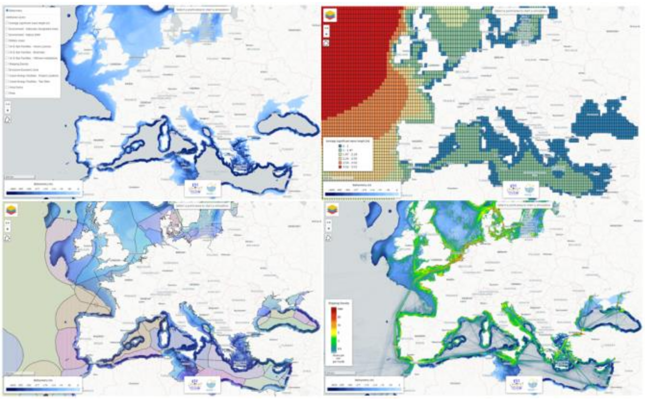

Figure 5. MORE-EST Platform, showing: bathymetry, significant wave height, exclusive economic zones, shipping density.

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Sectorial analysis of the fundamental criteria for the evaluation of the viability of wave power generation facilities in ports. Application of Delphi method

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This abstract is in line with the objectives of **Working Group 4**, as it helps potential wave energy investors to reduce their uncertainties regarding the feasibility of projects. By knowing which factors most influence the feasibility of a project, risk can be reduced, and outcomes improved.

Abstract

Ports, as industrial and logistical contexts, demand large amounts of energy. In addition to playing the role of logistical hubs, ports are called to play a key role in the energy transition towards decarbonised maritime transport.

On the one hand, ports are facilitators of sustainable technological development, both for the port communities of which they form part and for the industrial fabric that accompanies them, as well as being logistical platforms for the deployment of offshore marine energy generation facilities.

Ocean energy, according to the Intergovernmental Panel on Climate Change (IPCC) in 2019 [1], has been identified as one of the measures to mitigate these effects. Among the various sources of ocean energy, wave energy is called to play an important role in port facilities in the form of self-consumption [2].

The reasons why this type of energy has not reached the maturity level of other marine renewable energies yet are mainly economic, technological, environmental, and regulatory.

Studies to date on the use of wave energy in many parts of the world are not very conclusive in defining the critical variables for evaluating with certainty wave energy generation projects that can compete with more mature ocean energy in terms of performance and price.

By 2030, at least 1 GW of ocean power should be installed in Europe and this renewable energy deployment is projected to continue reaching at least 40 GW of installed capacity by 2050 [3].

Among the wave energy projects to be developed, those dedicated to ports´ self-consumption should we highlighted. Given the growing need for green energy that will arise in the coming years in ports due to their progressive decarbonisation, wave energy is a candidate with a good chance of success.

This paper aims to review the existing literature showing the approaches that other researchers have adopted to evaluate wave energy projects and, using the prospective method of expert consultation, Delphi methodology, will present the categorization of the most important criteria for assessing the feasibility of wave energy projects. The results obtained will be discussed for the use case of ports' self-consumption.

Keywords:

Clean energy, wave energy, renewable energy, SDGs, wave energy converter, sustainability, green ports.

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Wave energy on a multiuse framework for a 4.0 coastal economy

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The implementation of 4.0 technologies in our daily lives is called to be a key point to sustain economic growth and increase energy efficiency [1]; therefore, it has become one of the current top research priorities of our societies. In this way, concepts such as: autonomous marine vehicle (AMV), virtual reality (VR), internet of things (IoT), augmented reality (AR), digital twin (DT), and artificial intelligence (AI); are becoming more present day by day [2]. When it comes to the development of the blue economy [3] through the increasing integration of the industry 4.0 [4], multiuse of marine resources plays an important role to ensure their sustainable exploitation [5]. It is in relation to this novel multiuse framework, proposed by blue economy, that wave energy is called to play a pivotal role. Recharging stations for autonomous vehicles, self-powered monitoring and telecommunications buoys, power supply sources to marine aquaculture platforms and hybrid wind-wave farms are only a few examples on how wave energy multiuse can be implemented. In sum, novel market opportunities for the wave energy sector can be explored within this multiuse framework.

