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

BOOK OF ABSTRACTS

of the General Assembly 2020 (online event) of the WECANet COST Action CA17105

Editors:
- Vasiliki Stratigaki
- Matt Folley
- Peter Troch
- Evangelia Loukogeorgaki
- Moncho Gómez-Gesteira
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WECANet COST Action CA17105:

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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

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Abstracts for Working Group 1:

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

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Coupling between DualSPHysics and the Finite Element Module of Project Chrono: multiphysics modelling of waves-WEC interaction

Iván Martínez-Estévez[1], Joe El Rahi[2], José Domínguez[1], Bonaventura Tagliafierro[3], Vasiliki Stratigaki[2] Alejandro Crespo[1], Peter Troch[2], Tomohiro Suzuki[4], Moncho Gómez-Gesteira[1]

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The DualSPHysics code is a widely used numerical tool to model wave energy converters (e.g., modelling a point absorber wave energy converter [1]) using the two-way coupling with Project Chrono. The current configuration includes a rigid body solver and elements such as hinges and springs [2] which can resolve motion and simulate linear damping elements. On this basis, the aim of this work is to extend the coupling to include the finite element (FEA) module of the Project Chrono with additional non-linear elements such as cables and beams. This is achieved through a two-way coupling where finite element objects are reproduced in the DualSPHysics environment and discretized according to a user-defined nodal resolution. The forces exerted by waves are then transferred accordingly and applied to the nodes, to be later resolved by Project Chrono. As a result, this implementation reproduces non-linear deformations and provides internal stress analysis. The development of this fluid-structure interaction model has direct implications on the numerical modelling techniques used to simulate floating and fixed wave energy converters. Material properties such as stiffness and elasticity can be now introduced; thus offering the capability of analyzing stress limits and deflections of energy devices. Furthermore, the common linear spring damper currently used to model point absorber wave energy converters would be replaced by the elastic cable elements. This new functionality will allow simulating not only flexible parts of the WECs but also to improve the survivability of the WEC devices being DualSPHysics a suitable tool for this purpose.

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Digital Twins in a Marine Renewable Energy

with a focus on Wave Energy

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The term "Digital Twin" refers to a twin virtual object where digital refers to a twin that lives in a virtual world. A digital twin is an object entirely described by different mathematical models that are solved in near or real-time using measurements date from a real sibling as boundary conditions.

In WEC terms digital twin is a WEC in a virtual lab, connected to a real WEC at sea by different measuring tools. Measurements data can specify the almost complete state of a real WEC in some instant of time. From this point in time, it is possible to simulate or predict the next state of WEC. Here we pose a question: Is such a prediction today possible?

The answer to this question will be the contents of the proposed debate. Somehow, we should answer the following fundamental questions: how far, how fast and how accurate can we today realize the digital twin technology with the use of different tools like data analysis, machine learning technology and MSO-DE technology (Mathematical modelling, Simulation and Optimization with Differential Equations). Maybe, it would be interesting to compare WEC state with the automotive state-of-the-art.

There is a formal split of MSO design into three levels:

1. a mathematical model (a set of equations) that captures the conceptualization;
2. a simulation that implements this model and captures the visualization (making invisible things visible);
3. an optimization that enhances the design process (making the design realistic and optimal).

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Modelling of moored floating structures and marine renewable energy technologies using a non-linear numerical approach and experiments in wave testing facilities

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Moored floating structures are connected to the seabed through mooring line systems composed of cables or chains, and have wide applications in coastal and offshore engineering. Moored floating offshore wind turbines and Wave Energy Converters (WECs) are examples of such structures from the field of Marine Renewable Energy (MRE).

Mooring systems can represent a considerable part of the total cost of MRE technologies and they influence their dynamics. Therefore it is crucial to accurately model their behavior in a cost-efficient way. In the proposed research this will be achieved by employing a Smoothed Particle Hydrodynamics model as the basis of a numerical platform able to accurately predict the behaviour of moored floating structures and WECs with their power take-off systems, in operational and in extreme sea states. Within this new post doctoral research which started in November 2020, a numerical platform will be developed and validated using the experimental database obtained from the upcoming 'WECfarm' project. During the 'WECfarm' project, WEC interactions in farm configurations will be studied experimentally at the new Coastal & Ocean Basin in Ostend, Belgium (www.cob.ugent.be).

The main objectives of the proposed research aim to cover current knowledge gaps which hamper further development and commercialisation of these MRE emerging technologies. Results' valorisation will be achieved through scientific dissemination and cooperation with academic and industrial players from the offshore and the MRE sectors who have direct interest in the outcome of this new research project. As such this research is situated in the topics of three WECANet COST Action CA17105 Working Groups, i.e. Working Group 1: "Numerical hydrodynamic modelling for WECs, WEC arrays/farms and wave energy resources", Working Group 2: "Experimental hydrodynamic modelling and testing of WECs, WEC arrays/farms, PTO systems, and field", and Working Group 3: "Technology of WECs and WEC farms".

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Development of a fluid-structure interaction system within DualSPHysics for flexible oscillating structures with applications to wave energy converters (WEC)

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Among the numerical tools used in the modelling of wave energy converters, the smoothed particle hydrodynamics (SPH) method has emerged as a powerful tool to accurately model the behavior of WEC farms and other energy devices using fully non-linear simulations with high resolutions [1]. One software package in which this method is implemented is DualSPHysics (http://dual.sphysics.org), which has been extensively applied in studying a range of WEC devices, from oscillating surge to heaving point absorbers and wave attenuators [2,3]. The current configuration in the numerical model captures the hydrodynamic loads applied on the structures (energy devices) and the respective motion response generated for both fixed and floating wave energy converters. However, it misses out on modelling the deflection and stresses generated in the structure, which are two decisive parameters for defining design loads and accurately modelling behavior [4]. In this work, the aim is to develop a coupling with a finite element method solver in order to deliver a package which solves the fluid-structure interactions. As a result a single tool will be created that incorporates both the motion and structural loading of WECs. This is achieved through the expansion of the coupling interface with the structural solver Project Chrono (https://projectchrono.org/) to include elastic material and finite element solvers. The coupled model will provide a comprehensive tool which includes: (i) motion response from waves, (ii) non-linear deflections of structural elements, and (iii) generated internal stresses. In terms of application, the modelling accuracy of WECs will be improved by including the deflections and subsequent damping of the structural elements (especially for WECs such oscillating wave surge converters) Additionally, cables and other elastic elements will substitute the linear spring currently used in modelling of point absorbers and mooring lines of floating WECs and structures.

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Vasiliki Stratigaki is a postdoctoral researcher (fellowship 1267321N) of the FWO (Fonds Wetenschappelijk Onderzoek - Research Foundation Flanders), Belgium.

A preliminary analysis of pitch and heave motion induced thrust in a hydrofoil

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Flow passing a hydrofoil generates lift and drag, while for certain flow regimes the formation of the well-known Bénard-von Kármán (BvK) vortex street also occurs. The combination of appropriate 'self-induced' motions and foil shape leads to the advantageous formation of an inverse vortex street and the generation of thrust instead of drag, as illustrated by several marine organisms. In this work, we consider wave induced motions in the simplified form of distinct pitch and heave motions forced in a hydrofoil, which operates in a, otherwise, motionless flow. The latter, and higher Re (here 2×107) is one of the distinction points between this and previous works.

An additional point, is conducting the simulations using an in-house developed CFD code. The code solves equations derived from the distributed Lagrange multiplier and the so-called fully Eulerian one-fluid formulation, Yang (2018), which builds on the immersed boundary method and excludes the need to solve structure dynamics. The hydrofoil is represented as a Lagrange multiplier. Turbulence is not fully resolved but the code is suitable for resolving the remaining interactions between the hydrofoil and incompressible viscous flows.

The code is validated against, recently published, results for unsteady aerodynamics of a pitching NACA 0012 airfoil. Simulations were then conducted with the (now considered as) hydrofoil and for 3 different frequencies, 3 heave and 3 pitch amplitudes; all calculated considering sea states characteristic of the UK waters. This led to Strouhal numbers between 1 and 2 for which the thrust coefficient increased linearly.

Overall, thrust was generated for the (vast) majority of the cases considered. Characteristically, drag dominated over thrust only for very small frequencies and small heave/pitch amplitudes. Within the range of the testing conditions, pitch dominated the generation of thrust with heave having minimum to negligible influence. For thrust generating regimes, increasing the motion's frequency led to increased thrust. The work is currently being extend to consider the performance of the hydrofoil under directly wave induced motions.

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Numerical modelling of the wave energy along the European coastal environment

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There is an increasing emphasis on the use of renewable energy to stop greenhouse gas emissions and their effects on climate change. Wave energy is one of the widespread renewables and with very high potential, but unfortunately little exploited so far. Over the last few years, various studies have been conducted to evaluate the wave power potential in different locations around the world to find the best places for wave energy exploitation [1-3]. For the wave farm developers, this information can be useful. Of course, high-resolution results are necessary to capture all the bathymetric variations in a certain area, which may lead to the formation of hotspots with greater potential.

Taking into consideration the last developments of the SWAN model (Simulating Waves Nearshore, version 41.31A [4]), the implementation of a wave modelling system for the North Atlantic Ocean based only on this wave model has been made possible. This system has the advantage to use a single wave model for all levels of the numerical simulations. Furthermore, in this way the errors introduced by different numerical models are reduced. From this perspective, in the present work, the SWAN model is implemented on a coarse resolution domain that covers the Northern part of the Atlantic Ocean and then, various regional and local areas are nested to perform higher-resolution simulations. To calibrate and validate the wave modelling system simulations over six months are performed. Various parameterizations are available in the SWAN model and to find the best option four possibilities were tested. ERA5 wind fields, the most up-to-date reanalysis product of the ECMWF (European Centre for Medium-Range Weather Forecasts), with a spatial resolution of $0.25° \times 0.25°$ and 3-hour temporal resolution are used to force the wave model.

The results obtained were validated with buoy measurements located on the western and eastern coasts of the North Atlantic Ocean. A comparison of significant wave height results against the recent sea state climate data records including multi-mission satellite altimeter products along the tracks provided by the European Space Agency, Climate Change Initiative for Sea State was made [5]. A good agreement between simulations and measurements was obtained both at the level of the North Atlantic area and at the regional level (the western coastal area of the Iberian Peninsula). The products delivered by this new implemented system were compared with those provided by other systems based on two different wave models and the results are of better quality [6,7].

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The work is still ongoing and this system is a very useful tool to evaluate the climate impact on the wave power along the European coasts of the North Atlantic Ocean [8].

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Hydrodynamic analysis of an Oscillating Water Column Wave Energy Converter in the stepped bottom condition using CFD

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The primary efficiency of the Oscillating Water Column (OWC) Wave Energy Converter (WEC) device in the stepped sea bottom condition is investigated using both experimental and numerical approaches. Wave flume tests were undertaken to investigate the hydrodynamic behaviour of the device in regular waves. A 2D numerical model was developed in the open source computational fluid dynamics (CFD) software package OpenFOAM implementing the fully non-linear Reynolds Averaged Navier-Stokes (RANS) equations to simulate the wave power absorption and wave structure interactions. The numerical results have been validated against the experimental data. The influence of the wave characteristic as well as damping of the power take-off unit on the performance of the device, wave reflection coefficient and the energy dissipation rate is evaluated using the results obtained from the numerical simulations. Furthermore, as was proved in previous studies that the application of the stepped sea bottom condition might increase the efficiency of the OWC devices, the CFD simulation results have been implemented to present and discuss about the power absorption mechanism as well as the flow pattern characteristics in the vicinity area of the step.

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The impact of the wave energy farms on the coastal dynamics

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In the context of the climate change effects, extraction of marine renewable energy became an issue of increasing importance, representing one of the great challenges of the 21st century. While the land is almost saturated with wind farms and solar panels, the marine environment provides large spaces with huge renewable energy resources. Although the wave energy was initially considered as the most important vector in the marine renewable energy matrix, the offshore wind had an incredible advance. Thus, the attempt of extending rapidly the wind industry from onshore to offshore can be considered a real success and the process is still ongoing. On the other hand, the very high dynamics of the offshore wind, noticed in the last decade, should provide also momentum to the wave energy industry, which will benefit by the existing infrastructure of the wind farms considering the collocation approach as well as by the considerable experience acquired by the offshore industry.

Since the number of wave energy farms is at this moment quite limited, being operational mostly some pilot projects, there is no relevant practical experience in this direction and the possible effects expected from the future wave farms are not yet very well assessed. From this perspective, the objective of the present work is to provide a general and more comprehensive picture of the possible impact of future wave energy farms in the coastal dynamics. The methodology considered is based on the ISSM computational environment [1]. ISSM stands for the Interface for SWAN and Surf Models and, as its name indicates, this is a computational environment joining together in a MATLAB user-friendly interface a wave model (SWAN) with a nearshore circulation model (SURF). This computational environment was tested and validated considering different nearshore areas and configurations of the environmental matrix [2].

Thus, using ISSM computational tool, different configuration designs have been evaluated in various coastal areas. A first coastal environment targeted was the Portuguese continental nearshore, which has a very good potential in wave energy resources and with some pilot projects being implemented there [3-6]. Another nearshore area targeted is Sardinia Island in the Mediterranean Sea [7], taking into account that its western side is more energetic and also that in island environment the issue of extracting wave energy is of crucial importance. Finally, the last coastal environment considered in the present analysis is the western side of the Black Sea [8, 9]. Although not comparable from the point of view of the wave energy with the ocean coasts, this nearshore faces in general relatively high waves and it is subjected to a very dynamic erosion process.

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Since the wave farms should be implemented in areas where there are significant waves, in principle the effect would be quite obvious. This is, the converters extract the energy of the waves and the down wave processes will be attenuated with a beneficial effect at least from the point of view of the coastal dynamics. A comparison between the three environments considered is provided in [10] and it results that some important aspects should be highlighted as a brief conclusion. First, this process is extremely site-dependent and each coastal area represents a distinct case study, even if we discuss very close geographical locations. Second, while the effect of the farms operating very close to the shore is relatively significant, this effect decreases very fast when moving offshore. Finally, a very important issue is related to the impact on coastal circulation. Although the wave energy is absorbed by the farm, in certain conditions due to the changes induced in the wave direction the velocity of the nearshore currents may increase and this can affect the coastal dynamics and enhance some nearshore processes. The work is still on-going and various others case studies are currently considered and analyzed.

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Simulation, control and co-design of wave energy converters

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WG1 Numerical hydrodynamic modelling for WECs, WEC arrays/farms and wave energy resources

Ocean wave power has the potential to be a significant contributor to the European energy mix. As such, wave energy is a very active research field, which has attracted the attention of many academics and engineers. Considering the full life-cycle costs of wave energy technology, advanced control of WECs is a promising route towards reducing their levelised annual cost of energy, since control allows the extraction of significantly more wave power at a given investment cost.

WEC control development and mathematical/numerical modelling interact in complex ways. WEC control design must be developed, based on realistic WEC models. In fact, in the most advanced WEC numerical control techniques, a numerical model of the WEC or WEC farm is directly employed by the control algorithm to carry out control calculations in real time. Therefore, such control algorithms should be able to handle realistic enough WEC models, and, in return, WEC mathematical models for control should be developed so as to lend themselves to known control calculation techniques. Furthermore, power-maximising WEC control tends to substantially widen the WEC motion and force amplitudes, often referred to as the “operational envelope”, possibly beyond the range of validity of the WEC mathematical model, if the latter is based on overly restrictive assumptions. Hence, WEC control implementation also triggers the development of mathematical models, able to cover a wider operational envelope. A closely related issue is that of co-design. The WEC design choices (operating principle, material, size, shape, etc.) are taken into account in the development of a suitable control strategy, while, reciprocally, the chosen control strategy typically has an influence on the WEC design requirements. The WEC design and control strategy should thus be optimised jointly, which is the idea of co-design.

Based on our expertise in both WEC control and hydrodynamic modelling, we are involved in industry-oriented projects where we develop efficient simulation methods, control calculation techniques and optimisation tools, which are relevant to WEC performance assessment, control design and co-design. We wish to develop collaborations around projects involving WEC numerical modelling and control, with a particular focus on the interplay between WEC design and control.

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Numerical modelling of a wave energy converter for the WECfarm project

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This abstract refers to my ongoing master's thesis at the Civil Engineering department of Ghent University (Belgium) on numerical modelling of Wave Energy Converters (WECs). The numerical modelling is performed using the open-source software DualSPHysics [1]. This program applies smoothed particle hydrodynamics (SPH), which is a non-linear Lagrangian meshless method. This means that the fluid is described as a set of particles for which the physical properties are determined using Navier-Stokes equations as opposed to a Eulerian model where the fluid is discretized into control volumes.

The objective of this thesis is to implement the so-called "Master WEC", developed at Ghent University for the upcoming WECfarm project with arrays of point absorber type WECs, in the numerical domain and simulate the involved physical processes. One of the challenges in simulating a WEC compared to a normal floating body is the power take-off (PTO) system which is necessary to capture the wave energy and convert it into electricity. The modelling of this PTO system is done by coupling Project Chrono (an open source physics simulation engine) to DualSPHysics [2]. Initially one single WEC will be modelled and the dynamic response, the PTO system and the wave field effects will be simulated. As such this research is situated in the topics of "Working Group 1: Numerical hydrodynamic modelling for WECs, WEC arrays/farms and wave energy resources".

Subsequently these results will be validated using experimental data obtained from wave flume tests. Since a single WEC will not generate a sufficient amount of power the goal is to construct WEC arrays within the WECfarm project. As such, once this single Master WEC model is validated, additional WECs will be implemented in the numerical domain and the interaction between multiple WECs will be studied. This should allow further research into different array geometries and different WEC spacings. This thesis runs in parallel with two additional experimental theses at Ghent University which will enable back and forth interaction between both numerical modelling and experimental scale testing.

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A methodology based on the combination of structural, performance and economic analysis for the preliminary design of a wave energy converter

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Ocean wave energy is an enormous renewable resource that can be used to provide a consistent amount of electricity to the grid if a suitable wave energy technology is developed. Many wave energy converters (WECs) concepts were invented but none of these was yet commercialized on a large scale, for instance, as for the case of wind or solar energy devices. This situation exists mainly due to structural reliability issues, the high capital and maintenance costs, which exist due to WEC technologies complexities, and low wave power absorption efficiency. For commercializing wave energy, new solutions are required that are efficient and basic in terms of design, in order to minimize raw construction materials mass, costs and increase reliability. Up to this time, researchers working on wave energy mainly focused on hydrodynamic modelling directed to increasing efficiency, often neglecting structural assessments during an initial phase of development. Given this circumstance, next research work at the University of Porto will focus on the development of a methodology that will combine structural and hydrodynamic analysis so to allow a fast initial economic assessment of new WECs designs. The methodology developed will be initially applied for the development and optimization of CECO, which is a sloped motion type of WEC. CECO allows, with a simple design, high efficiency and reliability. In previous research works, this WEC was optimized from the hydrodynamic point of view. The mentioned methodology is applied for the preliminary structural optimization and analysis, which includes the use of the finite element method and optimization algorithms. Various structural design options are systematically evaluated in terms of hydrodynamic efficiency, material costs and Levelized Cost of Energy (LCoE). The procedure regards following iterations within a defined protocol.