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A Wave Energy assessment for the Atlantic Moroccan coast

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Morocco is a net energy importer and is looking to achieve energy independence through renewable sources. To achieve that, it is important to identify and assess the energy resources available. Its large coast provides excellent opportunities to implement wave energy as a complementary source to wind and solar. This study, part of a master thesis being developed in the University of Lisbon, aims to characterize the wave energy potential in Moroccan Atlantic coast and it is related with the working group 4.

High resolution wave fields were obtained for that region, by forcing the SWAN wave model over a 30 year hindcast period with the ERA 5 reanalysis dataset. The model was validated with observational data from three oceanographic buoys, located close to the Canary Islands, Cadiz, and Faro. The results of the model allowed the identification of the most energetic areas along the Moroccan Atlantic coast. Finally, the data was used to determine the potential power output of six wave energy converters installed at strategic points.

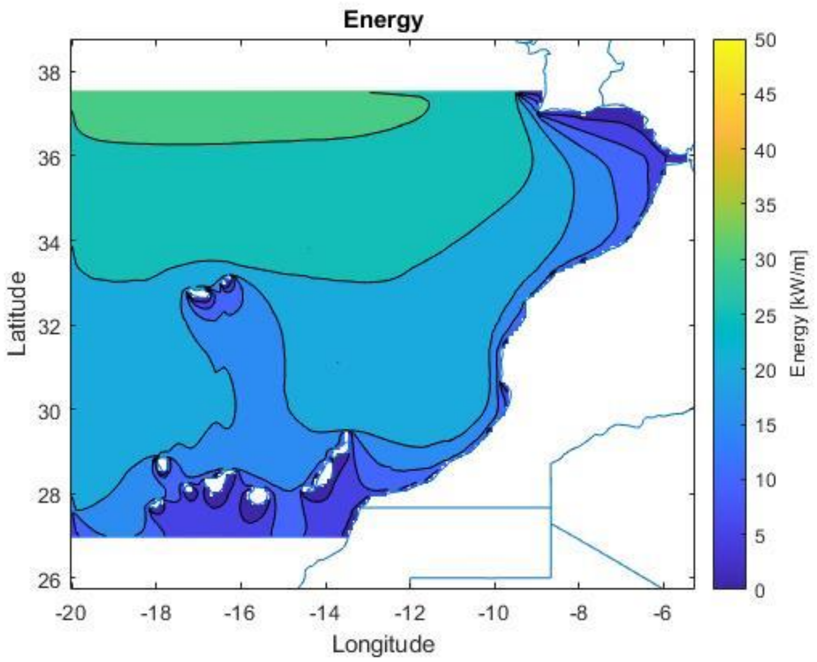

Figure 1- Mean wave energy

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Marine Renewable Energy in the Focus of the Smart Specialisation and the Black Sea Blue Economy Promotion

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2018 was a year when the Black Sea stood in the focus and was the favourite basin of the European Union policies towards the maritime issues and the emerging blue growth dimensions. 2019 turn to be the year of the so called "mission economy", when the research and innovation policies of the EU took the track towards five mission areas – one of them on healthy oceans, seas, inland and coastal. Unfortunately, at the end of 2021, when appeared the final version of this mission the Black Se was not namely written in its four limelight (pillars) – considering the majour basins around Europe. 2022 further escalated with the war that Russian Federation started against neighboring Ukraine. In this paper will be outlined both the logic of the mission "Restore our Ocean and Waters by 2030", and the business and innovation challenges when applying to the Black Sea basin and its coastal territories.

2018 was also the year of the Burgas Vision Paper on which the Black Sea Strategic Research and Innovations Agenda (BS SRIA) was adopted, and among its scopes the development of competitive, innovative, and sustainable blue economy for the Black Sea, and fostering investment in the Black Sea blue economy. More important was that for the years of the implementation of the BS SRIA, and mostly in the 2020 and 2021, when a Group of Seniour Official was operating a serious push was made for the developing products, solutions and clusters underpinning the blue growth. Both on emerging and traditional blue economy sectors were considered, marine and maritime research support innovation for the creation of synergies, and the enhancement of economic benefits. While reducing hazards for prosperous, resilient, and empowered communities. This includes sectors as energy, aquatic living resources and food, biotechnology, transport, and tourism.