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Further validation and comparison studies using SNL-SWAN for modelling arrays of wave energy converters

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Numerous methods for modelling individual wave energy converters (WECs) and arrays have been developed, tested and reported, including applications of spectral-, frequency-, and time-domain models. While frequency- and time-domain models can more accurately represent the interaction of devices with hydrodynamic processes, they are computationally expensive and geographically limited. Therefore modellers assessing potential far-field effects of devices typically utilise spectral phase-averaging models such as SWAN. These models are unable to fully represent wave-device interactions, instead representing devices as energy sinks extracting a percentage of energy in the sea state.

SNL-SWAN was developed by researchers at Sandia National Laboratories as a modified version of the nearshore spectral wave model SWAN, incorporating the power performance characteristics of a device in the representation of energy extraction from the sea state (Ruehl et al., 2015). A recent paper by McNatt et al. (2020) extended earlier validation studies using experimental data to compare results from SNL-SWAN with those obtained using the boundary element method code WAMIT. Results indicated factors which led to improved results from SNL-SWAN in far-field regions.

This project proposes an extension to existing comparison studies, applying a systematic approach to model devices with a range of characteristics to benchmark outputs using SNL-SWAN with those from a suite of time- and frequency-domain models to provide an enhanced understanding of uncertainties arising from the spectral model approach.

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Kuźniewski's type of WEC – its potential and directions of development

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Professor Bolesław Kuźniewski (June 22, 1935 - August 20, 2017) was a specialist in the field of fluid mechanics [1]. His research concerned, inter alia, sea wave energy conversion. His inventions are, among others, an innovative method of extinguishing sea waves [2, 3] and two versions of a vane motor driven by sea waves operating in a horizontal [4, 5] and vertical [6, 7] system. The inspiration for the development of Kuźniewski's vane motor was the movement of seagull wings [1]. The solution is potentially an alternative to the known and currently developed sea wave transducers, such as oscillating water columns, attenuators with hydraulic systems or point absorbers based on floats. The advantages of Kuźniewski's motor are its relatively simple design and the associated high operational reliability [6]. In addition, the solution can operate as a multi-module system, which allows to increase the efficiency of the sea area where the system of energy converters is installed. It is proposed to continue prof. Kuźniewski's work by building numerical models of the system and carrying out their simulation studies, and as the next step studying the physical model in the model tank. The research should particularly focus on analysing the influence of water wave characteristics and size of the vanes, the vane profile and the inter-vane angles on the operating indicators of the motor, such as the rotational speed of the motor shaft, developed power and general efficiency of the motor.

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Numerical benchmark study of “far field” effects of farms of WECs using linear and weekly non-linear models

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This work is a continuation recently completed doctorate research at the Civil Engineering department of Ghent University (Belgium) focusing on the numerical modelling of “far field” effects of Wave Energy Converter (WEC) arrays [1,2,3,4,5,6]. During this research a numerical coupled model has been developed between the wave propagation model MILDwave [7, 8] and the wave-structure interaction solver NEMOH [9] using the generic coupling methodology introduced by [10,11].

The aim of this study is to estimate the wave height reduction in the lee of a WEC farm for two different WEC types, a heaving point absorber (HPA) and an oscillating surge wave energy converter(OSWEC), using two different numerical approaches. Specifically for each WEC farm the wave height redistribution around the WECs which absorb wave power from incoming waves has been modelled using: (a) the traditional sponge layer technique which is implemented in MILDwave as presented in [8,10], and (b) the MILDwave-NEMOH coupled model [11,12,13]. Within the latter numerical approach, for each WEC the Power-Take-Off (PTO) is modelled considering: (i) an optimal linear PTO; (ii) a sub-optimal linear PTO; and (iii) a Wave-to-Wire (W2W) [4] model of an hydraulic PTO.

The above mentioned numerical approaches result into four simulations for each WEC farm in the present study. Comparisons between the different cases of the simulated WEC farms show that the numerical approach described in (a) tends to overestimate the wave height reduction in the lee of the WEC farms for both WEC types studied. When analyzing the results obtained using the second numerical approach (b), it can be seen that, using a different WEC PTO system (cases (i)-(iii)) does not have a significant impact in the wave height reduction in the lee of the WEC farms for both WEC types studied. Additionally, it has been observed that even though the wave height reduction in the lee of the WEC farm does not differ much for each PTO system (cases (i)-(iii)), there is a variation in the two WEC farms power performance for all simulations. This is reflected in different average power output of the WEC farms for both WEC types studied and different PTO systems. This work fits in the “WECANet **Working Group 1**: Numerical hydrodynamic modelling of WECs”, and more specifically in the topic that focuses on coupling between codes for WEC simulation.

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Modelling of an Oscillating Water Column in DualSPHysics

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The topic of this research is the numerical modelling of the Oscillating Water Column (OWC) of Ocean Energy Systems (OES) in DualSPHysics [1,2]. OES aims to verify and validate numerical models for Wave Energy Converters (WECs) (http://www.oceanenergysystems.org/oes-projects/wave-energy-converters-modelling-verification-and-validation/). One of these studied WECs is the OWC experimentally tested by the Korea Research Institute of Ship & Ocean Engineering (KRISO).

In a first phase a DualSPHysics model for the OWC was simulated without any damping caused by the orifice. Since the inside chamber of the OWC has a rectangular shape, this simulation was carried out in 2D. Good agreement was achieved between numerical and experimental results.

In a second phase the cases with Power Take-Off (PTO) system, or with orifice, were considered by applying a force on the free water surface inside the OWC chamber. This force was applied on a thin rectangular plate, floating on the free water surface inside the OWC chamber (Fig. 1). The PTO force is introduced by using the coupling of DualSPHysics with Chrono-Engine [3]. In order to get an estimate for the PTO force the method developed by Harry Bingham and Kim Nielsen was applied [4].

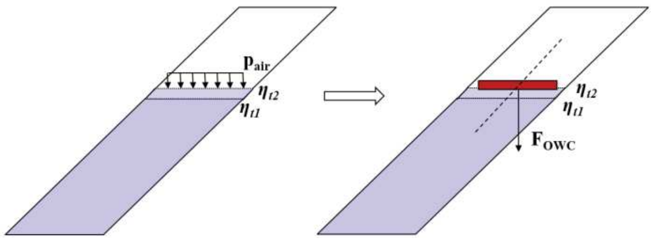

Figure 1: The pressure originating from compressed air is replaced by a force acting on a floating plate

In a third step, the accuracy of the water surface elevation, air flow and air pressure obtained from the DualSPHysics simulations was improved by adding the effect of air compressibility and by conducting 3D simulations.

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Numerical modelling of liquefaction around marine structures

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Wave induce liquefaction of the seabed is the process by which soil loses its bearing capacity due to the vanishing of the effective stress (M. Kudella, 2006), potentially leading to severe failures of marine structures. For wave energy converters, such liquefaction can have implications for the device mooring with, e.g., gravity anchors. Thus, enhanced understanding of the wave-structure-seabed interaction is important for more efficient device designs and, ultimately, the exploitation of the wave energy resource.

The NuLIMAS project aims to develop an open-source numerical modelling framework for liquefaction around marine structures, thereby matching the goals of the working group 1 of *wecanet*. In addition to the numerical model development, a number of small and large scale physical model experiments will be conducted to (1) fill knowledge gaps regarding the mechanisms of seabed liquefaction and find an appropriate constitutive soil model, and (2) allow the comprehensive validation of the numerical toolbox across different scales. The numerical model, as well as the results of all physical scale tests, will be documented and published online for future use by interested professionals.

NuLIMAS builds upon earlier experiences and efforts to investigate seabed liquefaction on national as well as transnational levels. The project consortium includes partners on the forefront of scientific and technological developments in seabed liquefaction, costal, and ocean engineering.

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Design optimization of wave energy technologies for multi-use marine areas and mild/extreme sea conditions

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UNIBO is presently working on i) innovative PTO systems (membranes) to increase the power conversion rate, ii) low-inertia devices to produce in mild sea climate sites, iii) reliable mooring systems to withstand extreme weather conditions and at the same time reduce the power losses. The research topics are therefore related to different WECANET working groups.

1. **Deployment of wave energy arrays (Working Group 1-2).**
   - The improvement of the mooring design can be reached by combining the results of physical testing (field data available from other projects) and numerical modelling (Ansys AQWA, openFoam, DualSPHysics). The research CFD models should be coupled to original procedures/scientific libraries to contemporarily account for the effects of the PTO and moorings systems. This research could be useful also for integrating the devices in multi-use areas and/or to boost the conversion of offshore O&G platforms (see for instance the Italian national project PLACE "Conversion of off-shore platforms for multiple eco-sustainable uses)".
2. **Development of new wave energy converters for power production in mild sea states, provided with mooring systems capable of withstanding extreme storm events. (Working Groups 2, 3).**
   - A new floating WEC is under development at UNIBO, based on an innovative PTO membrane. It will be tested in the new basin of the Hydraulic Laboratory of Bologna. The gathered data will be used to improve the WEC design, and specifically the WEC geometry, the moorings and the membrane resistance. The data will be also used to calibrate a CFD numerical model (openFOAM, DualSPHysics).

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Hydrodynamic modelling for wave energy converters: explore the computation/fidelity continuum

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Wave energy is a tremendous untapped energy resource that could make a decisive contribution to the future supply of clean energy. However, numerous obstacles must be overcome for wave energy to reach economic viability and compete with other energy sources. The amount of energy extracted from ocean waves, and therefore the profitability of the extraction, can be increased through a holistic optimization of the geometry and control strategy of the wave energy converter, both of which require accurate mathematical hydrodynamic models that are able to correctly describe the WEC-fluid interaction. While the effectiveness of the optimization/simulation is tightly linked to the accuracy of the model, the computational demand brutally limits the realm of applicability. Therefore, it is essential to be able to univocally measure the fidelity/computation compromise of each model, and consequently select which application it is appropriate for. However, despite its mature age, the “modelling problem” is far from being settled. This is certified by several recent collaborative projects, such as the OES-TASK-10 or the CCP-WSI Blind Test Series. In order to pursue the essential objective of confidence in mathematical model, some main issues need to tackled:

- **Lack of standardization in benchmarking**
- **Lack of a set of standardized, unambiguous, and representative comparison metrics**.
- **Lack of structured sharing platforms**:

My personal effort in this field is focused on the development and experimental validation of a novel nonlinear modelling approach, which realizes a good compromise between accuracy and computational time (much faster than real-time computation). After validation, the objective of the project is to create an open-source software in order to allow the community to avoid the learning curve and easily test the model. The method is applicable to axisymmetric buoys and prismatic platforms. An open-source demonstration toolbox is already available at its second version at https://doi.org/10.5281/zenodo.4065202 and in the QR-code in figure, implementing a computationally efficient nonlinear Froude-Krylov force calculation, enabling computing two orders of magnitude faster than real-time.

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Design of a heaving point-absorber WEC using SPH

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The aim of this research is to provide a unique numerical framework that enables to tackle the most important and challenging aspects in the design of Wave Energy Converters (WECs): efficiency and survivability. More precisely, our work is focused on one of the most widespread WEC devices: the heaving point-absorber. It is a relatively simple device that typically comprises a floater whose oscillating motion is converted into electricity by a Power Take-Off (PTO) system. This is a very challenging task, since the numerical model should be able to solve the interaction between the incoming waves and the floating structure, during both working and extreme conditions, while accurately considering the PTO system behaviour.

The numerical tool used here is the Smoothed Particle Hydrodynamics (SPH) software DualSPHysics coupled with the multiphysics platform Project Chrono. In this manner, we have a unique meshless framework where DualSPHysics solves the fluid dynamics of the problem and Project Chrono simulates the complex mechanisms of the PTO system.

We have already conducted a validation of the numerical approach as well as an efficiency and a survivability analysis in [1], and the outcomes are promising. However, it is fundamental to widen the numerical investigation to include irregular sea-states, more complex WEC geometries, different types of PTO and control systems, more realistic structures and moorings as well as considering arrays of WECs. We have also found a lack of well-stablished general methodologies to study the efficiency and survivability of WECs. Therefore, a fluid communication among theoretical, experimental and numerical researchers within the scientific community should be encouraged to develop the solid theoretical ground and reliable experimental campaigns needed to improve the numerical tools and methodologies used during the design stages of WECs.

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Time-domain wave propagation modelling for assessing the impact of WEC farms on the wave field and the local morphodynamics and sediment transport

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Ocean waves carry part of the energy transferred from the atmosphere to the sea surface over long distances. Some of this energy can be harvested using wave energy converters (WECs). The performance (energy extraction) of isolated WECs and WEC arrays is strongly dependent on: i) the dominant sea-state [1]; ii) its temporal and spatial variability; iii) the wave-structure interaction within the WEC array; and iv) on the local environmental features.

The most common approach to estimate the power absorbed by WECs is considering bulk parameters to represent the directional wave spectrum [2,3]. This approximation is not entirely accurate, particularly at regions with complex and variable wave conditions [4]. A full description of the waves, through the directional wave spectrum or the sea surface elevation, is desirable for such cases. Both can be approached by employing numerical simulations. In the literature, the wave energy redistribution around WECs has been widely simulated using the spectral numerical model SWAN (Simulating WAves Nearshore) [5,6], where WECs are represented as obstacles [7]. However, the SWAN model cannot solve the evolution of individual waves nor wave-structure interactions. Consequently, the wave-induced velocity field is not resolved, and hence the sediment transport cannot be adequately estimated using this model. For that reason, using a phase-resolving model is more convenient. Different numerical models have been used to resolve the wave propagation and far-field wake effects by the presence of WEC arrays [8, 9].

In this work, we propose to use the MILDwave phase-resolving wave propagation model, developed at Ghent University [9, 10, 11], coupled with a wave-structure interaction solver to take into account the WEC performance and its effects on the near and far-field [12]. It is intended to obtain the wave-induced velocity field, which will be used to solve the advection-diffusion equation for sediment transport due to the presence of WECs. For the numerical simulations, the boundary and initial conditions will be determined to carry out test cases with different WEC array configurations and for different scenarios of incident wave conditions. Finally, to analyze the effects on sediment transport and morphodynamics, several parameters will be studied. Such as bed shear stress, erosion and sedimentation, and other morphological indexes that had been previously established [13].

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Snap Loads in Cables for Marine Renewable Structures

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Marine cables are vital components in important marine renewable sub-systems such as station-keeping and power transmission. When mooring lines, power cables or umbilicals become slack (i.e., completely unloaded with zero tension), a snap load of potentially large amplitude is soon to follow when the cable is re-tensioned. When such a snap occurs, it is characterised by a sharp rise in axial tension that effectively is a propagating shock wave in the cable. Snap loads are known to cause mooring failures due to overloads and is suspected to contribute significantly to fatigue damage of marine cables. To investigate this a novel cable dynamics solver, called MooDy, based on an *hp*-adaptive discontinuous Galerkin method was developed [1]. The code was illustrated to accurately predict the generation and propagation of the tension shock waves associated with slack-snap occurrences [1]. MooDy is released as freeware [2] and has been coupled to hydrodynamic solvers such as WEC-SIM and OpenFOAM. Presently MooDy is expanded to include its own hydrodynamic solver. MooDy has recently been used to illustrate the influence of slenderness of submerged buoys with regard to generated snap loads [3] as well as a sensitivity analysis of how cable drag coefficients impacts snap load magnitudes [4].

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Prediction of wave energy resources of the Baltic Sea under climate change

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On the promotion of the use of energy from renewable sources, the EC Directive (2009/28/EC) stresses the need to use the possible energy of waves, marine currents and tides in the oceans and other water bodies. For evaluation of technical wave energy resources in the Baltic Sea, one of the first attempts was made by Swedish scientists (Bernhoff et al., 2006); the potential energy calculated by them is in the range of 24 TWh. Soomere and Eelsalu (2014) assessed the wave energy potential of the eastern Baltic Sea and concluded that the wave energy flux is about 1.5 kW/m on average, and reaches up to 2.55 kW/m in selected locations of the north-eastern Baltic Proper. The present assessment of wave energy resources in the Baltic Sea Lithuanian nearshore indicated that the mean wave energy flux was equal to 1.21 kW m^{-1} (Jakimavičius et al., 2018). These energy evaluations would be useful for determination of wave energy flux changes in the context of climate warming. Therefore, under the WECANet COST Action CA17105 umbrella we, together with PL, DE, DK, SE, and EE partners, offer to perform:

1) Estimation of wave height and wave energy flux in the Baltic Sea in 1986–2005 (baseline according IPCC AR5);
2) Determination of the statistical relationships between wave height (generated by wind) and wind speed in 1986–2005 in the different part of the Baltic Sea;
3) Projections of wave energy flux of the Baltic Sea nearshore based on statistical relationships, and selected climate models and RCP scenarios in the near future (2021–2040).

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Investigation of Flow and Scour around Bottom-Sitting WECs and WEC Foundations

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Numerous types of wave energy converters (WEC) have been developed since 19th century, most of which require a foundation or a mooring system constructed at the sea bottom or directly installed at the sea bottom of different shapes and working principles. The essential elements of the design of such structures such as the loads acting, scour protection, fatigue conditions of the structure, stability of energy transfer cables, maintenance and repair costs and economic lifetime of the structure require a proper understanding of flow characteristics and scour geometry around these structures. There are few studies considering flow and scour around these structures. Lancaster et al. (2020) study scour around a gravity based Oscillating Water Column (OWC) WEC experimentally. Huang et al. (2020) study flow around a bottom-sitting OWC-WEC using a multiphase Reynolds-Averaged Navier-Stokes equations (RANS) model. In the present study, the aim is to investigate the flow and scour both numerically and experimentally around the bottom-sitting WECs and WEC foundations. In the study, the computational fluid dynamics code used in Fuhrman et al. (2014), Baykal et al. (2015 and 2017) could be utilized. The code solves incompressible Reynolds averaged Navier–Stokes equations incorporating k-ω turbulence closure, sediment transport and sea bottom morphological changes. The immersed boundary method for the moving meshes and the porous media flow are intended to be incorporated in future applications of the model. The experimental study could be carried out in the wave flume of Department of Civil Engineering, Middle East Technical University. The flume is 6 m wide, 26 m long and 1 m deep, and is equipped with a piston-type random wave maker, laser bed profiler and acoustics Doppler velocimeter.