It is important to be mindful of the fact that the Black Sea SRIA was developed earlier in time than the SBEP (Sustainable Blue Economy Partnership under the Horizon Europe) SRIA, hence it has not been able to include a number of recent EU level priorities (notably twin transition, green, digital transition and COVID-19 related resilience). Considering all 39 objectives, SBEP SRIA pillars 1, 3, and 4 express the highest number of matches with the Black Sea SRIA, reflecting a balanced representation. A similar consideration applies to SBEP SRIA 3.D cluster, "A safe marine environment and blue economy". Indeed, the need for this priority may be less pronounced as the Black Sea has less significant presence of offshore installations, shipping fleets, and a less developed offshore energy sector.

Both Mission Ocean and SBEP have links with an important regional policy concept, namely that of smart specialisation, which helps nations and regions to define their economic and research specialisations. Over the last years, the smart specialisation concept has been applied to the Blue Economy as well, both within the EU Member States (3.3.1.1) and beyond (case study Norway, 3.3.1.2). Hence it is an important concept to take into consideration here too. Under the Blue Economy umbrella (referred to as "Blue growth" in the Eye@RIS3 tool), the regions prioritised several topics namely aquaculture, blue renewable energy, coastal & maritime tourism, fisheries,

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marine biotechnology, offshore mining, oil & gas, ship building & repair, and transport & logistics. In the 2014-2020 period, one in five EU regions focused on at least one of these domains. Blue Economy is also an important component when it comes to internationalisation of local value chains, both within the EU and towards neighbouring partner countries.

For example, a 2016 study by Ecorys for the JRC noted that while Blue Economy is considered a priority across European regions, it is not always necessarily referred to as a priority axis. Rather, it can be an important underlying theme within other axes, such as energy, manufacturing, tourism or infrastructure. The study also highlighted that the two concepts, smart specialisation and blue economy surfaced around the same time, and that they have certain similarities. For example, they both embrace an integrated approach, aiming to overcome the borders between sectors and silos through emphasising links and promoting synergies between different stakeholders (particularly economy and research), and different economic activities. Both concepts also embrace bottom-up approaches and pay considerable attention to value chains. Under the analysis performed by a team of Ecorys, in which the author shared his views SBEP 2.A.1 - Underpinning innovation to upscale renewable ocean energy BS 2.2.1 - Identify renewable energy sectors such as offshore wind and wave energy while investigating the potential of responsible exploration of gas hydrates (Short/Medium).

The smart specialisation is recognised as a useful tool for creating the necessary innovation ecosystems for a sustainable blue economy, both at national and regional levels. Recently, the role of maritime strategies in smart specialisation and blue economy has also been discussed, e.g. through involving experts from relevant maritime and macro-regional strategies (including sea basin strategies). Based on the experience gained to date, as reflected in the work already carried out under the current ERDF Funding period 2021-2027, we expect the smart specialisation to remain a powerful concept to the challenges of the Black Sea renewable energy potential too, and be used for identifying needs and priorities for the SBE Partnership work.

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The energy transition towards wave & tidal stream energy: technology costs and economic benefits

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The realization of the European Commission's Green Deal has increased its importance, especially, since the high uncertainty in energy markets triggered by the onset of COVID-19 pandemic and the subsequent Russia–Ukraine conflict. If fact, numerous countries undergo economic transition from non-renewable to renewable energy in effort to decrease their economic dependency on fossil fuels. However, not much is known on the relationship between economic benefits and research and development costs associate with transition towards renewable energy in European Union, which is a central question of this study.

The European Commission has strategically established deployment targets for tidal and wave energy: 100 MW by 2025, 1 GW by 2030 and 40 GW by 2050 [1]. The completion of this strategy requires lots of resources and the costs of those may impede the economic and environmental benefits ,especially, in European Union (EU) member states with less technology expertise. Nonetheless, the current literature on the tidal and wave energy is still very restricted to the science, technology, engineering, and mathematics (STEM) field and less is researched from economic perspective. This study plans to take into account different sources of renewable energy and rigorously evaluate their return on investment in terms of economic and environmental aspects compared to wave and tidal energy.

Assessing the economic and environmental benefits of future resources is only possible by means of suitable econometric models and, hence, the GVAR (Global Vector Autoregressive) is used to quantify the effects of wave and tidal stream energy developments in EU countries context.

The policy implications of this study aim to lead to a comprehensive approach for energy management embedded within a broad sustainable development strategy and firm policy commitments.

This study is situated in the topics of "**Working Group 4**: Impacts and economics of wave energy and how they affect decision- and policy-making" of WECANet.