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On the Modeling of Wave-Floating Body Interactions and Wave-Energy Converter Systems by SPH Method

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To enhance the productivity of the wave-energy converter (WEC) systems, there is an increasing demand on accurate, robust and reliable numerical models to achieve more efficient new generation WEC technologies. Based on this demand, a particle-based, Lagrangian method, namely, Smoothed Particle Hydrodynamics (SPH), has received a remarkable interest among scientist working in the field of Computational Fluid Dynamics [1,2].

Along this line, we have been working on the numerical modeling of violent free-surface hydrodynamics problems such as dam-break, sloshing, open/closed channel flows around bluff bodies, water-entry of rigid-bodies, regular/irregular numerical wave generators, wave-floating body interactions, determination of the hydrodynamic coefficients of rolling cylinders and numerical modeling of WEC systems. Our recent study that aims to investigate regular/irregular wave generation and together with examining the occurrence of wave-break phenomenon in certain wave conditions has been published in Journal of Ocean Engineering and Marine Energy [3]. In terms of WEC simulations, we are working on simulating floating offshore oscillating water column systems (OWC) and Overtopping Wave Energy Converter (OWEC) by means of a Weakly Compressible SPH approach. The preliminary validation studies have been completed for both wave energy converter systems where the modeling of OWC system have been compared with the results of the recent study of [2] and the results of OWEC system simulations were compared with the findings of [4]. For the initial validations, a relatively low particle resolutions were utilized in both test cases, however, our SPH algorithm produced compatible and promising results up to ~5-6% discrepancy with the literature data.

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Digital-Physical Convergence of Wave Energy Conversion

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World oceans and seas cover about 71 % of Earth, being the largest renewable energy reservoir. At the surface of seas, waves carry energy which can be tapped by combining technical and digital innovation. The main objective of the DPC-WEC initiative is to create a transferable methodology and a pilot database of sea state conditions in order to facilitate the development of WECs and give the marine research and development sectors essential data to rely on. The objective will be realized by (1) developing a method of collecting and assessing sea wave data in the Baltic Sea region, (2) creating a methodology to develop a user-friendly interface which corresponds with end-users needs and by (3) creating mathematical framework which can link different existing types of WEC with actual sea conditions. Efficacy of the developed model will be confirmed through the calibration of the real power output of an existing wave energy converter (WEC) model throughout the course of the model's development. We will also demonstrate a WEC model that would be optimized for a target area, in order to show how other marine energy projects could make use of the database in routine operation. This allows us to develop a WEC control system which will receive sea state data from the wave buoy and adjusts the conversion system accordingly, with the intended purpose of keeping the unit output at maximum at all times. DPC-WEC PRINCIPLE paves the road towards international cooperation in the marine energy sector and leads to a sustainable future. This will be realized through an open access database, which will become available for marine industry, scientists and for other stakeholders. All end-users will receive the unique ability to add valid data to the database. Additional added value of the project is the standardization of data protocols, ensuring coherence of existing and upcoming data. The project team consists of experts from academia and industry and trains the next generation of marine energy leaders.

Suggested activities to contribute to WECANET WG1 and WG3 objectives:

(1)Numerical hydrodynamic modelling of wave energy resources, (2) WEC and WEC control system development: video (3) Innovative wave measurement equipment: video

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Investigations on the WECs' Use for Smooth Transformations of Waves in the Areas of Maritime Port of Constanta

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Several numerical hydrodynamic models were deemed as appropriate for the study of the wave's dynamics around Constanta Port. Broadly speaking, our approach of the WEC's specific research area is precisely linked to the mechanics of the fluids and with coastal ports hydrodynamics, in particular.

The MOHID hydrodynamic model, used for the study of marine currents, the SWAN spectral model, used for the modelling of waves propagation processes in portuary waters, as well as the BOUSS 2D model, used for the transformation of waves nearby the port's basins, allow for subsequent developments that can in turn be used as a basis for the elaboration of various services, which at present underlie the interconnected informatics systems, with specific applicability to the field of wave energy systems, maritime transport, or MSP/Maritime Spatial Planning.

The results we obtained as part of the simulations, using a numerical models, of the marine and coastal currents, as well as the results of the joint impact of the currents and waves, on the transition area of the Constanta Port entrance, have been analyzed comparatively, against in situ and satellite measurements. The collection of data required for the validation of the circulation model has been carried with a Doppler Effect current-meter, as part of a hydrological measurements expedition in the coastal port areas, and also the data required for the validation of the wave hydrodynamic model were provided by the marine geo-hazards warning system, EMSO EUXINUS, which is operated in Romanian waters by the GeoEcoMar Institute.

Even the present study is requiring a deeper research process, the numerical approach, as well as of the approach related to filed measurements and observation activities, for an accurate knowledge of hydrodynamic processes, given the considerable variability for the parameters involved, it gives certain recommendation for WECs use for the extension of sheltered areas in the vicinity of the Constanta port enclosure breakwaters.

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Wave energy forecast using optimised deep learning neural networks

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Ocean renewable energy is a promising inexhaustible source of renewable energy, with an estimated harnessing potential of approximately 337 GW worldwide, which could re-shape the power generation mix [1]. As with other sources of renewables, wave energy has an intermittent and irregular nature, which is a major concern for power system stability. Also, wave conditions are known to exhibit variability over monthly, seasonal, inter-annual, and decadal time-scales. This is a consequence of various factors, such as fluctuations of the yearly wind index, climate indices, seasonality of wind speed, and solar irradiance. Consequently, to integrate wave energy into power grids, it must be forecasted.

Recently trending approaches have continued to cover soft-computing methods, such as support vector machines, extreme learning machines, sequential learning NN, genetic fuzzy systems, and machine learning applications [2,3]. An approach to properly forecast the wave energy flux, and other wave parameters, is the use of optimised deep learning neural networks. In particular, the moth-flame optimisation as the central decision-making unit to configure the deep neural network structure and the proper data selection. Also, the moth-flame algorithm can be modified to improve its search space mechanisms.

The authors already applied the described approach and assessed forecasting skills by using 13 datasets from locations across the Pacific and Atlantic coasts, and the Gulf of Mexico. The proposed optimised deep neural network performed well at all the sites, especially over short-term horizons, where it outperforms statistical and physics-based approaches. The authors now intend to develop a similar study, based on optimization techniques to be applied in European coast sites [4], to reduce decision uncertainties for wave energy investments.

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Numerical study of water impact of a sphere with mesh-less and mesh-based approaches

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This paper contributes to fill the gap of comparison studies between mesh-free and mesh-based CFD models by using two popular non-commercial codes DualSPHysics (mesh-free model) and OpenFOAM (mesh-based model) to analyse the water entry of a sphere. This problem is related to wave energy converters where, under some wave conditions, floaters mechanisms can experiment high vertical displacements. The convergence and accuracy of the numerical models DualSPHysics and OpenFOAM to reproduce the water entry of a rigid sphere into calm water was analysed by different metrics (normalized standard deviation, correlation coefficient and root-mean square error) using Taylor diagrams. These metrics were applied to the vertical motions and total force on the sphere during the water impact. Both models provide a similar level of accuracy when considering fine spatial resolution. Therefore, this analysis suggests that mesh-less models have attained the level of maturity required to provide results with an accuracy similar to mesh-based models for this kind of problem.

Acknowledgements

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Internal wave generation in a non-hydrostatic model for modelling wave-WEC (array and farm) interactions and far field effects

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One of the challenges in the field of renewable wave energy is to determine the optimal geometrical layout for wave energy converter (WEC) arrays or farms, targeting the maximum energy production and the correct assessment of the impact of WEC arrays or farms on the surrounding wave field. For this purpose, accurate and detailed numerical modelling of WEC arrays and farms under realistic 3D wave conditions is considered crucial, which is a topic addressed by "Working Group 1" of the WECANet COST Action CA17105. This kind of application requires a homogeneous wave field in the entire numerical domain and thus a new internal wave generation technique (Figure 1) has been developed and implemented for the non-hydrostatic wave model, SWASH (Zijlema et al., 2011).

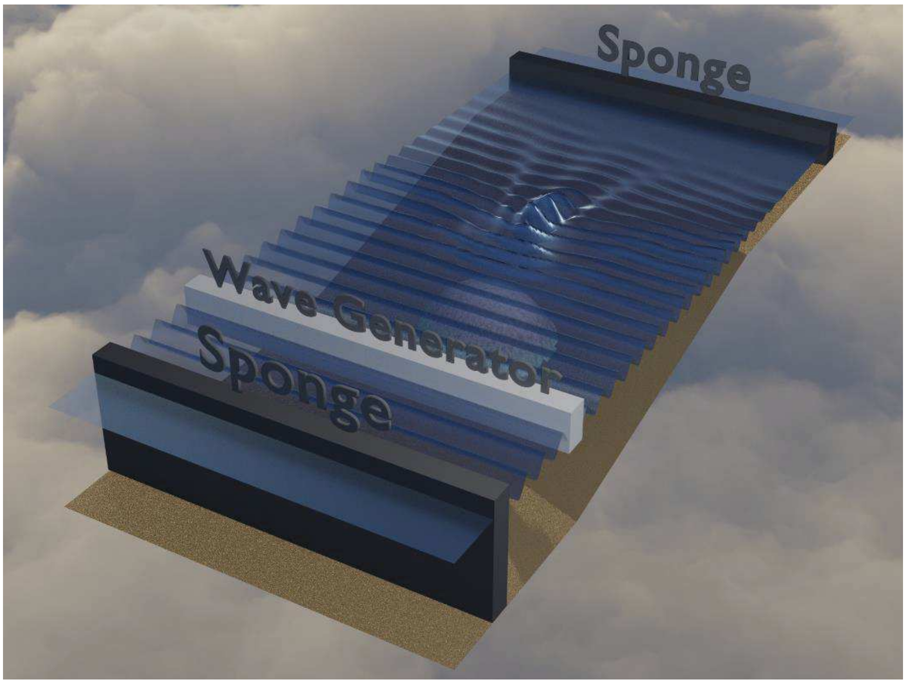

Figure 1 Wave propagation over the Berkhoff shoal, showing the 3D SWASH results of water surface elevations, using internal wave generation.

Traditionally, in time-domain models the waves are generated by using the weakly reflective wave generation method which is based on the assumption that the waves propagating towards the boundary

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of the computational domain are small amplitude shallow water waves with direction perpendicular to the boundary. As a result, this method is weakly reflective for directional and dispersive waves, leading to loss in absorption performance of the domain boundaries. The internal wave generation was proposed by Vasarmidis et al. (2019) as an alternative, for the open source non-hydrostatic wave model, SWASH, to avoid wave reflections. With this method, a spatially distributed source term in the form of mass is added to the continuity equation. This source term is a function of a velocity that is called the energy velocity and for the system of SWASH equations has been mathematically derived by Vasarmidis et al. (2019).

A comparison has been executed by Vasarmidis et al. (2020) between the performance of the new internal wave generation method and the weakly reflective wave generation, and it is shown that internal wave generation leads to much better results in case of waves reflected back to the numerical boundary. Thus the method provides a significantly more accurate prediction of the resulting wave field for cases with man-made structures (e.g., breakwaters, artificial reefs, artificial islands) and wave energy converter (WEC) farms, where the radiated and reflected waves cannot be estimated a priori.

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Vasiliki Stratigaki is a postdoctoral researcher (fellowship 1267321N) of the FWO (Fonds Wetenschappelijk Onderzoek - Research Foundation Flanders), Belgium.

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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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Tests with a single WEC unit from the WECfarm project

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The continuous development of affordable high-fidelity numerical models allows the simulation of complex structures, such as wave energy converter farms, that was inconceivable just few years ago. These models have been and are still under an intensive phase of verification and validation in order to quantify their true capabilities. In the wave energy sector there is a global attempt to create a cross validation framework through the "Ocean Energy Systems Task 10" (OES Task 10), but the main objective of this task is limited to simple WEC geometries such as sphere or cylinders. Although it is fundamental to ensure the basic modelling capabilities, an important number of research groups are now capable to simulate farms of wave energy converters, and thus the experimental validation of these numerical simulations is essential.

In the attempt to cover this discrepancy between model availability and validation data availability, Ghent University with the support of several international partners is developing an ambitious test program (the 'WECfarm' project) for arrays of wave energy converters. The WECfarm project are a follow-up of the WECwakes project in which up to 25 point absorber WEC types have been tested simultaneously in various array configuration in the wave basin of DHI [1-2].

In order to create an agnostic dataset, the single WEC unit selected for the WECfarm experiments is a single degree of freedom WEC, where the floater is only allowed to move in the vertical direction. The floater is shaped from a flat cylinder (small draft compared with the diameter), in order to stimulate non-linear behavior and therefore challenge the validation of numerical models.

The WECfarm project aims at testing 9 WEC units in different WEC array configurations, but before commissioning the full development of the arrays, it is important to verify that a first single WEC unit properly works both in dry and wet conditions. The verification of the functionality of a single WEC unit has been already carried out at the laboratory of Ghent University in a dry test-bench, while the functionality in wet conditions will be carried out at the Coastal and Off-shore Wave Basin of Aalborg University.

The main objectives of the test campaign are to:

1) Verify that the single WEC unit can properly work in normal wave conditions, including DAQ, Motor, Communication and Controller;

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2) Verify the applicability of different control strategies in real-time;
3) Verify the structural rigidity of the WEC system under extreme wave conditions;
4) Verify the quality of the recorded experimental data.

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Vasiliki Stratigaki is a postdoctoral researcher (fellowship 1267321N) of the FWO (Fonds Wetenschappelijk Onderzoek - Research Foundation Flanders), Belgium.

The WECANet-RORO testing program

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The interactions between Wave Energy Converters (WECs) and wave motion lead to complex fluid dynamics, mechanical and electrical phenomena. The experimental modelling seems to be the most powerful scientific approach to explore such dynamics up to their full extends. Laboratory effects may alter some physical processes under study and controlling such effects is fundamental to produce good-quality data. Advanced numerical modelling techniques, able to simulate very complex physical systems where fluid-dynamics and mechanical components interact, are emerging and in support of their further development there is an acute need of good-quality experimental data. The execution of an experimental test program in different laboratories, 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, an experimental and numerical ROund-RObin testing program (WECANet-RORO) was proposed (Cappietti, 2019) and a first group of WECANet partners joined this initiative. A managing committee was formed, aiming at: i) setting up starting activities and coordination; ii) promoting the formation of a group of experimental and numerical infrastructures participating in WECANet-RORO. The Oscillating Water Column Wave Energy Converter (WEC) has been selected as the reference model. Studying such kind of WEC permits to explore

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the inherent difficulties of numerical modelling in simulating a two-phases physical system, namely, water and air.   Moreover, in order to acquire laboratory measurements of those physical phenomena that are still very challenging in term of numerical modelling (e.g. mooring dynamics, moving rigid boundaries) one floating and one fixed laboratory-scale models will be tested (Fig. 1).

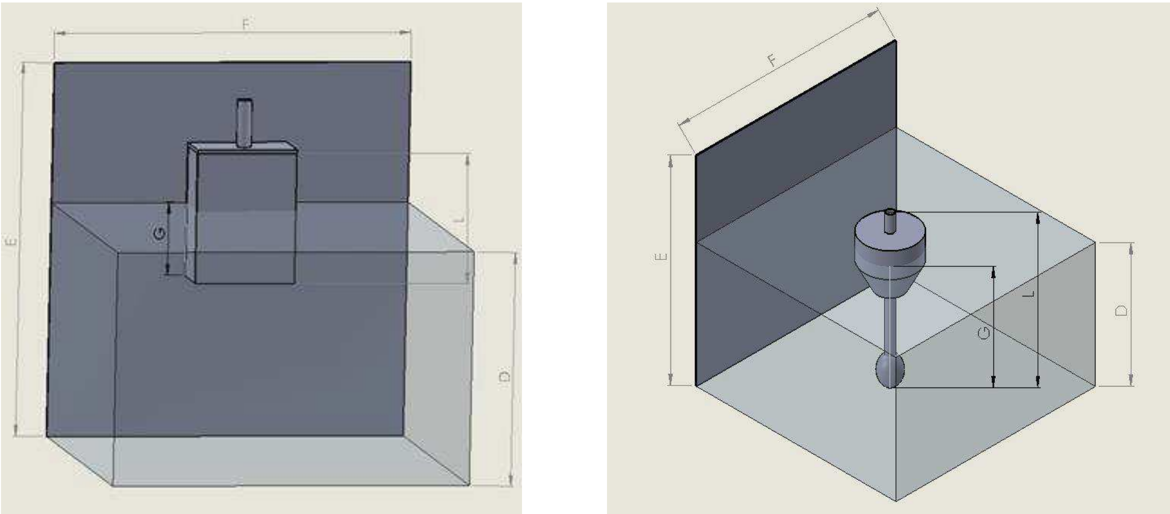

Figure 1 – schematic layout of the WECANet-RORO OWC models, fixed (left) and floating (right).

Belgium (awww.ugent.be), Denmark (www.build.aau.dk), Greece (www.auth.gr), Italy (www.unifi.it), Portugal (paginas.fe.up.pt/~nemarwebsite/), Spain (www.uvigo.gal, lim.upc.edu), Turkey (http://imst.deu.edu.tr), and United Kingdom (www.qub.ac.uk) countries are presently participating in the WECANet-RORO. Advancements in the organization is going to be presented in the 2020 General Assembly aiming at attracting the interest of more WECANet members and increase the number of the WECANet-RORO experimental and numerical participating infrastructures, but also the number of the WECANet-RORO data users for numerical validation purposes.

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Wave energy research in the new Coastal and Ocean Basin in Ostend, Belgium

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The new Coastal and Ocean Basin (COB) [1] is located at Ostend Science Park, in Ostend, Belgium (http://COB.ugent.be). The laboratory will provide a versatile facility that will make a wide range of physical modelling studies possible, including the ability to generate waves in combination with currents and wind at a wide range of model scales.

The facility is designed to serve research and industry needs in the fields of mainly offshore renewable energy and coastal engineering. The wave basin will have state-of-the-art generating and absorbing wave generators, a current generation system and a wind generator. The aim is to generate waves and currents in the same, opposite and oblique directions. The wave basin will be fully operational in 2021.

In the field of renewable energies we aim at a detailed understanding of the optimal geometrical lay-outs of wave energy converter (WEC) arrays and farms under realistic 3D wave-current conditions, as well as of the interactions between the WECs of the farms. This comprises the establishment of a generic dataset to validate the recently developed high precision numerical models ([2] - [4]) used to simulate WEC farm effects. This new dataset will be realised at the COB within the upcoming 'WECfarm' research project, designed to follow-up the completed 'WECwakes' project [5] - [6]. Furthermore, experimental research aiming at numerical model validation of wave slamming on complex floating objects such as (but not limited to) WECs, as well as on WEC mooring effects, is planned.

This research is situated in the topics of "Working Group 2: Experimental hydrodynamic modelling and testing of WECs, WEC arrays/farms, PTO systems, and field data" and "Working Group 1: Numerical hydrodynamic modelling for WECs, WEC arrays/farms and wave energy resources".

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Experimental testing of wave energy converters for the WECfarm project

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This abstract refers to an ongoing Master Thesis, conducted by Bono the Witte and Hendrik Claerbout, at the department of Civil Engineering of Ghent University (Belgium) on the optimal geometric configuration of multiple WECs in a WEC array. A new experimental campaign within the WECfarm project is planned in a new wave basin which has been constructed in Ostend, Belgium; the Coastal & Ocean Basin (COB). WECfarm will deliver a database for validation of new advanced numerical models which are worldwide employed for WEC array modelling. At the time of the 3rd Online WECANet General Assembly (November 2020), dry-testing takes place at Ghent University of one single WEC. The importance of dry-testing is to check the proper working of all mechanic, electronic and control aspects before deploying the WEC in a wave flume or wave basin.

The working principle of the WEC is the one of a point absorber operating in heave. The power take-off consists of a rack and pinion system in combination with a rotational Permanent-Magnet Synchronous Motor (PMSM). To control the WEC, a Simulink 'Real Time torque control' model is used. This model is built on a development computer and subsequently loaded on a Speedgoat Performance real-time target machine. In this context, real-time is the capability of the algorithm to execute within a prescribed update rate. The input of the control model consists of the position, velocity, acceleration of the buoy and the vertical force on the buoy. These are obtained with a laser sensor, motor encoder, accelerometer and configuration of three loads cells, respectively. The output of the control model is the torque to deliver to the motor.

Within the present Master Thesis a single WEC is scheduled to be tested at the wave basin of Aalborg University, as part of the WECfarm collaboration with Aalborg University, Denmark (dr. Francesco Ferri). The test matrix will contain diffraction tests, radiation tests and power absorption tests. It will also contain (extreme) wave conditions to induce non-linear effects. If possible within the timeframe of this Master Thesis (to be completed by June 2021), a second WEC will be constructed which will be identical to the first one that is currently tested. Following that, an array of two WECs will be firstly dry-tested and secondly tested in the wave flume at Ghent University with a focus on interaction and control strategy. These steps will allow us to make recommendations for the WEC array experimental set-up where up to five WECs will be employed, which will be experimentally tested at COB wave basin in 2022.

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During the present Master Thesis, there is close collaboration with other Master Thesis work at Ghent University focusing on control strategies and on the testing of one single WEC in order to fully characterize the hydrodynamic performance of the WEC. The obtained dataset of the 3D testing of the first WEC at the wave basin of Aalborg University will serve as input for numerical model validation that is currently taking place at Ghent University based on Smoothed Particle Hydrodynamics methods.

This research situates itself in the topics of the WECANet Working Group 2, “Experimental hydrodynamic modelling and testing of WECs, WEC arrays/farms, PTO systems and field”.

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The Behavior of Monopile Foundation for Hybrid Wind-Wave Energy Converters

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To design offshore wind turbines (OWTs) with wave energy devices on the same structure is an effective solution within the context of combined wind-wave systems since they are supported by the same foundation. Monopile is the common used foundation type for OWTs. The OWTs with monopiles move to deeper waters with depths of 40-50 m and with a large capacity of 8-10 MW. The monopiles for OWTs in deeper waters are evaluated to become more suitable for the designing of hybrid wind-wave systems.

A number of concepts have been recommended and studied in the last decade for the integration of wave energy converter (WEC) into an OWT with monopile: Oscillating body-wind concept, Wavestar concept [1], oscillating water column (OWC) concept. Experimental and numerical investigations were conducted on dynamic and hydrodynamic response of the OWC-WEC and torus heave-type WECs installed on OWTs with monopiles [2, 3]. It should be noted that the studies were carried out without embedment of the monopile into the soil. The soil-monopile interaction is an essential issue for the design of the monopile. To combine the WEC on OWTs alters the subjected vertical, horizontal and moment load characteristics on monopile. Therefore, it is obviously necessary to perform model test and numerical simulation studies to understand the behavior of the monopile with installed WEC device. For this purpose, the numerical models which are validated with the laboratory or field tests results of monopiles could be utilized taken into account the additional estimated loads raised by the integrated WEC devices. The experimental and numerical simulation results will be performed particularly to understand the effect of the loading change on pile deformation, and soil reaction along the pile length.

To set-up the model tests and to develop numerical models of monopiles with soil around the pile provide to understand the monopile response within the context of soil-pile interaction for the recommendation of design approach for hybrid wind-wave systems.

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A combined WEC-TENG concept for wave energy conversion

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Around the world, hundreds of different wave energy converter (WEC) concepts have been developed independently, without any specific design attaining consensus amongst the community. As a result, not only is the wave energy sector lacking a “flagship” concept around which to rally, but there is also a potentially excessive division of resources and efforts put into developing so many different WECs, with very little commercial success being verified thus far. These technology maturity and economic challenges, alongside others, have been identified by the authors in [1]. To address them, disruptive technologies and synergies must be found, developed and promoted.

Here, a combined approach to wave energy conversion is proposed. A WEC concept, designated as the E-Motions [2], has recently been subjected to a physical modelling study with an incorporated triboelectric nanogenerator (TENG) system [3]. While the E-Motions converts energy from wave (and wind) induced roll oscillations, TENGs are capable of harnessing low frequency, low amplitude mechanical motions, through triboelectrification and electrostatic induction, and converting it into usable electricity. Both concepts are versatile and adaptable to a wide variety of floating structures, benefit from protection from the ocean environment and can function complementary, yet independently, with low potential O&M costs. Within the scope of WG2, preliminary results of the experiments indicate a very good hydrodynamic response, alongside relevant energy outputs from both the E-Motions and the TENG components. Further work will be developed to demonstrate the pertinence and potential of considering such a hybrid approach towards the successful development of wave energy.

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Development of the methods for modelling the wave climate in the towing tank

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Recent works of Maritime Advanced Research Centre CTO S.A. related to the topics of Working Group No. 2 were focused on improvements in modelling the waves in the towing tanks. Special focus was paid to:

1. Accurate and non-invasive method for wave measurements. New ultra-sonic device was developed; using three sensors in optimized pattern instead of one sensor prevents the loss of signal in steep waves and imroves accuracy. The system is also maintenance-free.

2. Improved control system for the wave maker. Adaptive control system with a fuzzy-logic controller has been developed on the basis of the studied theory, established conception and the research carried out. The optimized control algorithm was verified for wide range of wave spectra including two-peak spectra, and showed high accuracy and stability. The control takes into account the tank characteristics resulting from its limited dimensions. The control is realized in user-friendly manner.

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Experimental activity for a benchmarking test case of WECs in its stand alone and array configuration.

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Several communities are currently working on Wave Energy Converters (WECs); all of them have highlighted the need of experimental open-source benchmark test cases, they are fundamental to validate the different numerical algorithms that are used to model WECs.

Outside the WeCANet community, the need for publicly available experimental data has been underlined by the ITTC specialist committee on hydrodynamics modelling of marine renewable energy devices [1]; it is an objective of the Marinet2 project, in the framework of this project some round robin experimental tests are underway and some experimental data are made available in the OES TASK 10.

The wide variety of WEC devices and the shortage of available data leave space to new multi campaigns tests. While the development of the WECs technology also asks for the introduction of experimental round robin tests on arrays.

The wave basin n.2 at CNR-INM well suits the study of WECs in open sea. In fact, it has already been used for several experimental campaigns related to WECs [2],[3],[4]. Its dimensions (length = 220 m, breadth = 9.0 m, water depth = 3.5 m) allow for a reduced blockage effect and it can even host arrays of small scale devices.

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Development of a single wave energy converter for the WECfarm project

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This work refers to PhD research performed at Ghent University, Belgium, within the topic: "Experimental study and numerical modelling of combined near-field interactions and far-field effects of wave energy converter farms". A new experimental campaign within the WECfarm project has been initiated to obtain a database to validate new advanced numerical models for WEC array modelling. At the time of the 3rd Online WECANet General Assembly (November 2020), dry-testing of the first WEC is occurring. The importance of dry-testing is to check the proper working of all mechanic, electronic and control aspects before deploying the WEC in a wave flume or wave basin. After wave basin testing and the corresponding performance evaluation, four additional WECs will be constructed. The WECfarm experiments with arrays of up to five WECs will be conducted at the Coastal and Ocean Basin (COB) [1] in Ostend in 2022, as part of the collaboration between Aalborg University, Denmark (dr. Francesco Ferri), Queen's University Belfast, UK (dr. Matt Folley) and The University of Edinburgh, UK (dr. David Forehand).

The working principle of the WEC is the one of a point absorber operating in heave. The hydrodynamic part of the design consists of a thermofolded truncated cylindrical buoy. The performance of the buoy is numerically evaluated in WEC-Sim. The mechanic part of the WEC design consists of a rack and pinion power take-off. A gearbox with ratio 1:4 connects the pinion with the Permanent-Magnet Synchronous Motor (PMSM). The motor torque-speed curves are obtained from a MATLAB Simulink Simscape Multibody model. A guiding system of three air bushings excludes friction effects in the power absorption measurements. The motor operates in torque control and is powered by a motor drive. The MATLAB Simulink control model is built on the development computer and loaded on a Speedgoat Performance real-time target machine. The input of the control model consists of the position, velocity, acceleration of the buoy and the vertical force on the buoy. These are obtained with a laser sensor, motor encoder, accelerometer and configuration of three loads cells, respectively. The output of the control model is the torque to deliver to the motor.

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Blue Accelerator: the new testing site in Ostend for maritime technology developments to enhance Blue Economy

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The Blue Economy established sectors are embedded within the overall EU economy with a stable contribution to the Gross Added Value, *GAV*, of 1.5 % from 2012 to 2018, while the employment has grown from 1.8 % to 2.2 % from 2015 to 2018 [1]. Some of these Blue Economy sectors (Marine living resources; e.g. aquaculture, Marine non-living resources; e.g. Oil and gas, Port activities, Maritime transport) are presented in Table 2.1 of [1]. However, still there are sectors such as marine energy (wave, tidal, etc.) that need support for further development in order to reach an established and commercial-stage [2-4]. In order to achieve further development in this sector, testing facilities and numerical modelling simulations for new and existing concepts of marine energy technologies are crucial.

Therefore, the Blue Accelerator project was recently introduced by the Flemish consortium of Ghent University (UGent), the Public Provincial Economic Development Agency of West Flanders (POM West Vlaanderen), the Flanders Marine Institute (VLIZ), the Technical University Alliance for economic transformation in West Flanders (TUA West) and VITO NV. The Blue Accelerator project aims at providing a smooth path for marine energy and maritime technology developers from early design stages to scaled models testing at the UGent wave flume and the Coastal & Ocean Basin (both managed by Ghent University), and to scaled prototype testing at the Blue Accelerator open sea test site.

The Blue Accelerator platform, see Figure 1, is located about 500 m off the port of Ostend. At this location, the average water depth is about 10 m and the tidal range 4 m. The testing zone is delimited by a circular area with a diameter of 440 m. The annual average significant wave height, $\boldsymbol{H_s}$, and the energy period , $\boldsymbol{T_e}$, are 0.65 m and 4.9 s, respectively, with a wave power of 4.33 kW per metre of wavefront (wave energy resource assessment from historically recorded data at 51.247° N, 2.928° E. Data provided by [5]). A long term statistical study has predicted extreme values up to 8.5 m of wave height, when considering a return period of 100 years [6]. Ocean currents between 0.15-0.9 m/s can be found at the Blue Accelerator testing site with values up to 1.87 m/s, when a return period of 5 years is considered [7]. Given the range of the local wave and current conditions, the Blue Accelerator test site is ideal for testing new marine energy and maritime engineering technologies, see Figure 2; e.g. WECs, aquaculture, remote monitoring equipment for offshore applications, maritime transport, and leading research programmes in combination with other existing infrastructure offered by Ghent University.

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Figure 1. The Blue Accelerator platform.

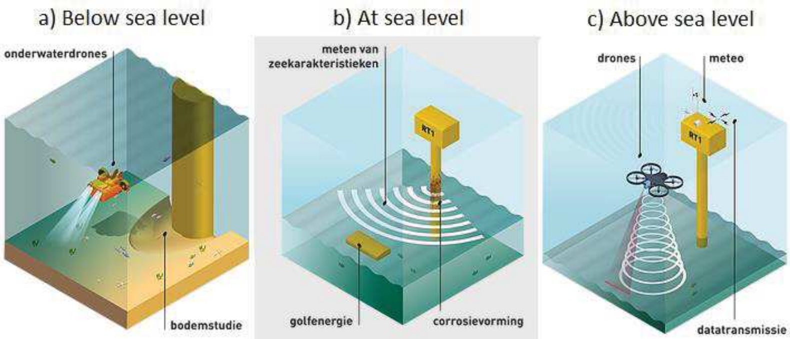

Figure 2. Offshore configuration testing options.

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Abstracts for Working Group 3:

Technology of WECs and WEC arrays

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Electrical layout optimization for wave power parks

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Large deployment of wave power parks depends on various factors, where maximization of the energy extraction in common less energetic sea states whilst ensuring the survival of the wave energy converters (WECs) in storms [1] is one of the challenges that directly impacts the LCOE of the wave energy devices. Many design choices have to be made when optimizing a WEC, and, particularly, power and voltage level from the perspective of electrical aspects of the WEC. This is influenced by whether few large scale or many small scale devices will be installed. In either case, the installation and maintenance costs should be included in the analysis.

Interconnection of WECs into a wave power parks includes individual direct device connection, radial connection, connection of clusters of devices etc. [2] Though planning of electrical infrastructure for a single WEC is usually limited by deciding of the parameters of one power cable to shore and power cable connectors, the future planning of wave power parks shall be done at earlier stage in order to decide on the optimum installed capacity of each WEC, farm layout and configuration, interconnection between units in the WEC array. Moreover, installation of WECs further away from shore, the power transmission becomes more challenging since the power losses become substantial. Questions related to optimization of an electrical systems for certain types of wave energy converters and consideration of other alternative transmission systems (such as DC) and associated (wave energy specific) challenges is of interest.

This work aligns with the priorities on optimization WECs and WEC arrays and electrical aspects of technology of WEC arrays and therefore fits into the WECANet COST Action and the Grant Period 3 framework.

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A Review Study on the Technology used related to Survivability and Optimization of WEC arrays

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WECs are in a reconsideration phase as far as design methods, tools and criteria while different types of WECs arrays are in the pre-commercial phase. Optimum design of WECs arrays is a great challenge that will address the basic today drawback of WECs related with their Levelized Cost of Electricity (LCoE) compared to other renewable energy technologies. At the same time, WECs should be able to survive in the harsh and inhospitable environment of oceans. Optimization and survivability are driving factors for the efficient implementation of WECs in array configurations.

In this context, we perform a review study in order to examine the current technology used as far as survivability and optimization of WECs arrays and identify possible challenges and gaps. With regard to the optimization of WECs, relevant studies reviewed were related to: (a) basic theory and definitions dealing with optimization problems (single and multi-level), (b) numerical methods and tools for solving optimization problems of WECs and WECs arrays, (c) details about the formulation of the mathematical problem (objective functions, design variables, constraints), (d) control issues and optimization methods and (e) LCoE integration in optimization. As for the survivability the review study was related to: (i) suggested survival modes of different types of WECs and WECs arrays, (ii) methods and tools for the assessment of the survivability of WECs and their components due to cyclic and extreme loading conditions, (iii) experimental campaigns and survivability, (iv) existing technical guidelines and (v) good practices for eliminating survivability related problems.

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Integration of wave power farms into power systems of the Adriatic islands: technical possibilities and cross-cutting aspects

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Wave energy is of interest for regions with a high wave power potential as well as for regions with a modest wave power potential such as the Adriatic / Mediterranean coastlines and islands. In the present research, a possibility to integrate a wave power farm to a power system of an island in the Adriatic Sea, combining the wave power with a battery energy storage system (BESS) and a solar PV, is explored and impact on the local weak low voltage grid is investigated. The load profile is typical for an Adriatic island demand substantially increased during summer (the tourist season). The wave power technology is a point absorbing wave energy converter (WEC) with a direct drive linear permanent magnet synchronous generator power take off. Wave power farms (WPFs) consist of two up to ten WECs.

The case study presented a concept of integration of a WPF into the grid with optimal number of WECs mainly influenced by the net consumption of the feeder. Additional generation of electricity is provided by the residential-scale PV systems and concerning problems with voltage regulation and loadability occured and considered. BESS used for WPF output power profile smoothing proved to be very efficient with intermittency mitigation while power-electronic-based device can be utilized to regulate power flows with reactive power provision to regulate loading and voltages.

Since a potential wave power farm is to be installed in the recreating area, the technical study is complemented by discussion on cross-cutting aspects such as environmental and social impact. Electricity generation by WECs is environmentally friendly, it creates new jobs and economically is effective since O&M costs are lower for a resource price then when fossil fuels are utilize for energy production but economical and life cycle analysis of the WPF installation needs to be carried out to see financial benefits and to estimate CO_2 reduction for the region in the continuing research.

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A Review of the Existing Technical Standards for Wave Energy Converters

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The standardization (and regulation) of structural objects is one of the most significant stages of their market development, as it accounts for their safety, integrity, and insurance. If no proper technical standards (TS) are available, then a starting point for design generally includes establishing guidelines and, recommended practices (RC) derived from comparable industries and research. These guidelines are usually based on "the first principles", adapted for the WEC design.

Nevertheless, there are standards related exclusively for WEC design, as most of the them (guidelines and standards) are presented by the European Marine Energy Centre (EMEC) an the International Electrotechnical Commission (IEC), see [1] and [2]. EMEC and IEC are in the process of developing standards for more than 10 years. Furthermore, maritime and offshore authorities have either published or are in the process of producing their own set of documents, especially DNV-GL [3]. Excepting rules and standards, DNV-GL offers a RC that can be used in the design and operation of ships, and marine installations as well. Other classification societies (authorities) also lack with developed rules or standards on WEC. They are generally developing or have some guidance related to marine energy [4], but rarely for particular structure. For instance, ISO has wind energy standards that can be used for the estimation of consequent forces above the waterline. Furthermore, The European Committee for Standardization (CEN) publishes Eurocode standards regarding the reliability analysis of structures in general, and might be employed in WEC design, but there are no regulations related to WECs specifically. In addition, note that a number of projects were aimed, in one of their specifics, to help the market regarding the TS.

Standardization is crucial to market internationalization ensuring the comparable practices across the globe. However, standards need experience. Structural design should be assessed more specifically, according to, for instance, an area of installment and years of exploitation, which govern the final design. The present guidelines are to be updated with new data, experience, and failure/incident reporting. Some WEC guidelines are mostly based on performance and not so much about the structural integrity. The guidelines are too flexible at the moment; they are not prescriptions but rather recommendations for procedures to be used in the design process, which is typical for industries in infancy. But perhaps it is time for the industry to mature. Regulatory bodies firstly form a guideline, then a standard. Moreover, this development, currently, does not appear to be followed by legal process that designers has yet to follow.