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Prospects for the development of marine renewable energy and potential economic benefits for society

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Europe's first-mover advantage in offshore renewable energies can rely on the vast potential offered by European Union's seas, from the North Sea and the Baltic Sea to the Mediterranean, from the Atlantic to the Black Sea, as well as the seas surrounding the EU outermost regions and the overseas countries and territories. Tapping this technological and physical potential is crucial if Europe is to achieve its carbon emission reduction targets for 2030 and become climate neutral by 2050.[1]

Market forces, technological advances and price developments will continue to drive offshore renewable energy growth over the coming years. Nonetheless, such a change in pace requires overcoming a number of obstacles and ensuring that throughout the supply chain all players can both accelerate and sustain this increase in deployment rate. A greater involvement of the EU and of Member States' governments is needed, as under current policies the present and projected installation capacity would lead to only approximately 90 GW in 2050.[2]

To change gear, the EU and Member States need a long-term framework for business and investors that promotes a sound coexistence between offshore installations and other uses of the sea space, contributes to the protection of the environment and biodiversity and allows for thriving fishing communities. It helps create quality jobs, facilitates grid infrastructure development[3] , enhances cross-border cooperation and coordination, ensures that research funding is channelled to the development and deployment of non-mature technologies and promotes the competitiveness and resilience of the entire EU supply chain and industry. Digital technologies should be a key enabler, fostering an acceleration in the development and integration of the offshore energy production into broader energy systems, while minimizing environmental impacts, providing precision, efficiency, advanced data analysis and AI-based solutions.

The investment needs for the large-scale deployment of offshore renewable energy technologies by 2050 are estimated to be almost EUR 800 billion, around two thirds to fund the associated grid infrastructure and a third for offshore generation[4]. This means that a significantly larger amount of capital will have to be channelled to this sector than has been so far. Annual investment in onshore and offshore grids in Europe over the decade to 2020 have amounted to around EUR 30 billion but need to increase to above EUR 60 billion in the coming decade, and then increase further after 2030.

Private capital is expected to provide the bulk of this investment. The EU sustainable finance taxonomy will guide investment in these activities in line with our long-term ambitions. However, efficient and well-targeted use of EU support will also play a strategic catalytic role. Grid development is a precondition in every sea basin to enable the energy generated offshore to reach customers. For mature offshore energy technologies, such support can help mitigate market failure,

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[1] https://eur-lex.europa.eu/
[2] https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en
[3] Energy transmission infrastructure and EU nature legislation
[4] Financing of offshore hybrid assets in the North Sea (Guidehouse, 2020-11)

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for instance by addressing the risk of launching more projects and of a larger size, or help reduce capital costs, usually very high in these type of projects. For less mature technologies, or projects still at an early stage, EU public funding will be crucial for market creation, by bringing on board more private actors, improving competitiveness, reducing uncertainties, bringing down costs and accelerating progress on early deployment and commercialisation.

Renewable energy brings environmental, social and economic benefits. Also renewable energy provides many direct and indirect economic benefits on both a micro and macro level. For example: Job Creation - The sector provides many different types of jobs, including positions in manufacturing, installation, engineering, sales, marketing and more; Landowner Income - renewable energy also provides an additional source of income for landowners situated by coastline; Reduced Energy Costs - Switching to renewable energy is an excellent way for residential, commercial and industrial energy customers to save money on their bills; Stable Energy Prices - Installing renewable energy facilities requires a substantial upfront investment, but after installation, they are cheap to operate. This is in large part because they don't require you to purchase fuel. Eliminating fuel costs lowers the cost of the electricity produced. It also means the price of electricity isn't susceptible to changes in the price of fuels, like it is with natural gas or coal. This may lead to more stable energy prices over the long term; Avoidance of Climate Impacts - Switching from fossil fuels to renewables could help slow down climate change and avoid some of these potential economic losses.[5]

This is the place to mention some benefits and advantages of **marine energy**: is a renewable, clean source of energy, only requiring water’s natural movement to generate power; is highly predictable due to the cyclical nature of waves, tides, and currents; is a resilient source of energy. Usually positioned close to where power is needed, marine energy technologies would require short transmission lines, supporting the power grid’s reliability and resilience; can provide power to remote, coastal, and island communities; technologies open the door for other innovations in the maritime sector, such as turning seawater into clean drinking water and powering sea and ocean exploration; Build real-world, hands-on experience working in the blue economy – a multi-trillion-dollar industry growing at twice the rate of the rest of the global economy.[6]