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The Effects of PTO sizing on the Techno-Economic Performance of Wave Energy Converters

Working Group 3: Technology of WECs and WEC arrays

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As an abundant renewable energy resource, wave energy has been emphasized over 40 years. However, the large scale utilization of Wave Energy Converters (WECs) is still far away from commercialization. An important reason is that the techno-economic performance of WECs is not competitive with other renewable technologies. Recent studies show that size optimization of WECs could make a difference [1]. By properly sizing WECs for different wave locations, the Levelized Cost Of Energy (LCOE) could be reduced.

Although, as a core component, Power Take-off (PTO) system accounts for over 20% of total CAPEX, PTO sizing is rarely considered in the studies regarding sizing optimization of WECs [2]. The research focus is still mainly on the buoy sizing, or alternatively called geometry sizing. In general, the PTO size is simply scaled with the buoy scale factor. However, the original PTO size is only optimized for some specific sea states or wave locations. Hence, it is significant to investigate the effects of PTO sizing on the techno-economic performance of WECs. Meanwhile, PTO sizing is expected to interact with buoy size optimization of WECs, and it is interesting to look at the interaction between PTO sizing and buoy sizing.

Our future activities would mainly include: 1) establish a size optimization method of WECs to include both buoy sizing and PTO sizing; 2) investigate the influence of the representation of PTO sizes, in which PTO force constraints, PTO peak power rating and the peak to average power ratio would be considered.

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Modelling wave energy converters for power network dynamics simulation

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The use of renewable energy sources has been shown to provide an effective contribution towards reaching stringent decarbonisation targets. Wave energy is a promising emergent resource which provides huge potential, as it takes advantage of the high energy density of ocean waves. Exploitation of wave energy however presents a challenge due to the oscillations in the extracted power reflecting the unsteady nature of ocean waves. Various forms of wave energy converters (WECs), with distinct mechanisms for absorbing the energy and converting it into electricity, have been proposed.

The unsteady nature of wave power has a direct impact on the reliability of a power network. The effect is exacerbated by the coastal location of WECs, where the networks are generally weak, leading to subsequent power quality issues such as voltage fluctuations and flicker. Proposed solutions in the literature to smoothen the extracted power include the grouping of WECs into clusters, control of power generation and introduction of energy storage systems at the network interface.

It is typical for network operators to assess the impact of integrating additional RES on the network. The assessment sets the motion to devise suitable mitigation measures and serves as basis for revising relevant grid codes. In order to facilitate the process, I propose the development of a simplified WEC dynamic model which can generate time-domain power profiles for a specified input. The model can be driven from actual data or generate synthetic wave data from specified sea states. One approach is to consider a generic model [1], incorporating a number of sub-sections representing the power conversion train. The level of hydrodynamic and power take-off detail can be limited to that necessary for reproduction of the relevant dynamics at the network interface under both normal and faulted conditions. The model can contain suitable ranges of hydrodynamic coefficients which can be selected by the user to represent specific cases. The work aligns with the Electrical Aspects topic of WG3 and would benefit from collaboration with WG1.

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Optimised permanent magnet arrangements for the electrical generators applied in wave energy converters

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

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]. Their global performances are strongly affecting the overall WEC operation and conversion efficiency. Since now, a great variety of electric generator types were proposed and implemented in WECs, as synchronous permanent magnet, transverse flux, switched reluctance, etc., both rotational and direct driven linear ones [2], [3]. Most of them are of synchronous permanent magnet type since these electrical machines are exploiting in a best manner the perpetual magnetic flux available from the permanent magnets [4].

Therefore, the correct sizing and placement of the permanent magnets in these electrical generators are critical and a lot off research effort was concentrated on this topic. My research interests are, and will cover in the near future, identifying new and improved topologies of low speed permanent magnet linear electrical generators. The researches concern the placement of the permanent magnets, selection of their type and the definition of their sizes.

I should like to emphasize that I am opened for new collaborations in this field in the frame of the WECANET project (but also outside it), inclusively for hosting in our laboratories young researcher fellows (Ph.D. students, postdocs, etc.).

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Wave Energy Developments in Norway

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The marine energy research and development in Norway is focused on the sustainable energy systems and offshore resources, where wind and wave energy play an important role. Several projects has been performed or are active on the wave energy converters by Norwegian research and industrial partners. One example is the modeling and control of wave converters performed at Norwegian University of Science and Technology (NTNU). Another example is MegaRoller project coordinated by SINTEF Energy Research, where the focus is to monitor the development of technical specifications, guidelines and standards relevant to the WEC industry, and in particular to the MegaRoller technology.

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A novel Barge Platform Design for Stabilization of Floating Offshore Wind Turbines using Oscillating Water Columns

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Energy harvesting from floating wind and wave converters has been widespread in the recent decade because offshore wind and wave resources are considered as two clean and renewable energies with vast area for deployment.

In order to harness the most energy from Floating Offshore Wind Turbines (FOWT), platform stabilization and vibration reduction on the FOWT are required. In [1], M. Tomás-Rodríguez et *al.* used a Tuned Mass Damper in the nacelle for vibration reduction whilst in [2], an inerter between the tower and the barge is placed to deduct the vibration. J. Jonkman et *al.* presented studies and simulations of a FOWT in [3], where they modeled a 5 MW NREL FOWT fully coupled aero-hydro-servo-elastic of the barge. In [4] F. M'zoughi et *al.* controlled an air valve of an Oscillating Water Column (OWC) in the capture chamber to adjust the airflow speed to harvest the maximum energy from waves.

In this context, we redesign the platform by installing OWCs in order to reduce the platform's pitch and roll as well as the side-to-side and fore-aft tower displacements. In this study, the effect of the OWC operation has great impact on pitch and roll reduction by opening and closing the air valves to change the pressure accordingly. Regular waves and winds from different directions are considered to show the simulation results in different scenarios. The simulation results indicate that the new platform is able to reduce the vibration on the tower.

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Slow Stochastic Motion (SSM) concept used by a WEC based on a floating vessel-buoy

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By analysing techno-economic models of available wave energy converters (WEC) at the east coast of the Adriatic Sea and similar locations with weak wave potentials, conclusion for optimal design is to wide use simple and non-expensive (specific investment – EUR/kW installed) WEC technologies like oscillating water column (OWC) or point absorber buoy but mounted very near to coast infrastructure. A technical and economic challenge of WEC is connection power line to electric grid. The best solution is to decrease length of undersea cable or even more efficient to use air turbine and generator mounted on-shore (coast installation).

To simplify the built-in components in WEC projects, a brand-new idea (SSM – Slow Stochastic Motion) is proposed here by author: each vessel anchored in marinas and ports need to additionally install one of the simple WEC technologies (or several number of WEC depending on the size of the vessel and sea wave conditions) during their stay in harbor so that the vessels themselves become buoys. WEC should be infrastructure harbor equipment and installed by harbor experts and connected on pair of air turbines (income buoy' air turbine and outcome buoy's air turbine), for instance like Wells turbine. Each buoy should be connected with air turbine by two pipes (income air pipe with income air turbine and outcome air pipe with outcome air turbine). Due to non-simultaneously motion of all buoys, vent pipes should be controlled by PLC according to direction of compressed air. SSM concept can be realized in the relationship between the vessel-seabed, the vessel-shore and the vessel-vessel. SSM idea would further increase the safety of anchoring vessels in extremely rough conditions and represent an interesting potential for electricity generation due to the large number of buoys (vessels) despite the fact that the water in ports and marinas is relatively protected from high waves.

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Indirect Matrix Converter based Power Stabilizing in WECs integrated Smart Grid Application

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The fossil resources used in electrical energy production are limited and these limited resources will be insufficient in energy production in the future. Because of this problem, electricity generation from renewable energy has become very important. Wave energy from renewable energy sources has high continuity, durableness and potential in Europe. 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.

Modelling of the WECs and analysis of grid integrated WECs are big deal for real application of WECS connected smart grid. Only WECs modelling is not enough for a smart grid application. Therefore, power electronics components, converters and grids should be modelled very well. Variable output voltage problem for integrations of WECs applications in smart grid is a problem that has been tried to be solved for many years. Using a reliable control system and matrix converters (MC) for WECs can provide a stable output voltage to electrical grid. System block diagram is given in Fig 1 and the electrical power flow is shown in Fig 2.

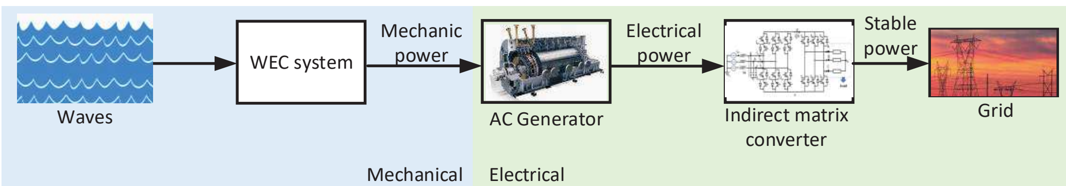

Fig 1. Grid integrated WECs systems block diagram

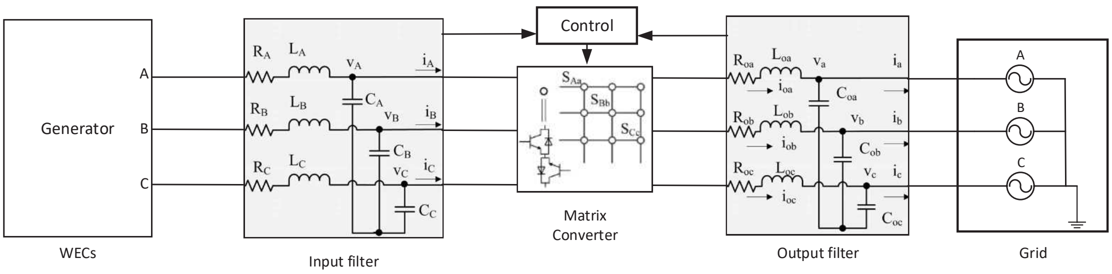

Fig 2. Electrical power flow in WECs integrated power system

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WEC survivability (WG3) – design guidelines and good practices.

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The Centre for Marine Technology and Ocean Engineering (CENTEC) has been dedicated to the development of a concentric system of point floater Wave Energy Converters (WECs) adaptable to floating offshore wind turbine platforms. The long term objective of this concept is to provide favorable conditions for the utilization of bigger power rated wind turbines by using WECs to increase the platform dynamic response to permanent and fast changes in wind speed and direction. The system may work together with the conventional one, where the water is actively distributed throughout the platform ballast tanks. In this case, the utilization of the WECs is expected to overcome the lower dynamic response of the ballast system while the later may be provided time to adjust. Moreover, the harvested wave energy may be used for both systems, while providing energy to the electrical grid.

However, the impact of this concept on the platform and WECs survivability in extreme sea and wind state conditions is unknown, because very few studies have been performed on the survivability of combined floating platforms, and these have a different geometry from the proposed one. Therefore, a review on the literature related to WECs survivability, alone or together with combined platforms, have been performed to know which existing survival modes, design guidelines, experimental campaigns and good practices have been proposed. This review allowed the improvement of the concept by defining a survival strategy, which has been experimentally tested in an ocean basin at MaREI (Ringaskiddy, Cork).

This review has been also our current contribution to the WECANET activities about survivability (WG3, review topics 2.2 – 2.4, 2.6). This assembly is an excellent opportunity to exchange our findings with other researchers, fine tune the WECANET review study and find future collaborations for concept development.

Acknowledgements

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Wave Energy Utilization on the Croatian Coastline and Islands of the Adriatic Sea

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Within WECANet framework/WG3 based on an idea to discover opportunities for WECs implementation on Croatians coastline and islands on Adriatic sea a group of authors from Croatia and Sweden all together with me (Serbia) start to do research of above mentioned issues. A few case studies were developed and analyzed. Among them possible deployment of WECs in smart WEC/PV energy systems or microgrids with or without battery energy storage on Adriatic Sea (applicable to other Mediterranean) coastline and particularly islands.

Energy (electrical and mechanical/hydraulic side), economic and environmental aspects are analyzed. I'm dealing with technology in general, economics, environmental and social aspects.

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Energy Sustainable Communities through Distributed Generation

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The Agenda 2030 defines 17 Sustainable Development Goals (SDGs) that act as a common global framework when pursuing economic development alongside reduced environmental damage and social equality. Achieving sustainable communities is related to one of these goals. In that context, energy communities have been introduced as legal entities that empower citizens to implement community-owned energy projects. These projects are usually implemented to realize a variety of economic, environmental or social goals which can easily be set in the SDG framework. However, there are certain trade-offs that need to be considered throughout the implementation of such projects. The security-affordability-sustainability trilemma is defined in these terms and outlines the synergies and trade-offs between the various goals. For instance, the investment in a low-carbon community project may not always be affordable to all members. On the other hand, an affordable, low-carbon project may have adverse technical impacts. The technical impacts on the energy system can be benchmarked with respect to different indicators, such as the self-consumption, self-sufficiency, loss of load probability, energy export and primary energy consumption. They are used to evaluate the overlap of the supply and demand profiles, as well as the reduction of net energy demand. The temporal mismatch between the supply and demand can be reduced by combining consumers and generators, such as wave converters, with diverse load and generation profiles. However, for energy systems with high shares of renewables, the integration of batteries, smart electric vehicle charging and other flexibility alternatives can also contribute to improving the load matching capabilities of the energy community. Possessing an understanding of the trade-offs between the costs, benefits and environmental impacts that occur as a result of these technologies can be valuable both to the members of the energy community and to policy makers.

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Power Absorption Maximization of an Array of Heaving Wave Energy Converters in front of a Wall by Optimizing the Array's Layout

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Arrays of heaving Wave Energy Converters (WECs) deployed at near-shore locations may be integrated with existing coastal structures, such as vertical (wall-type) breakwaters, facilitating cost reduction. Recent relevant studies (e.g. [1]-[2]) demonstrated that the array's power absorption ability is affected positively by the existence of the leeward vertical barrier; however, this ability depends strongly upon the location of the WECs with respect to the wall. Thus, optimizing the array's layout is a key issue towards the efficient deployment of heaving WECs in front of wall-type coastal structures.

In this context, we develop an Optimization Numerical Process (ONP) to determine the optimum layout of a linear array of heaving WECs in front of a bottom-mounted vertical finite-length wall under irregular waves. The term "optimum" refers to layouts that maximize the yearly power absorbed by the array and satisfy spatial constraints. The ONP consists of: (i) a metocean numerical model for determining the wave matrices at locations of interest, (ii) a frequency-based hydrodynamic model for solving the diffraction/radiation problem of the multi-body arrangement in the presence of the wall and (iii) a Genetic Algorithm, appropriately coupled with the hydrodynamic model in an integrated computational environment, for solving the constraint optimization problem. The ONP is applied for oblate spheroidal WECs and for specific near-shore locations in the Aegean Sea. The corresponding optimized layouts are characterized by non-equally spaced WECs situated at a small distance from the wall.

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Marine Renewable Energy at the Institute of Chemical Engineering – Bulgarian Academy of Sciences

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Marine renewable energy is one of the latest fields of research interest of the Institute of Chemical Engineering at the Bulgarian Academy of Sciences. Despite the low wave energy potential of the Black Sea, energy conversion has its place with solutions appropriate for closed seas with mild conditions. Our analysis showed that most perspective for the Black Sea are wave and current energy conversion and utilization of hydrogen sulfide for production of hydrogen or power. The Black Sea is the largest anoxic basin, where almost 90% of the seawater is anaerobic. Hydrogen sulfide is dissolved in the sea water at a depth below 150 meters, reaching about 20 g dm^{-3} at the sea bottom at 2300 m depth. At present the level of the anaerobic water is rising due to pollution. The research for utilization of the H_2S aims at controlling this process and producing energy. The available methods for hydrogen production from H_2S, at different stage of development, include thermal, thermochemical, electrochemical, photochemical and plasmochemical methods. A research group form our institute suggested a method of electrolysis of hydrogen sulfide for production of hydrogen [1]. A setback was the high energy demand of that process. Another method developed at the institute is to use hydrogen sulfide in a fuel cell, by pumping sea water from adequate depths (e.g. 1000 m) to a rig on the sea surface [2]. A problem for the practical application of this method are the low current and power densities achieved by now. Another challenge is lifting of huge amount of water (over 30 ts^{-1}) from the sea depths (comparable to an Ocean thermal energy conversion plant), which requires a technically feasible and economically liable design of a floating platform.

A progress in the field of wave converters will help for the development of an offshore sulfide power plant by solving the following tasks: to cover the energy demands for hydrogen production; to transfer the available design solutions and calculation methods; to increase the power plant output by harvesting wave energy in combination with other marine energy sources.

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Optimum Layouts of an Array of Heaving Wave Energy Converters in front of a Vertical Wall under Regular Waves

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In the present research, we investigate optimum, in terms of power absorption optimization, layouts of an array of five, semi-immersed, oblate spheroidal heaving Wave Energy Converters (WECs) situated in front of a bottom-mounted vertical wall of finite length under the action of regular waves. The optimum layouts are determined for a given incident wave frequency and incident wave direction and they satisfy spatial constraints related to: (a) the perpendicular distance of the WECs from the wall, (b) the WECs' in-between distances, (c) the length of the wall available for the WECs' placement and (d) symmetry considerations (for perpendicular to the wall waves). The required diffraction/radiation problem is solved in the frequency domain by utilizing the conventional Boundary Integral Equation method, which is numerically realized using WAMIT software (www.wamit.com). For solving the constrained optimization problem, a Genetic Algorithm solver is developed and it is coupled with WAMIT in the MATLAB computational environment. The developed algorithm is validated by comparing its results with the parametric results of Loukogeorgaki et al. [1] for the case of a linear WEC array.

Under the action of perpendicular to the wall waves with frequency equal to the WECs' heave natural frequency, the formation of the array's optimum layout depends upon the length of the wall available for the WECs' placement. When the total available length of the wall is utilized, an "arrow"-shaped optimum layout, situated at a large perpendicular distance from the wall, is formed. However, by exploiting part of the total available length of the wall, a "trapezoidal" optimum layout is realized. Under the action of perpendicular to the wall waves with frequency smaller than the WECs' heave natural frequency, the WECs are arranged as close as possible to the wall along a straight line parallel to the boundary regardless of the wall length utilized for the WECs' placement. Moreover, WECs are grouped into 2-body "clusters". The above optimum layouts satisfy symmetry considerations with respect to the incident wave direction, which enhance the array's power absorption ability compared to the case of a totally random WECs' placement. Finally, the action of oblique incident waves leads to optimum layouts that show a significantly decreased power absorption ability compared to the layouts obtained for perpendicular to the wall waves.