Decommissioning, reusing and recycling wind turbine components, in particular blades made of composite material, is another challenge to address. Research on recyclability and the impact on design is still rather fragmented and often based on niche, non-generic applications. It is necessary to integrate the principle of ‘circularity by design’ into renewables research & innovation more systematically. This will mean improving existing technologies (and developing new technologies), bearing in mind both production process efficiency and the longer life-time of installations and the ‘end of life’ of components. This will increase the value retention of products and services in the renewable energy manufacturing industry and reduce pressure on natural resources. A thorough assessment of the materials used for offshore renewable technologies is needed. This should cover not only cost and toxicity aspects but also issues such as material reuse and recyclability, sourcing constraints, and increased security of supply of critical materials. Reusing and recycling practices associated with onshore wind turbines should be explored, as they will need to be decommissioned in the near future.

[5] https://www.renewableenergymagazine.com
[6] https://www.energy.gov/eere/water/advantages-marine-energy

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The EU renewable offshore value chain is underpinned by a global supply chain, relying on imported raw materials and components for production (rare earth for permanent magnets, steel and composite materials). As demand for those materials is projected to increase (for instance, rare earths used in permanent magnets could increase tenfold by 2050[7]) it is necessary to focus on how to ensure undistorted supply, reduce dependency and shorten supply chains. Improving the circularity of the full supply chain will play an important role in mitigating increased dependencies.

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[7] European Commission's 2020 Strategic Foresight Report

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Uncertainty, confidence, and investment decision-making: How removing barriers and improving policy may support the wave energy industry forward

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My name is Olof Lindahl and I am an assistant professor at the Department of Business Studies at Uppsala University, Sweden. For the last several years, my research interest has mainly been focusing on the economics and business of new, not yet entirely commercially viable, technologies. I have been interested in (a) identifying barriers to commercialization and causes for investment risk or uncertainty, and (b) how policy incentives or legal framework changes could help commercialization by enhancing investor confidence. Lately, I am increasingly interested in wave power, such as the wave energy converter (WEC) designed at Uppsala University (link). I have been involved in recent studies on the economics and environmental aspects related to WECs, including discussions on lithium extraction from wave powered desalination, and the use of WECs for niche uses such as powering desalination plants for the purpose of providing potable water in remote locations or disaster areas. Also, I have an interest in the economic aspects of the materials in WECs, such as permanent magnet material for the linear generator of the Uppsala WEC.

In particular, I have previously investigated how subsidies, legal/regulatory change, innovation prizes, and other interventions can reduce decision uncertainties for investment and thereby positively affect investor confidence in a new technology. A previous focus of my research has been on how policy changes may allow for the development and successful market launch of new technologies in the pharmaceutical, medical technology, and automotive fields. Wave energy seems to have many similarities (such as the importance of investor perceptions of barriers), as well as certain unique characteristics such as the particular socio-economic and environmental impacts, compared to other industries I have previously studied.

I would be very interested in partaking in WECANet and in particular the work of Working Group 4, discussing the economic, business, and associated aspects of wave power. In this context, any issues relating to the economics of wave power and how this affects investor decision-making (for example due to risk and uncertainty) as well as how barriers, in turn, can be influenced by policy-making is of great interest. Thereby, I am highly interested in getting the chance to take part in the discussions at the WECANet conference in Ghent. By doing so, I hope to both get to know, and to learn from, colleagues in this important field as well as create a basis for future research collaboration.

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Multi-dimensional sustainability framework of wave energy

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The European Commission revealed in 2019 the European Green Deal, the European Union plan to make its economy sustainable. Together with the targets set in the Paris Agreement and the UN Agenda 2030, policy developments in the EU make a priority the increase of renewable energy sources in the energy mix and the decarbonization of the economies of its Member States. For a resilient future, decarbonization, energy transition and development of renewable energy technologies, including wave energy, should go hand in hand with just transition in the labour markets, sustainable use of the resources and sound environmental protection and preservation. Towards this end robust and forward-looking financing, legal and regulatory frameworks need to be developed. The formation of the first pan-European Network on marine wave energy, with its WG4 specifically focusing on the impacts and the economics of wave energy and how they affect decision- and policymaking, provides an excellent opportunity to develop and implement a multi-dimensional sustainability assessment toolbox of wave energy in the EU. The aim should be to develop an integrated sustainability assessment toolbox that considers the: i) Environmental (e.g., hydrospheric and atmospheric impact of wave energy), ii) Social (e.g., acceptance, perceptions, labor market impacts), iii) Financial (e.g., innovative financing tools that internalize the social costs and benefits of wave energy, innovative risk sharing financing options), iv) Technological (e.g. innovation and the links between technology and society), v) Economic (e.g., resource use, implementation of circular economy models) and vi) Institutional (e.g., modernization of existing/development of new institutions) sustainabilty. The multi-dimensional sustainability assessment framework developed can be used as a decision support tool for policy makers and related institutions (e.g., regulatory authorities, financing institutions, etc.) that need to make sustainability-targeting decisions based on complex information.

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A Business Model Canvas to Caputure Ireland's Wave and Tidal Energy Potential

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Ireland's historic Atlantic coast was long believed to be the edge of Europe, today it evinces interest in its immense potential of wave energy as a renewable, clean, and sustainable source of energy which would be the key element in Ireland's transition to net zero energy emissions. Ireland has a key role in this transition with a total potential of 70 GW (wind, wave and tidal) within 100 km of Irish cost which could help in realizing the ambitious EU directive of sourcing 1 GW of energy from wave and tidal sources by 2030 and 40 GW by 2050 (Commission, 2020). Ireland has set itself a target of 5 GW of marine energy by 2030 to meet the burgeoning energy demand and pressure on conventional energy due to geopolitical factors while progressing towards net-zero emission commitment and exponentially increasing jobs in the sector (Department of Housing, 2021).

The Offshore Renewable Energy Development Plan (OREDP)(Department of the Environment, 2018) identifies major barriers to the development of marine energy in Ireland, in particular wave and tidal energy are practically non-existent in Ireland with the exception of prototypes in Galway and Cork, which are research projects rather than commercial ventures. This paper looks at developing a business model canvas to bring in all the stakeholders, barriers, and enablers in developing wave and tidal energy in Ireland. Integration pathways like green hydrogen, community-linked wave energy farms, development of coastal infrastructure, competitive tariff reconciling environmental impact, and promoting marine innovation and entrepreneurship would be explored in detail in an Irish context to culminate in a comprehensive entrepreneurial framework for wave energy commercialization in Ireland.

Apart from providing evidence-based guidelines in the Irish context, the business model canvas has the potential generalizability in other European countries like Belgium, France and Spain with similar wave energy potential and could act as a valuable reference for young researchers and entrepreneurs in the ocean energy sector. This would also help governmental agencies- local, regional, national, European, and Global to support innovation, and entrepreneurship based on commercialization and upscaling start-ups in the area with an adequate and sustained support framework.

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Benefits of wave energy in highly renewable energy system

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Integration of wave energy for its large scale incorporation of wave energy in high renewable energy systems, as the 2050 European strategy suggests has not been yet completely investigated. We use a fully dynamic climate driven energy system model, which has undergone modifications to include wave energy converters. From a system perspective the allocation of solar and onshore wind over other technologies, is more favourable, due to lower costs. In fact, in some cases the model favors binary results. The dual-technology approach hides the issues of country grid stability and dependence. Cost-driven only systems often times require significant amounts of energy. As an example, we take two countries with similar consumptions and vastly different energy mix characteristics, Hungary has mostly solar, onshore and battery storage. Romania shows more diversity, with run-of-river, hydro, wave energy shallow, offshore wind, onshore wind, solar, with predominately battery and H_2. Romania, intermittent generation time series compared to Hungary, whose diurnal generation patterns are determined by its mostly exclusive solar generation. Romania's hydro and offshore wind generation seem to satisfy most of its electricity demand, while excess generation from the other technologies is mostly exported while the latter for diurnal generation (see Fig 1).