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Finland wave energy technologies

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Government of Finland is supporting households with 4000€, if they are changing oil based heating systems to environmental friendly options like geothermal heating, wind or solar. Wave energy is not an option in Finland, but similar support systems can be taken into consideration at the areas where wave energy is a possibility. Nevertheless, there is no wave energy production in Finnish territorial waters there are two manufacturers situated in Finland.

These two main industry actors have two totally different technologies. AW-Energy Ltd.'s (http://aw-energy.com/) starting already at 1993 when the power in the wave surge is observed by the mariner and diver Rauno Koivusaari during a dive on the Finnish coast. He saw the strong back-and-forth movement of a large hatch in a shipwreck and realized that the power could be harnessed. Ever since development work took place and The First-Of-A-Kind commercial-scale WaveRoller was deployed near Peniche, Portugal. The device began to feed electricity to the Portuguese national grid in November 2019. WaveRoller®, is a submerged wave energy converter based on a hinged panel that is attached to the sea bed in the near shore area. It generates electricity from the movement of the waves (surge phenomenon) and is connected to the electric grid on shore. WaveRoller is certified by classification society Lloyds's Register.

Wello Ltd. (http://wello.eu/) uses the rotational movement of a Penguin device is derived directly from wave motion, and it's captured by the hull shape. History of the company is very similar to AW-Energy as starting from the hobby of the founder Mr. Heikki Paakkinen. Wello Ltd. has from small beginnings in the Finnish countryside to a team of international experts working for a sustainable future. The Penguin has no hydraulics or joints, and all moving components never come into contact with sea water. Both devices can be manufactured by any shipyard and transported to the site.

As COVID-19 is also influencing the technology of WECs and WEC farms due to longer start-up period and certainly hindering exploring possible suitable wave energy production sites there is one new project called SafeWAVE. Wello's Penguin to start a round of continuous 2-year deployment and testing period at the Bay of Biscay. SafeWAVE project will work collaboratively with coastal communities to co-develop and demonstrate a framework for education and public engagement of marine renewable energy. The final element, sea, is slowing down their operations, as new Wello Penguin device got as far as Falmouth from Orkney, before it was deemed by marine specialists that the weather window was not long enough to tow it across the English Channel and Bay of Biscay to Bilbao. Towing operation planned to continue on spring 2021.

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Review of Wave Energy Converters' Design Optimization Methods

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Over the last decades, various types of Wave Energy Converters (WECs) have been proposed. Considering the difference in size, shape and operational principle of the various WECs, the optimum design of a single WEC or a WECs array (including layout optimization) has been widely investigated so far by many researchers. In order to demonstrate the current state-of-the-art in this field and highlight potential existing relevant research gaps, an extended literature review related to WECs' optimization problems has been implemented for single WECs as well as for WECs arrays. This review focused on citing, grouping, categorizing and homogenizing literature data related to: (a) the utilized optimization method, (b) the applied optimization tool, (c) the objective function, the design variables and the constraints taken into account, as well as (d) the consideration or not of specific site conditions in the aforementioned problems. For both single WECs and WECs arrays, data were grouped per device type, while, for each device type the information related to the examined optimization problem was grouped according to the applied optimization method (e.g. analytical, heuristic etc.) and the nature of the objective function. Moreover, a further categorization has been introduced aiming at harmonizing the nature of the design variables (e.g. geometrical, functional etc.) and of the constraints (e.g. geometrical-structural, PTO-related, etc.) taken into account in each optimization problem.

The aforementioned categorization and harmonization contributed to seek answers on the following questions: (a) which device type has been mostly studied so far, (b) which optimization method has been mainly deployed, (c) what percentage of the existing investigations is related to multi-objective optimization problems, (d) what kind of objective functions are mainly considered, (e) what kind of design variables and constraints are mostly taken into account, (f) how many optimization problems are site specific and (g) what percentage of the reviewed literature focuses on the optimum design of the device geometry by taking into account the PTO control.

Within this context, it has been concluded that up to now point absorbers have been extensively considered in optimization problems either as single WECs or as components in WECs arrays, while for the rest WEC devices the relevant studies are quite limited. Furthermore, it has been revealed that design variables and constraints related to functionality issues could be taken more into account in the formation of the optimization problem, especially in the case of WECs arrays. On the other hand, efficiency, constructability- and survivability-related constraints could be further utilized both in the case of single WECs and WECs arrays. With regard to the optimization of single devices, more research efforts could focus on the simultaneous design of the WEC's geometry taking into account the PTO control. Finally, the present literature review has revealed a limited number of studies that deals with a multi-objective optimization problem. Further research efforts could lie along this direction addressing the need to handle simultaneously multiple, conflicting, in some cases, optimization objectives, as exist in the real-world problems.

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Sharing and structuring of cost data for design optimisations

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In order to optimise the design of wave energy converters and converter arrays for different sites and wave climates it is essential to have access to high-quality cost data. Efforts should be made to gather and make such data available in a generic form that allows both developers and researchers to access and use the data in optimisation studies. The quality of the optimisation will not be any better than the quality of the cost data upon which it is based. Examples of relevant data could be direct or derived cost per:

- Mean and peak power capacity
- Machinery stroke
- Horizontal mean and peak mooring force
- Vertical mean and peak mooring tension
- Structural mass of different processed materials
- Ballast mass
- Vessel, on hold and in operation

If the cost data is structured and parameterised purposely and used in combination with design and modelling tools, this would enable precise optimisation of, e.g.

- Hull design
- Machinery design
- Mooring and anchor design
- Sizing of units
- Sizing and layout of arrays
- Maintenance schemes

Many converter designs are currently being tested or about to be so, and a substantial amount of up-to-date cost data can be expected to become available over the next few years. Companies and academia should work together to exploit the information contained in this data for the common good of enhancing the development of the wave energy industry.

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Electrical stability issues of Wave Energy Converters

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Intermittent and unpredictable production from renewable sources imposes new challenges to Transmission System Operators/Distribution System Operators (TSOs)/(DSOs) to keep power system in stable operation mode. Significant participation of renewable sources in a power system jeopardize power production/consumption balance, i.e. power system stability. Probability to lose renewable generation production, part of it or total, is much higher in comparison with production from conventional sources. Consequently, responsible TSOs/DSOs require a study of their behavior in both steady state and transient conditions.

Electrical connection solution for wind offshore and wave energy converters (WEC) are very similar. Produced energy from wind and WEC need to be collected at one point by submarine cables, offshore power transformer station platform, usually. From such platform, submarine cable(s) are required to make connection with onshore grid, at higher voltage level in most cases. An optimal grid integration solution is very case dependent, so each project has to be evaluated individually [1] [2].

In order to mitigate variable production produced in WEC, the interface between grid and WEC is recommended to be AC/DC/AC convertor which enables stable production in various operating circumstances connected either to a strong grid or a microgrid/islanded grid. Controlled AC/DC/AC convertor is capable to respond on various TSOs/DSOs demands imposed to producers, as system frequency support and fault ride through capabilities. These tests can be performed in PSS/E software tool to simulate real operating conditions and estimate required stability capabilities.

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The Novel Concept of OWC Type Floating Wave Energy Converter Device

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The novel concept of dual chamber floating Oscillating Water Column (OWC) system has been introduced for the first time in the Centre for Marine Technology and Ocean Engineering (CENTEC) by Rezanejad and Guedes Soares (2018, 2019). The novel WEC system involves two chambers located in the upstream (fore chamber) and in the downstream (rear chamber) with respect to the incident wave direction. The rear chamber acts similar to a Backward Bent Duct Buoy (BBDB) system, while the design of the fore chamber follows conventional types of OWC systems with the harbour plates (supporting bottom plate). Each of the OWC and BBDB parts has been dedicated to absorb the wave energy within the specific frequency bandwidth ranges. The primary efficiency of the introduced concept has been evaluated based on the numerical and experimental approaches by Rezanejad et al. and Xu et al. (2020). The obtained results have proven that the devised system is capable to harvest the energy of waves in a broad range of frequencies with improved hydrodynamic performance. The indicated characteristics of the introduced device might help to overcome one of the main barriers on the way of the commercial development of WEC systems caused by their poor efficiency.

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Optimization of silicone elastomers for active elements in dielectric elastomer generators (DEGs), including WECs

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Silicones are among the preferred elastomers for applications in DEGs due to their suitable mechanical properties, weather resistance and environmental friendliness. However, silicones have the disadvantage of low dielectric permittivity. Different strategies, from the architecture and chemical modification of the base polydimethylsiloxane (PDMS), to the cross-linking pattern and the use of additions of inorganic or organic powders or polar organic polymers, are approached in our group for optimizing and increasing performance of silicones for such applications, either as dielectrics or electrodes [1]. Thus, in a previous study [2] titanium dioxide nanotubes were used as active fillers in a PDMS matrix resulting in high conversion efficiency of mechanical energy in electrical energy, e.g. 8.84% at 400 V input voltage and 150% balloon-like elongation. Interpenetrating polymer networks (IPNs) represent an interesting strategy for tuning the properties of silicone elastomers due to the possible synergism that may arise between the two networks. One of our ongoing projects (https://silweb.icmpp.ro/index.php) is focusing on adopting the geometry of spider webs by combining two silicone-based networks cross-linked by different pathways aiming to increase the conversion efficiency of polymeric wave energy converters. Other concerns and recent results of ours, which may be of interest to the WECANet scientific community, can be seen on http://greenergy.icmpp.ro/index.html and https://www.icmpp.ro/projects/l6/about.php?id=5 or https://www.smartsil.ro. Based on the team`s expertise in silicones chemistry and processing, we may be able to provide data and to customize silicones according to certain requirements of those who want to model or build DEGs, including WECs.

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BEM analysis of Point-absorber WEC and OWSC over variable bathymetry with application to coastal area in Aegean Sea

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Among many different proposed concepts of WECs, many of them are or will be hopefully deployed in nearshore and coastal areas, where the arbitrary and steep topography of the seabed may impose significant effects on their performance. The Oscillating Wave Surge Converter (OWSC), exploiting the horizontal-surge oscillation by the interaction of a flap with the fluid, attracts a great quota of R&D interest. The Boundary Element Method, enhanced with extra features for the treatment of the hydrodynamic problem and firstly validated against analytical solutions, is the main computational tool used (Magkouris et al., 2020). A parametric study of hydrostatic features of the flap-body and characteristics of Power Take Off (PTO) system is also considered. Results prove that bottom slope and curvature could affect the response and performance of an OSWC, especially for low and moderate wave frequencies. Comparison for an array of OSWCs and Point absorber-type WECs, which were also studied by the same computational tool (Belibassakis et al., 2018; Bonovas et al., 2019), are also presented. In this indicative scenario the area of deployment is in a coastal region in Greece, near the island of Evia, characterized by an increased wave potential, compared with other regions in Aegean Sea. Conclusions from this study indicate that the OSWCs, by exploiting a larger fraction of wave fluid channel and having a larger bandwidth of effective frequencies than point absorbers result in slightly better performance index. Future steps will be guided towards the extension of the computational code in three dimensions for the OSWCs case as well in order to investigate interactions in array layouts. Optimization of WEC layouts in terms of performance and cost will be considered, while more accurate solutions for the responses of a device in a park arrangement and under more realistic wave conditions will demonstrate crucial parameters for their survivability in such harsh environment.

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A framework for wave energy control: The moment domain

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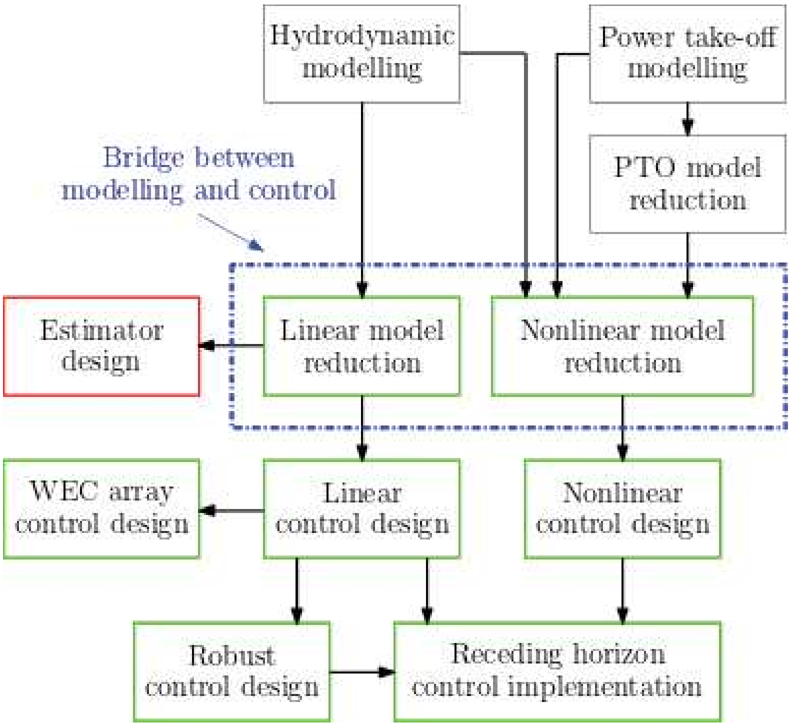

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WEC control strategies for the WECfarm project

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This abstract refers to an ongoing master's thesis at the department of Civil Engineering of Ghent University (Belgium) on control strategies of a wave energy converter which is being prepared for the upcoming WECfarm project. A new experimental campaign within the WECfarm project is planned in a new wave basin; the Coastal & Ocean Basin (COB) in Ostend. WECfarm will deliver a database for validation of new advanced numerical models which are worldwide employed for WEC array modelling. At the time of the 3rd Online WECANet General Assembly (November 2020), dry-testing of the first WEC is occurring.

The working principle of the WEC is the one of a point absorber operating in heave. The power take-off consists of a rack and pinion system in combination with a rotational Permanent-Magnet synchronous motor (PMSM). To control the WEC, a Simulink 'Real Time torque control' model is used. This model is built on a development computer and subsequently loaded on a Speedgoat Performance real-time target machine. In this context, real-time is the capability of the algorithm to execute within a prescribed update rate. The control model on the target machine processes the input signals from the laser sensor, accelerometer and load cells to provide, depending on the control strategy, the torque request as output to the drive.

Within this master thesis, the performance of a single WEC (the so-called "Master WEC") will be evaluated for different control strategies. The baseline strategy will be a passive controller, consisting of a force proportional to the velocity. A literature study will identify possible other advanced strategies. Model Predictive Control (MPC), Latching control, Reactive loading control and Linear Quadratic (LQ) Control are among the possibilities [1], [2]. Although the performance evaluation will be for the single Master WEC, the later extension to an array of five WECs will be taken into account as this is the WEC number that will be used in the WECfarm project. The passive control and the selected advanced control strategies will be implemented in the MATLAB Simulink model.

Firstly, the efficiency of the MATLAB Simulink control model will be evaluated in a dry set-up. Secondly, the passive controller will be evaluated in wave flume tests. Tests in a wave basin will allow to determine the power production for the passive control strategy. If possible, tests with the selected advanced control strategies will be executed to compare the power production relative to the baseline strategy. These consecutive steps will allow us to make recommendations for the control of the arrays of

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up to five WECs, to be experimentally tested at the COB in 2022. This part of the research is situated in the topics of "Working Group 3: Technology of WECs and WEC arrays"

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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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Identifying the optimal selection site for a WEC using the SIWED index in the Aegean Sea.

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Offshore energy farms, both potential wind and ocean technologies, rely on the effects of dominant metocean conditions on energy production and operational characteristics. Particularly, wave energy converters (WEC) have seen a wide variety of innovations capable to harness the vast untapped energy source of the Seas. This wide array of WECs often has varied applicability and power production capabilities, making the selection of a device overwhelming. Increasing the uncertainty in selecting a WEC are the interaction and suitability of the device with local metocean conditions, and the impacts to its long-term reliable operation. The study focuses at the Aegean Sea and presents a comprehensive approach in selecting a WEC, using a novel **Selection Index for Wave Energy Deployments (SIWED)**(Lavidas,2020), which accounts for resource, extreme events, power production capabilities, reducing uncertainties and biases. Subsequently, a selected WEC is optimized by considering an array configuration as affected by wave-WEC interactions, with important elements included such as hydrodynamic interactions and uneven bathymetries that affect the resource. As a case study our approach explores (i) the viability of WECs at milder resources (ii) use of SIWED to select the “optimal” location and (iii) an approach to optimize for the resource and propose a deployment configuration (Loukogeorgaki,2020). The study provides a comprehensive assessment of the “hidden” benefits of wave energy in the Aegean and its methodology is universally replicable. Finally, a discussion and overview on the importance of this interdisciplinary method for wave energy converter deployments is underlined.

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Innovations Support in the Blue Economy through Starting and Small Scale Businesses

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The scope of this abstract is on the business start-up opportunities among students who consider the energy generation based on vibrations transformation, including the wave energy production at harbour piers walls. The team of students from the Burgas Free University (situated in Burgas – the Black Sea Coast) was already promoted through a pre-acceleration programme at Sofia Tech Park in Bulgaria and achieved the prize in a Smart City category of the JA Rising Stars ceremony in June 2020. They had both their active coaches (the author of this material one of them) and people in the business when they developed the business model.

The roles played by innovation-support organizations in the acquisition and diffusion of technological ideas, solutions, and know-how through- out the marine science and technology innovation system. Often the regional innovation-support systems comprises a group of actively co-operating organizations that support the innovativeness of firms, especially SMEs. Such support organizations manifest themselves through different operational contexts (Doloreux, and Melanc, 2009). At the same time the emerging concepts of "Blue Growth" and "Blue Economy" are used across the world to capture this potential and bring these concepts to the forefront of the political agenda. In the international development sphere, the FAO Blue Growth Initiative seeks to reconcile economic growth with improved livelihoods and social equity through sustainable use of aquatic natural resources in capture fisheries and aquaculture, ecosystem services, trade, livelihoods and food systems (Van den Burga, et al, 2019). The European Commission coined the term "Blue Growth" to emphasize the economic potential of the maritime sectors aquaculture, offshore energy, marine biotechnology, seabed mining and tourism.

Based on these understanding and considering that a startup is most often a temporary organization, created with the idea of growing and developing into a large company, and the fact that the creators of technology startups consider that their product will be important for society and will be able to change the world in their field was initiated the experiment with the student start up at BFU oriented towards a solution in Blue economy and specifically the utilization of the wave energy. Here is where the main difference in the business model of the creator of a small business and the founder of the startup comes from. Kinetic energy is energy of motion and everybody possesses it - when it moves, the kinetic energy always has a positive value and the greater the acceleration of the moving body is, the greater numerical value of the kinetic energy gets (Georgieva, Baltov, Daskalova, et al., 2020). And as soon as it is the

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energy of motion, therefore it could be found in every object that moves. In our daily round we are surrounded by it, people who go for a walk or people who ride bicycle around the city. Based on their ideas, a prototype was designed for accumulating the vibrations both from transport vehicles and from waves and transforming them into electricity. The concept is to perform it to isolated parts of the harbours whether it is not efficient to provide an electricity grid and at the same time to store some of the energy in batteries.

Still the company is not registered as it is in application process for the Burgas Municipality start-up fund, but we expect it will be more flexible than older firms because of more flexible business models, will have fewer limitations in terms of technological trajectories based on their lower risk aversion or the knowledge filter (Gimenez-Fernandeza, Sandullia, and Bogers, 2020), will suffer reduced cognitive distance between the existing knowledge base and emerging technologies or fewer constraints in terms of adapting innovation routines and organizational structures. Next months are expected to be crucial both for the business model and for the efficiency of the vibration pad that was designed in the pilot phase.

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Condition forecast on components of hybrid wind-wave systems for lifetime analysis

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Combining wave energy converters (WECs) and offshore wind turbines (OWTs) provides an opportunity to use both offshore energy sources in the same farm. Bottom fixed hybrid wind-wave and floating hybrid wind-wave energy converters are supported by the same foundation system, which can be stated as another significant feature of the combination. A number of countries have already explored their regional potential and tested the performance and environmental impact of hybrid wind-wave converters in laboratory and field studies [1, 2].

By assessing the feasibility, the offshore deployments of hybrid energy systems, especially the components, challenge the analyzers and operating companies [2]. Both operational and extreme lifetime conditions put a high level of stress on farms and their components. Condition monitoring and inspection require a high level of expertise as well as are very time- and cost-intense due to multiple component-based processes. The effects on single components of WECs and OWTs such as oscillating floats, oscillating water columns, mooring system, monopile, jacket foundation have not been investigated in detail.

Condition monitoring supports damage detection and performance forecast, especially in manufacturing. Well-acknowledged methodologies such as failure mode and effects analysis (FMEA) as well as design of experiments can be combined for the determination of components' conditions. In the case of hybrid offshore energy systems, it provides a solution approach to determine causalities between pre-defined conditions and their impacts on single components. The expected results will devise a useful forecast for determining the condition of the hybrid offshore energy systems and their remaining lifetime before failure.

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Renewable energy integration at the port of Valencia's infrastructure

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EU Green Deal strategy, together with other regulatory measures recently came up with the focus on the development of the renewable energies to fulfil with the emissions reduction targets for 2050. Ports may be considered as "energy islands" where large amount of energy is consumed, therefore seaports' energy strategy should rely on the use of renewable energy. Presently, the share of renewable energy used by many of the ports worldwide is negligible. Some initiatives are in process of implementation to produce some of the energy used by the Port of Valencia, one the largest ports in the Mediterranean Basin. Among these initiatives, a photovoltaic plant in an installed capacity of 7 MW is under a tendering process and the assessment studies for the deployment of wind turbines with an estimated installed power of 20 MW are close to being finished. However, this is not enough to become a "zero emissions port" as some of the energy demand would still be covered by fossil fuels. Therefore, we should consider clean alternative energy sources. Other energy sources should be considered to grant the total renewable origin of the energy. Wave and tidal energy are suitable candidates to fill this gap, however, there is very small chance to extract power from the Mediterranean tides consequently it remains wave energy as the most promising one. The power production from solar and wind energy is easy to estimate, being in this particular case around 45 GWh/year and 10 GWh/year might be obtainable from wind turbines and solar photovoltaic panels respectively. On the other hand, the estimated production from a wave energy converter array is, at present, more difficult to estimate as there are several technologies suitable for ports integration depending on the level of the development of the infrastructure. When considering a fully developed shelter infrastructure of a port, a suitable technology might be the oscillating weaving bodies connected to the external port's infrastructure. There are already several pilots working along the Mediterranean Basin such as Gibraltar, Jaffa or Cyprus and the information collected is very valuable to estimate its performance at a place like the port of Valencia. Considering that, and with a typical wave characteristics of Hs between 0.5m and 1m and a Tp between 7s and 8s, a 300 kW array might theoreticaly generate around 2.6 GWh/year, however, this system is fully scalable and bigger arrays might be installed.

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Risk Management of Wind and Wave Energy Resources: Insights from Portfolio Theory

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Wind and wave energy resources are characterized by high levels of stochasticity and seasonal variability. An interesting research question is whether part of the generation variability could be mitigated by combining different energy production sites/technologies in a single portfolio. Such portfolios of interconnected wind/wave farms could provide additional benefits to policy makers and system operators, as they could lead to an improvement in the reliability of the overall power supply with a better control on the occurrence of zero-production events. The key-factor in the capacity allocation decision is to employ heterogeneous resources that can counterbalance power losses of other generation sites when those fail to deliver. The Aegean Sea is an ideal environment for testing such aggregation strategies due to the diversity of meteorological patterns and intense microclimatic effects.

The purpose of this study is to evaluate the benefits of applying portfolio selection techniques to the management of renewable energy sources in the Aegean Sea. Our energy portfolios perform spatial and technological diversification of generation risk, taking advantage of the correlation structure between different locations marked for energy harvesting and/or heterogeneous resources (e.g wind and wave). Principal component analysis sheds further light to the nature of generation risk and the effectiveness of the portfolio strategy, by identifying systematic factors commonly affecting generation in designated Aegean islets.

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Environmental Assessment of Wave Energy Converters (WECs) through Life Cycle Assessment (LCA)

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Need of alternative renewable energy sources to substitute fossil fuels increased the interest to wave energy converters. Wave energy is an emerging technology and various types of new devices are at their development stages. This also brings the need of elucidating the environmental performance of the mentioned technologies before and after their deployments into the marine environment.

LCA is a methodology which provides quantitative data on the environmental performance of products and processes through their entire life cycle. Most of the LCA studies are executed for already developed existing systems. In addition, LCA also can be used for environmental assessment of emerging technologies through their development stages (from lab-scale to industrial scale). Thus, it is also a valuable tool for providing quantitative data related to environmental consequences of wave energy systems both at their design and installation stages (Elginoz & Bas, 2017; Thomson et al., 2019; Paredes et al., 2019, etc) . With this aspect, it might be possible to integrate the environmental performance as a decision factor into R&D phase as well as evaluating the design in comparison with the existing technologies.

In line with WG4 which aims to clarify uncertainties on non-technical aspects (cost, environmental impacts, legal issues, policy, etc.) of wave energy systems, a guide on LCA of WECs that elucidates the important points to consider, problems to be solved and knowledge gaps will be beneficial. It is proposed that a bibliometric analysis will be a good starting point to see the existing level of knowledge and development through time and location. Besides, making effort to develop a systematic database specific to WEC studies in various countries, by firstly focusing on the existing research groups in the Action, might be an advantage of the Action that brings together WEC designers, industry and researchers working on LCA of marine renewable energy systems.

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A new approach to mitigating the investment risk of wind and wave power projects

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Wind and wave power projects are associated with considerable investment risk emerging from the stochasticity of the resource. Even in feed-in-tariff renumeration systems, in which investors enjoy a fixed selling price for each generated MWh, large fluctuations in the generation volume distort the revenue profile and increase the levels of project risk. Although wind farm production uncertainty has been thoroughly studied on different temporal and spatial scales, the volumetric risk of wave power projects is still poorly understood. This adds to the slow uptake of these projects by the investment community.

In this study, we make a systematic assessment of volumetric risk for an array of uninhabited islets in the Aegean Sea. These sites have been marked for wind and wave power generation, as besides the richness of recourse they also meet environmental regulations and grid proximity criteria. We go beyond the assessment of volumetric risk with proposals for specially-designed financial instruments (*aka* wind power derivatives) that could improve the risk profile of wind/wave power projects by providing monetary compensation to the investor in periods of underproduction. The effectiveness of these contracts is demonstrated on simulated meteorological data and implied generation capacities assuming state-of-the-art wind and wave generation technologies.

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Current status and future developments for the European legal framework of the wave energy sector

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Within the wide variety of marine renewable energy resources, wave energy appears as a promising, virtually untapped, alternative, with multitude of sites around the world with the potential of being exploited. However, wave energy exploitation is far from being commercially feasible. Among the obstacles faced by the sector, the complex legal framework that applies to wave energy projects stands out. In this context, the objective of this communication is to assess the main aspects of the European legal framework applicable to wave energy exploitation, and when necessary, discus and propose corrective measures for further development of the sector.

In general, wave energy projects are subject to complex policy frameworks, which involve country-specific regulatory frameworks for sea-space occupation, grid connection, tariff support schemes, inland works, maritime safety, and Environmental Impact Assessment (EIA). In this context, the adoption of Marine Spatial Planning (MSP), may benefit significantly the development of the wave energy sector, by identifying priority areas for its exploitation and, establishing clear preference criteria with other maritime users. Another limiting factor is the complex licensing procedure, which may take a significant amount of time (up to 2 years) since, involves several consents and granting authorities. Consequently, streamlining licensing procedures, ideally adopting, one-shop-stop approach (e.g. Scotland), becomes essential for the future development of the sector. Finally, the adoption of sectoral plans (i.e., including actions for port, grid, technology, and supply chain development as well as financial support for promoters), is essential to attract new developers and investors to. In this sense, countries like Portugal, Ireland and especially the UK are examples of success.

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Enhancing Wave Energy's Potential within a Hybrid Energy System

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Working Group 4: Explore market potential of wave energy in current (and future) mix of renewables, suggesting niche market/ applications where WECs can contribute

The share of renewables in the energy mix is expected to keep increasing significantly. Currently, wind and solar are the resources predominantly exploited, although research shows that wave energy's potential is significantly larger (energy density of 2-3, 0.4-0.6 and 0.1-0.2 kW/m^2 for wave, wind and solar respectively) [1]. However, despite considerable effort and investment, wave energy devices have not reached technological maturity [2]–[6].

Within the context of hybrid systems, wave energy devices could reach maturity and deployability faster, through synergy with other renewable technologies as well as on-site storage. Such hybrid renewable energy systems, where on-site storage can balance out resource intermittency [7], [8], can yield decreased investment and operation costs by co-locating energy generation and storage [9]. Furthermore, adaptability on different timescales to optimally generate and deliver electricity can be considered in hybrid systems: with precise control strategies the system can both optimize the energy extraction and respond to price fluctuation to maximise revenues. This hybrid technology will enable for large-scale deployment of highly interconnected wave energy devices with a guaranteed stable production of electricity that balances supply and demand in a cost effective way.

Offshore renewable power plant projects are characterised by location-dependent parameters such as costs, resources, and function within the energy market; thus, for each situation and location a tailored solution is necessary. To highlight the market potential of wave energy and hybrid systems, a new metric should be introduced that considers the parameters mentioned above and the time in which the energy is provided, as price fluctuations considerably alter the revenues to be expected and the actual value of an energy generation device. Currently, most financial decisions are made considering well-known metrics such as the LCOE [10], [11]; however, these give inaccurate or incomplete assessments as they neglect crucial beneficial aspects of innovative renewable energy systems. A new metric is needed to clearly show investors the benefits and market potential of hybrid devices including wave, wind and storage.

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Hybrid wind-wave energy resource assessment in a climate change context

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Europe's decarbonization plan to achieve the net-zero greenhouse gas emission target relies heavily on an offshore renewable energy strategy through its Strategic Energy Technology (SET) plan [1]. Hybrid wind-wave farms can reduce installation and maintenance costs and increase the availability of a location. The combined resource exploration requires to find the most suitable locations for wind and wave energy devices (WEC), taking into account not only the durability of the devices and current climate conditions, but also the effects of climate change in the future. Assessing future resources is only possible by means of numerical models and the adequate model inputs from global climate models, which allows a high spatial and temporal resolution discretization. However, to assess the feasibility of operating a hybrid wind-wave farm, it is necessary to take into account not only wave and wind resources for the near future but also environmental conditions and cost factors [2]. This assessment should include more than the physical point of view of the resource, by complementing with the technical features of different devices, legal, and environmental constraints.

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Wave energy converters standards as an easy way to go from prototype to implementation

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The introduction of appropriate standards to improve the implementation of proposed technologies for obtaining energy from sea waves 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**.

Two-thirds of the Earth's surface is covered by seas and oceans. It is estimated that conversion of kinetic energy of sea waves into electric energy can be very efficient. For example, the use of ocean wave energy in the US Coast of North America could generate around 20 times more electricity than using wind farms in this area. The energy resources of the sea in the regions off the coast of Great Britain could be viewed similarly. Wave energy is one of a few sources of renewable energy that is less sensitive to the rapidly changing environmental and climate factors. Unfortunately, so far the technology of obtaining electricity from sea waves, unlike traditional hydropower, has rarely gone beyond the phase of experiments. The reasons for this can be, among others, due to the absence of standards that could significantly improve the implementation of the proposed technologies. For this type of investment, implementation is a complex business process, since it requires the involvement of large interdisciplinary teams of specialists, including scientists developing the theoretical foundations of the production process and designers. Improving technology implementations is also an element of a state policy. Therefore, in order to be able to use wave energy more effectively, it is worth improving this process. Standards or procedures can become powerful tools that can help overcome the chaos, speed up the process of technology implementation, and help manage costs.

As the current literature shows, the most important element in the process of implementing wave power plant projects are high investment outlays for research and a long process of conducting preliminary economic and technological analyzes. The introduction of appropriate norms and standards applied to the projects of wave power plants will significantly reduce the costs of implementation, facilitate access to processes related to the implementation of this type of investment and indicate economic, social and ecological benefits. It will also allow to develop suitable methods for avoiding conflicts related to environment protection, while predisposing locations related to the right surroundings and climate.

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Diversification of the WEC technology markets attracting new sources of financing

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Working Group 4: Impacts and economics of wave energy and how they affect decision- and policy-making **Subgroup 3:** Identification of innovation and financing potential, Life Cycle Analysis (LCA), to devise a helpful metric for WECs convergence

Almost 50 WECs technology solutions can be identified. Prototype installations are at different levels of technical and business advancement [1, 2]. The subject of key analyses is to assess the potential for full implementation of the technology on energy market. In this context, finding financing for this type of implementation projects is an extremely demanding task. In terms of investment evaluation, these are very capital-intensive undertakings and are burdened with a high level of risk resulting from technological and economic conditions, i.e. high agility and indeterminacy. Such investment risks tend to deter small and medium-sized private investors and therefore WECs can be financed by large private consortia or public funds. According to the author, however, there is a chance to separate certain segments of the WEC technology that could be of interest to smaller players on the energy market. This applies to coastal waters with lower energy potential and, at the same time, lower energy demand, e.g. installations supplying navigation signs or off-shore platforms. Such defined WEC market has a good chance of attracting smaller ventures and local investors. The key decision-making factor for the majority of small and medium-sized investment funds that could be interested in WEC technologies is their readiness to commercialization, which can be measured by IRLs (Investment Readiness Levels). This scale was created by Steve Blank following NASA's approach to TRLs (Technology Readiness Levels) [3].

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Wave Energy and Existing Breakwaters: How to select a good candidate ?

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Previous studies on wave energy resource assessments for Turkey showed that there is a potential, but it is limited. The selection of WEC type and feasibility of offshore WECs could be challenging due wave climate (low energy with extreme events). Additionally, many of the possible locations are either away from the shoreline or an urban area or very close to other stakeholders using the area. On the other hand, there are many coastal structures along the coast to provide shelter as ports, marinas or fisheries or as coastal protection such as seawalls, groins, etc. There are also new projects where breakwaters or similar coastal structures are being designed. Therefore, for Turkey, WEC devices integrated with coastal structures could be the way to attract more interest into wave energy either for new projects or as modification of existing structures. Although most studies focus on WECs combined with vertical wall type structures, majority of coastal structures in Turkey are rubble mound. However, those located along high energy coasts such as Black Sea or Mediterranean are actually large structures which could provide enough surface area to be modified for the implementation of overtopping devices or OWCs. However, an exchange of know-how on how to assess and design such integration as well as feasibility for both new and existing structures is required so that relevant stakeholders such as the port authorities, Ministry of Energy and Natural Resources and private owners of such structures could be informed. Turkey also could provide a variety of wave climate test locations to assess the performance of such implementations. Within the working group or WECANet, it could be possible to develop a joint paper or project that provides a guideline or best of practices type of document that presents this option (use of rubble mound structures) and how to simply assess the suitability of an existing structure considering limitations on wave climate, cross sectional design of the structure, construction techniques, etc.

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Wave Energy Studies and Strategic Perspectives in Latvia

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Renewable energy has important place within policies of the sustainable development. National Renewable Energy Action Plans (NREAPs) are roadmaps to follow for each and every new renewable energy technology. EU Directives recommend specific actions to be taken by the public and private sectors in form of legal obligations, which require implement policies and support measures aiming to increase use of renewable energy sources at national, regional and local levels. Wave energy is a renewable source of the energy which can be used with certain limitations in open sea environment closer to the coastline from practical, physical as well as legal reasons.

Sustainable action plan and practical work can be outlined and this concept in future might fulfil this idea in reality. So far in Latvia research has been done in theoretical and mathematical assessment levels as well as measurement according newly established methodologies has been performed. One of methods is Projection Method for the Baseline Waves of Energy Directions. Calculations have been performed using the data on wave parameters over the five years and more calculations done for modelling and economic valuation. Wave energy potential in the Gulf of Riga and open coastline of the Baltic Sea was done. The wave energy amount was assessed for Latvia around 6-7 TWh/yr and according distribution calculation method it was concluded that Gulf of Riga has 3 times less potential than the Baltic open shelf zone, at least 90% of wave energy comes from main wind direction (SW-W and NW). Flow utilization factor of 0.18 is needed if economic payback in 26 years is expected. Further in references is given list regards of wave energy calculations, practical measurements and economic assessments.

Latvia has no huge energetic resources therefore wave resources and possible use of those are of yet unexplored strategic interest. However support from the government in initial stage might be important (tax reduction, legal adjustments at municipal and State levels, infrastructure help etc.). The future of wave energy use for energy production is highly dependant of cooperation among stakeholders e.g. energy companies, NGO's, municipalities, governments, energy users. Local municipalities such as Liepaja and Ventspils near open Baltic Sea coastline already have expressed interest to expand the potential of energy transition including to acknowledge wave energy perspectives.

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Renewable Energy and Income Inequality: the case of wave energy

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The central theme of this study is the impact of investments in renewable energy projects, in the case of wave farms, on income inequality. Indeed, the motivation of this study is driven by the sharp upsurge in the energy costs in emerging countries, due to high demand for energy, that widens the gap between different income level groups. This raises the question of whether the energy costs, and thus income inequality, can be reduced by further investments in renewable energy projects such as wave farms. Does the distribution of income increase or decrease in the course of renewable energy investment projects?