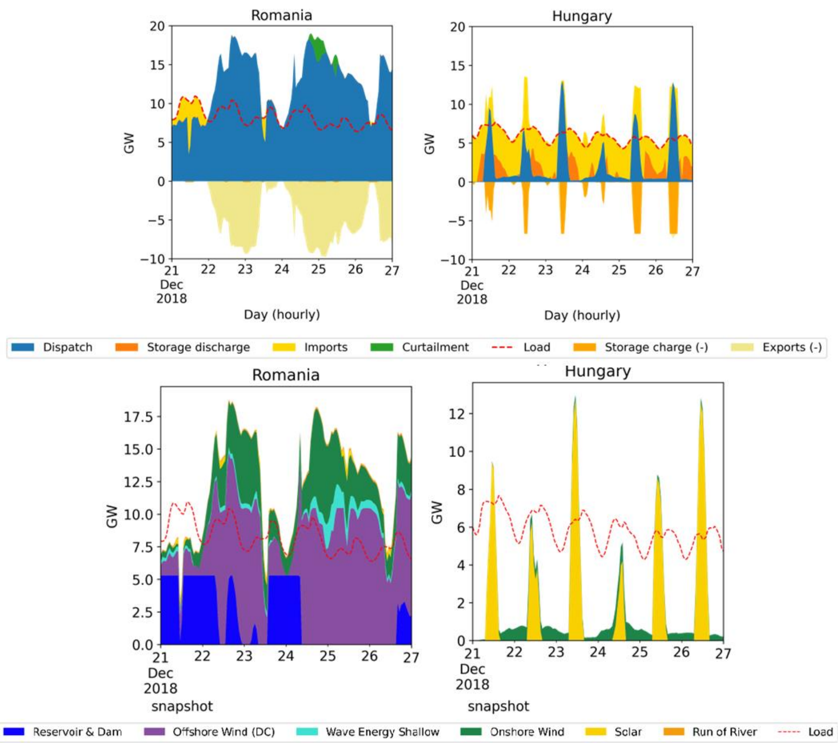

Fig 1: Snapshot of generation profiles and system power needs

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Understanding the role of stakeholders in the wave energy consenting process: engagement and sensitivities. A case study from Greece.

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As a relatively new industry, wave energy faces many hurdles, including questions concerning its environmental impacts and public and stakeholder group attitudes towards wave energy sites. My research study aims to address these issues by providing recommendations for the streamlining of approval processes for wave energy developments in Greece. This proposal attempts to analyse the results of two surveys conducted to assess the opinions of developers and maritime space users on wave energy and to investigate commonalities and differences in stakeholder groups' perceptions of wave energy in Greece.

The first questionnaire was developed in the context of identifying non-technological barriers to wave energy developments and accelerators of wave-energy impact assessments. The questionnaire was thus designed to determine what regulatory procedures site developers have needed to undergo in developing their test sites, how stakeholder groups were involved, and how their concerns were taken into consideration.

The second questionnaire was designed to identify and assess the main problems created by conflicts between wave-energy projects and the activities of key stakeholder groups, such as commercial fishing, surfing, and other users of marine areas for recreation and commercial purposes. The survey sought to analyse common and contrasting hopes and concerns about wave energy expressed by stakeholder groups at different test centres. The questionnaire was divided in three main themes: 1) opinions on marine energy in general; 2) participation in consultation or outreach events on marine-energy developments; and 3) opinions on the adequacy and fairness of consultation processes.

Insights are discussed and a number of conclusions and recommendations can be drawn from both of them.

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Introduction of wave energy standards into national legislation

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The importance of introduction of wave energy standards into national legislation should be one of the basic elements of discussion in thematic group **No. 4: Impacts and economics of wave energy and how they affect decision- and policy-making**.

In the last few years, there has been a clear shift towards the development of renewable energy in the world. Certainly, one of the things that contribute to this development is the adaptation of national renewable energy legislation. One important issue where there is international divergence is the approach to the renewable energy sources definition. According to market research, most countries support wind, photovoltaics or hydropower plants. The literature indicates that out of 120 countries surveyed, only 70 have law regulations regarding wave energy plants (Ramczykowski, 2020).

In Poland, renewable energy is just starting to be used on a larger scale, and wind farms used by municipalities are an increasingly common sight. Unfortunately, Polish energy production is still based on traditional sources such as hard coal and brown coal. However, the depletion of fossil fuel resources, the problem of excessive carbon dioxide emissions and the energy crisis caused by the war in Ukraine mean that even in Poland there is a growing interest in renewable energy sources. As a consequence, the concept of RES, including water energy, is slowly gaining recognition in the Polish energy policy and environmental protection strategy.

In the context of water energy, the Polish Ministry of Energy has allocated insignificant support for the use of flowing waters in recent years, but it is assessed that it is worth looking for new ways to use water energy, including possibly wave energy. However, in order to increase Poland's motivation to establish and adopt legislation on renewable energy (including wave energy), local non-governmental organizations should be supported and the needs of producers should be taken into account, because, as the literature and experience of other countries show, this reflect in regulatory support mechanisms. The objectives set out to guide the legislation should clearly indicate the social, economic or political objectives that the legislation is seeking to achieve.

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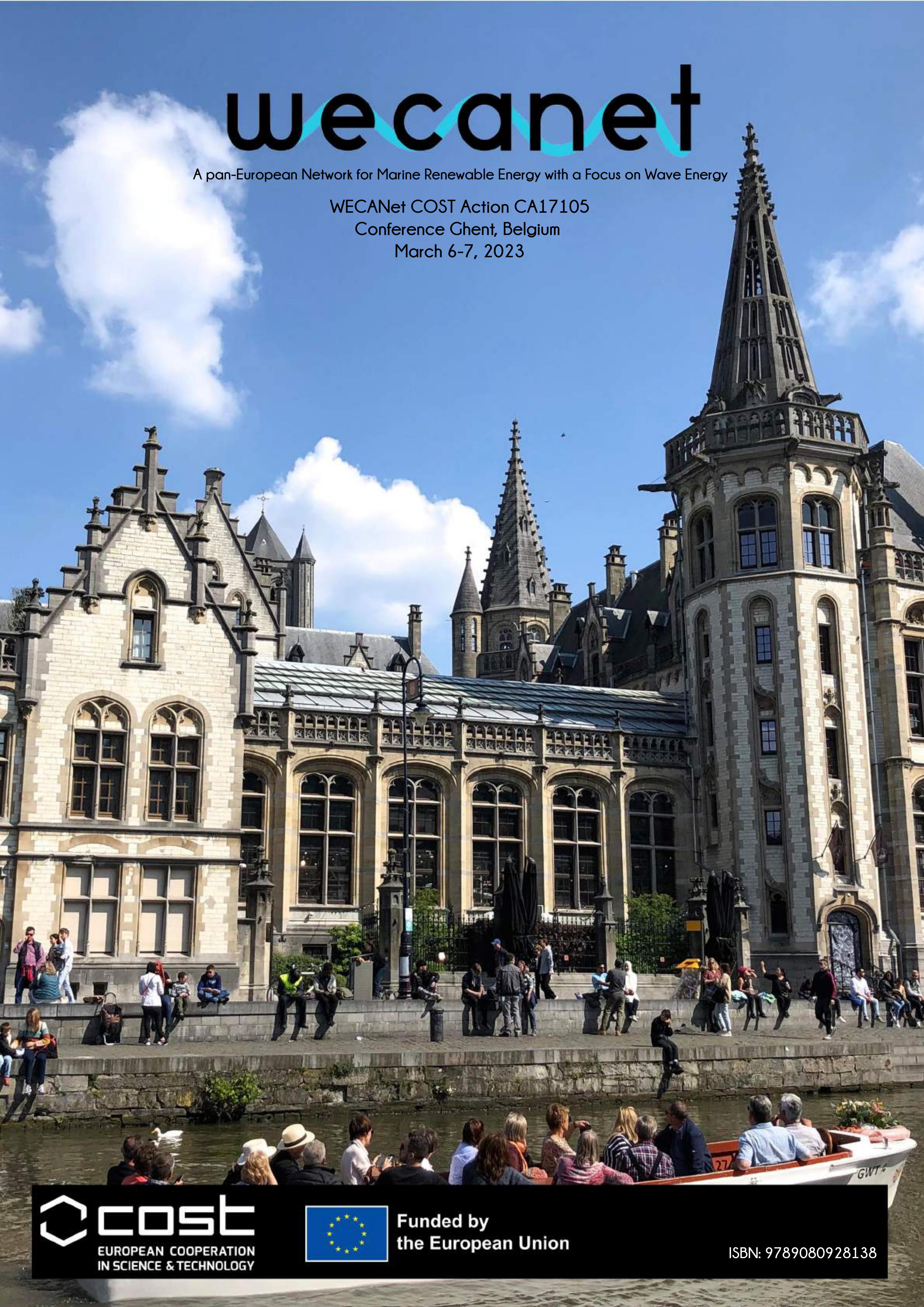

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