The economic development of many countries attribute to their transition towards industry, such as manufacturing and service, undertakings that require large energy inputs. Indeed, the rapid economic growth of many emerging countries in last few years, such as China and India, has triggered an upsurge in the energy demand, with global energy consumption projected to increase by 28% between 2015 and 2040 (US EIA, 2020). In that way, the demand for energy has increased its principal contribution to economic growth worldwide, and historically, with world's heavy dependence on fossil fuels, an increase in CO2 emissions in unavoidable (UN DESA, 2019). Thus, the main objectives of governments have to pursue policies and alternative energy sources that strive to urgently replace the current energy sources, such as oil, gas, and coal. The global wave and tidal energy market provides a potential solution to this issue.

The global wave and tidal energy market is expected to increase by a 42.5% CAGR by 2025 (Grand View Research, 2018), which exceeds the projection for global energy consumption demand almost double. With persistency of these trends, the wave and tidal energy sector has potential to reduce dependency on fossil fuels, increasing investments, and sustenance local households. Indeed, the wave and tidal energy projects can lead to job creations that have immediate impact on the regional unemployment in these areas and, hence, conduce to an improvement in economic welfare through higher real GDP, an improvement in literacy skills, better infrastructure and reduce poverty. Another important policy implication of this study is whether investments in wave and tidal energy projects can reduce regional income inequality in poor areas by diminishing the share of energy spending from the total household expenditure. Last but not least, government investments in wave energy projects can make electricity

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more accessible for low-income households in less developed regions. This action will eventually alleviate the income inequality between different countries and regions.

The results obtained from the proposed study aim to exhibit the economic impacts of government investments in wave and tidal energy in less developed regions and whether such investments can benefit local households in these areas by reducing the income inequality gap with the other more developed regions.

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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Continued development of a specific metric to assess the potential of wave energy technologies

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Levelized cost of energy (LCOE) is the standard and ultimate measure of cost-performance (competitiveness) for an energy generating technology. But LCOE is difficult to estimate accurately for nascent technologies with little operational experience and large uncertainties in costs. For this reason, the Technological Performance Level (TPL) was developed as a reduced cost-performance metrics that can account for the main cost drivers at a utility farm scale. This metric provide some measures of the investment potential of the technology, and attempt to facilitate a practical approach to update and improve performance until operational experience can narrow uncertainty gaps.

The TPL assessment method has been initiated about ten years ago by Jochem Weber to help developers implementing the right development path (Weber, 2012). Since then, the original TPL assessment methodology and tool has undergone several reviews and improvements through economic wave farm life-cycle assessment and a complete stakeholder analysis. The TPL is designed to be an assessment of the suitability of the technical solution for satisfaction of the stakeholders' needs (Babarit, 2017).

The Marine Energy Alliance (MEA) project aims at progressing the combined technical and commercial maturity level of early-stage (TRL 3 – 4) European marine energy technology companies by delivering a suite of bespoke integrated technical and commercial services. Through this project, the LHEEA lab will perform the TPL assessment of several wave energy converter technologies, including KNSwing, NoviOcean, and SWEL. In addition of providing third party assessment of the technologies and a roadmap for the developers, this work will enable to further refine the TPL assessment method in close collaboration with the Marine Energy Alliance partners, and the National Renewable Energy Laboratory (US).

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Wave energy integration feasibility in the EU Outer Regions

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In a framework of increasing energy demand, small islands face demanding energetic challenges due to its isolation from the continental electrical networks and strong dependence on imported fuel. Often, these islands have better renewable energy resources than the continental mainland, but they are not being used to their full extent due to technical, economic and legislative barriers. Such is the case of the European Outer Regions (OR), formed by the Azores, Madeira, the Canary Islands Guadeloupe, French Guiana, Martinique, Mayotte, Reunion, and Saint-Martin. Most efforts in small islands to date had a special focus on the integration of solar photovoltaic and onshore wind energy. However, given the vast surrounding ocean, strategies should also be driven towards the exploration of wave energy.

Detailed studies should be developed to demonstrate the feasibility of wave energy integration on the OR electric markets. Some critical steps must be followed: firstly, exhaustive analyses of each regional electric market and the capacity of the electric network and the available storage capacity are needed. This would give insights on the wave energy penetration opportunities and help on the dimensioning tasks of a potential wave farm. Secondly, the legal and environmental framework needs to be put under inquiry to understand potential barriers and put forward alternatives or solutions. Thirdly, spatial surveys are required to comprehend the marine space availability. Studies aiming at calculate the spatial LCOE of potential wave energy exploration facilities is also mandatory in a fourth step in order to optimize its economic performance. In the last two steps, Geographical Information Systems can play an important role. Finally, specialized local human resources should be reinforced and private or public funding opportunities need to be spotted.

The OR should thus be seen by governments, investors and policy makers as good opportunities for the on-site development of innovative wave energy conversion systems that would lead the transition towards islands self-sustainability, becoming lighthouse projects for other islands and all over the world.

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A stakeholder-based decision support system to manage wave energy farms

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The purpose of this study will be to examine the current level of stakeholder involvement during the wave farm project planning process. Stakeholders often provide the needed resources and have the ability to control the interaction and resource flows in the network. They also ultimately have a strong impact on an organization's or enterprises' survival, and therefore appropriate management and involvement of key stakeholders should be an important part of any project management plan.

A series of literature reviews will be conducted to identify and categorize significant phases involved in the development and consent of a wave energy farm. For data collection, a questionnaire survey will be designed and distributed among the main stakeholders (companies, regulatory bodies, environmental organizations, etc.) who will be involved in the wave energy sector in the European Union.

The results of the analysis will provide the engagement levels of the stakeholder groups as well as the input data that will be involved in the wave farms planning process. Moreover, the result of surveys will be conducted to establish the basis for decision improvement related to the proposed model for wave farms site selection [1,2].

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Abstracts for WECANet Short Term Scientific Missions

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The Dynamic Mesh Method in CFD Simulations of Flap-type Wave Energy Converters

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In this research, a Computational Fluid Dynamics (CFD) analysis is conducted in order to simulate the free-decay motion of a flap-type Wave Energy Converter (WEC) and, thus, quantifying viscous damping effects. The numerical model was set up in OpenFOAM, considering a rectangular flap and an elliptical flap similar to the one proposed in [1]. Within the context of COST Action CA17105, a Short Scientific Mission (STSM) was granted to the first author of this abstract for implementing the numerical set up of the CFD model.

The examined flap configurations are fully-submerged and their initial position is defined by applying an initial rotation to the flap. Several tests have been performed with different angles of release. Since the examined flap is rotating about a fixed axis, the mesh has to be adapted at every time step. Accordingly, the dynamic mesh method is selected for the CFD simulations along with the 'interDyMFoam' solver. This solver utilizes a Volume-Of-Fluid (VOF) phase-fraction based interface capturing approach and it can apply adaptive re-meshing for addressing the required mesh motion. The rotation of the flap is specified as a combination of constrains in the 'sixDoFRigidBodyMotion' library of the solver. Since the dynamic mesh is a complex process in CFD modelling, a series of trial simulations was implemented to address correctly the physical problem and achieve the required motion of the mesh. The results of this research will be further utilized for enhancing the numerical modelling of the system proposed in [1] and for optimizing its design.

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Technical Assessment of the Black Sea Wave Power

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The activities proposed in the present Short Term Scientific Mission (STSM) are focused on the Black Sea environment, being related to the WG1 (Wave Energy Resources). According to the recent studies, was highlighted the fact that the western part of this basin is defined by more consistent wave resources, that are expected to increase in the near future as the climate changes will become more visible. Therefore, Romania and Turkey are very active in this field, especially in the implementation of regional wave models that can replicate very accurately the local wave conditions.

Motivated by this aspect and by the fact that at that moment in the two mentioned countries were in progress some research projects [1,2] aiming to identify the theoretical performances of some state-of-the-art wave energy converters, the present proposal was considered to be opportune. The proposed work plan was divided in two distinct parts defined by the following objectives, namely: A) Improve the knowledge's regarding the implementation of the SWAN wave model for the Black Sea area; B) Performance assessment of some WECs operating in the western part of the Black Sea.

At the end of the proposed STSM, were identified some similar research interests in terms of the wave energy, that can be used as a framework for a joint project involving the participants from Turkey and Romania.

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Wave Energy Converter Power-take-off System Scaling and Physical Model Testing

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Absorbing power from ocean waves for producing a usable form of energy represents an attractive challenge, which for the most concerns the development and integration, in a wave energy device, of a reliable, efficient and cost-effective power-take-off (PTO) mechanism. During the various stages of progress, for saving time and economic resources, it is convenient to carry out experimental testing that, opportunely, take into account the realistic behaviour of the PTO mechanism at a small scale. To successfully replicate and assess the PTO, good practices need to be implemented aiming to correctly scale and evaluate the PTO mechanism and its behaviour. Our work aimed to explore and propose solutions that can be applied for reproducing and assessing the PTO during experimental studies, namely experimental set-ups' enhancements, calibration practices and error estimation methods. A series of recommendations on how to practically organize and carry out experiments was identified and three case studies were briefly covered. It was found that, despite specific options, which can be strictly technology-dependent, various recommendations could be universally applicable. Find more information at: https://doi.org/10.3390/jmse8090632 [1].

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Scale model tests for a benchmark laboratory-scale model of an Overtopping Device (OD)

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A benchmark laboratory-scale model of an Overtopping Device (OD) WEC (see fig. 1) is built and tested in the LABIMA Wave-Current Flume in order to enlarge the Data Base in the field of wave energy. The database will contribute the reference database for benchmarking numerical models.

In this manner, the concept of a Stilling Wave Basin at the top of a coastal protection structure (dike, seawall, etc.) which is becoming popular is considered as an OD. The basin of the SWB is considered as the reservoir of an Overtopping Device (OD) WEC. As a first step, 2D physical model tests are done for Benchmarking tests to investigate the governing physical processes of the OD WECs and to calibrate and validate numerical models. The experiments were performed in the Wave-Current flume of the Maritime Engineering Laboratory (LABIMA) at Florence University (abbreviated as 'LABIMA-WCF') in Italy. The scale model consists of three main parts: the simple caisson, rubble-mound amour protection and superstructure parts. The Froude model scale was set as 1:36 after considering possible water depth in the flume and wavemaker capacity to ensure the correct reproduction of all wave processes. Based on the combination of the parameters related to the Mediterranean sea state conditions, 54 different combinations of the SWB models on the armored caisson are considered. In addition, to analyse the SWB effect, three different armored caisson models which have the same crest height ranges are also considered for comparison of the results.

The overtopped water was collected over a specific crest width (0.2 m) that drained into a tank down a chute. The mean wave overtopping discharge q (m^3⁄s per m width) is calculated based on the WG's result. The difference between the amounts of overtopping discharges from the model with and without SWB are related to the water which will run the turbine of OD WEC.

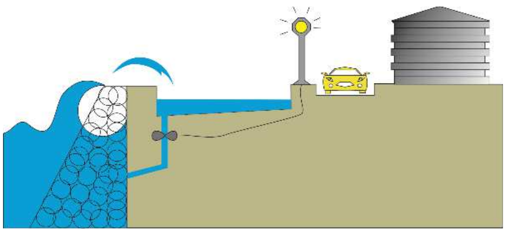

Figure 1: Sketch of the model tests

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Large Scale Experiments for OWC Type WEC

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Small scale physical model experiments are commonly used tools to develop and assess the effectiveness of a Wave Energy Converter (WEC). However, high scale-effects have been recognized concerning air compressibility in small scale experiments on the Oscillating Water Column (OWC) type WEC. It has already been proven that the capture width is overestimated in small scale experiments. The purpose of STSM has been to contribute to an ongoing research project headed by LABIMA-UNIFI and supported by MARINET2-TN action that granted access to FZK center in Hannover. The objective of this project is to collect good quality measurements of fluid dynamics phenomenon taking place at an OWC type WEC, under different combinations of wave height and wave period.

A large-scale model of a conventional OWC type WEC was 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. The OWC caisson model with a 2.5m height was placed with the front face 96m from the wave generator. The model covers three chambers: left, right, and the center. Inside the OWC caisson, there were two wave gauges at the left and the right chambers. Moreover, to control the air flows in and out of the caissons, a hotwire anemometer was used to measure airflow velocity inside the fitted duct. There were also four pressure transducers to measure air and water-induced pressures both at the left and the right chambers. The tests were run at a water level of +4.5m (above flume floor).

During testing, the followings were measured:
- water surface elevation (4 on the paddle, 4 in the middle of the flume and 1 across the OWC model)
- air velocities in the air duct at the central chamber;
- air and water-induced pressures at the left and the right chambers;
- water levels within the left and the right chambers.

34 Tests were conducted totally including regular, irregular and solitary wave cases. Videos and pictures were taken during the experiment. The use of the FZK Large Wave Flume allowed to model OWC type WEC at a large-scale and thus ensured accurate results unaffected by scale-effects. Large scale experimental results will be used to verify the numerical model results based on laboratory measurements in future studies.

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Control and Forecasting Strategies for a Wave Energy Converter based on the Roll Oscillations of Multipurpose Offshore Floating Platforms

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Wave energy converter performance can be greatly improved through the introduction of control systems. Through manipulation of PTO characteristics, such as torque, it is feasible to maximize the captured power whilst ensuring that the physical constraints of the WEC device (*e.g.*, end-stops and maximum displacements/forces) are not exceeded. However, there are considerable challenges related to accurate WEC representation, namely due to non-linearities, as well as finding suitable optimal/sub-optimal control solutions. One key topic to be addressed is complexity reduction, which can be achieved if certain elements of the control problem can be avoided. An important example is that of excitation force estimation and forecasting, commonly adjusted in order to maximize WEC performance through phase tuning with the velocity of the device [1].

The Short-Term Scientific Mission that involved the authors of this abstract prompted the prospect of applying control strategies and systems to the E-Motions WEC concept [2]. This unique device converts wave energy into usable electricity through wave (and/or wind) induced roll oscillations, which drive the translation of a PTO along an enclosing superstructure. As such, the core electromechanical components are protected from the sea environment. Moreover, the E-Motions' simple design makes it versatile and adaptable to a myriad of different floating platforms. However, geometrical optimization can also be applied in order to maximize the energy conversion performance of the E-Motions, which should consider the introduction of control strategies from early on [3]. During the STSM, the candidate came in contact with the latest control procedures applied to wave energy conversion, gaining invaluable insight. Moreover, it was found that the E-Motions' PTO likely does not require knowledge of the excitation force on the floating platform for the control problem to be solved, but rather knowledge on the acting forces on the PTO itself (gravity, friction, damping and inertia). Complementary data, such as accelerations and motions, should be measureable and allow real-time control strategies to be implemented, a hypothesis to be tested through a physical modelling approach in the near-future, during an upcoming STSM.

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A decision support system to implement wave energy farms

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The implementation of wave energy converters (WECs) in the EU is barely developed yet and requires more active research. The main barriers for the deployment of the wave energy industry in the region are the lack of political, legislative and regulatory support, low prices for electricity and heat generated from fossil fuels, lack of information for decision-makers as well as the preference for centralized energy supply schemes. These barriers are contributing to the inadequate investment for the implementation of new RES facilities.

Being Europe, a continent highly constituted by coastal countries, efforts should be focused on taking advantage of the marine resource and lead the strategies towards different ways of marine energy. Especial attention should also be put on small insular states. Islands have vast ocean resources at their disposal in comparison with their landmass and are distant from the big continental energy networks; thus, they constitute excellent opportunities for boosting marine energy exploration. This would help to reduce energy dependence and guarantee competitiveness, employment, and quality of life.

Consequently, more attention needs to be put now into providing policy-makers and investors with meaningful information about current technical, spatial and economic constraints of wave energy exploration and its possible contributions to the different nation's energy systems.

In the proposed research, different regions across the European coasts (Baltic Sea, North Sea, Atlantic Ocean, and the Mediterranean Sea) will be examined to identify the most suitable areas for the potential exploration of wave energy. For this purpose, a multi-criteria (MC) methodology will be implemented based on Geographic Information Systems (GIS). This methodology allows the combined assessment of the wave resource, together with technical requirements of WECs, economic cost, environmental impacts, inland energy demand and different spatial and socio-legislative constraints in a continuous space (see Figure 1). Further, resulting in suitable sitting alternatives will be ranked in terms of adequation for the sitting of a wave energy farm through a Multi-criteria decision method (MCDM).

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To include the energy demand and economic feasibility as ponderable factors in the MC and MCDM analyses, previous in-depth analysis is required for these factors. Moreover, the current energetic framework in the different EU inland territories is characterized in order to justify the relevance of implementing wave farms as new sources of renewable energy. On the other hand, the ranking of WECs by location is calculated to trough an equation that combines techno-economic parameters. This equation provides information about where the wave energy converters would deliver power at or below a given competitive cost. In this way, the best WEC could be identified for each location previously selected.

The study will be carried out for different case scenarios considering different kinds of WEC technologies. The results of this research constitute a prerequisite at early-stage research towards the installation of offshore wave farms across the European marine territory.

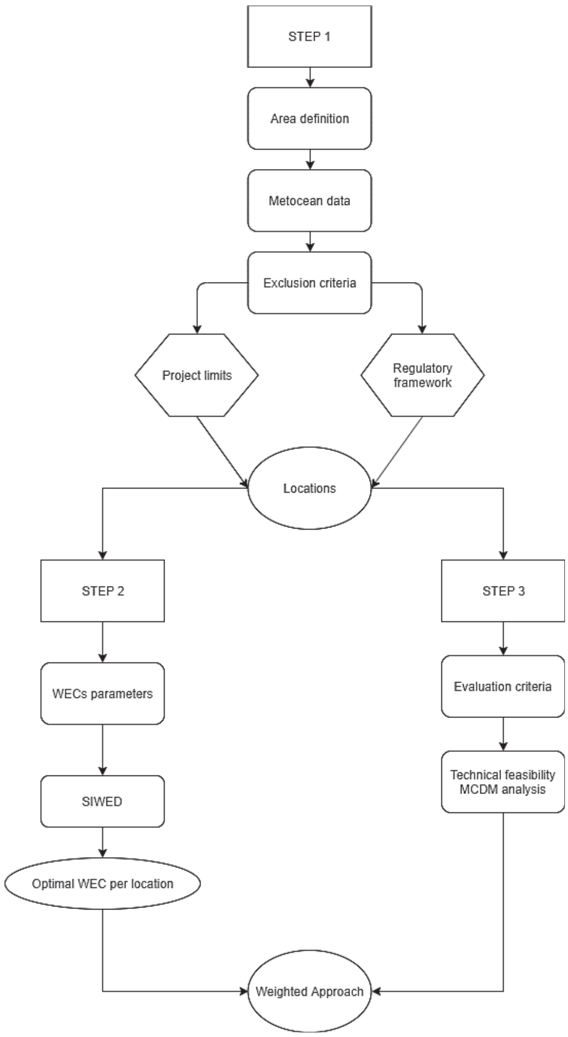

Figure 1. Methodology flowchart.

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