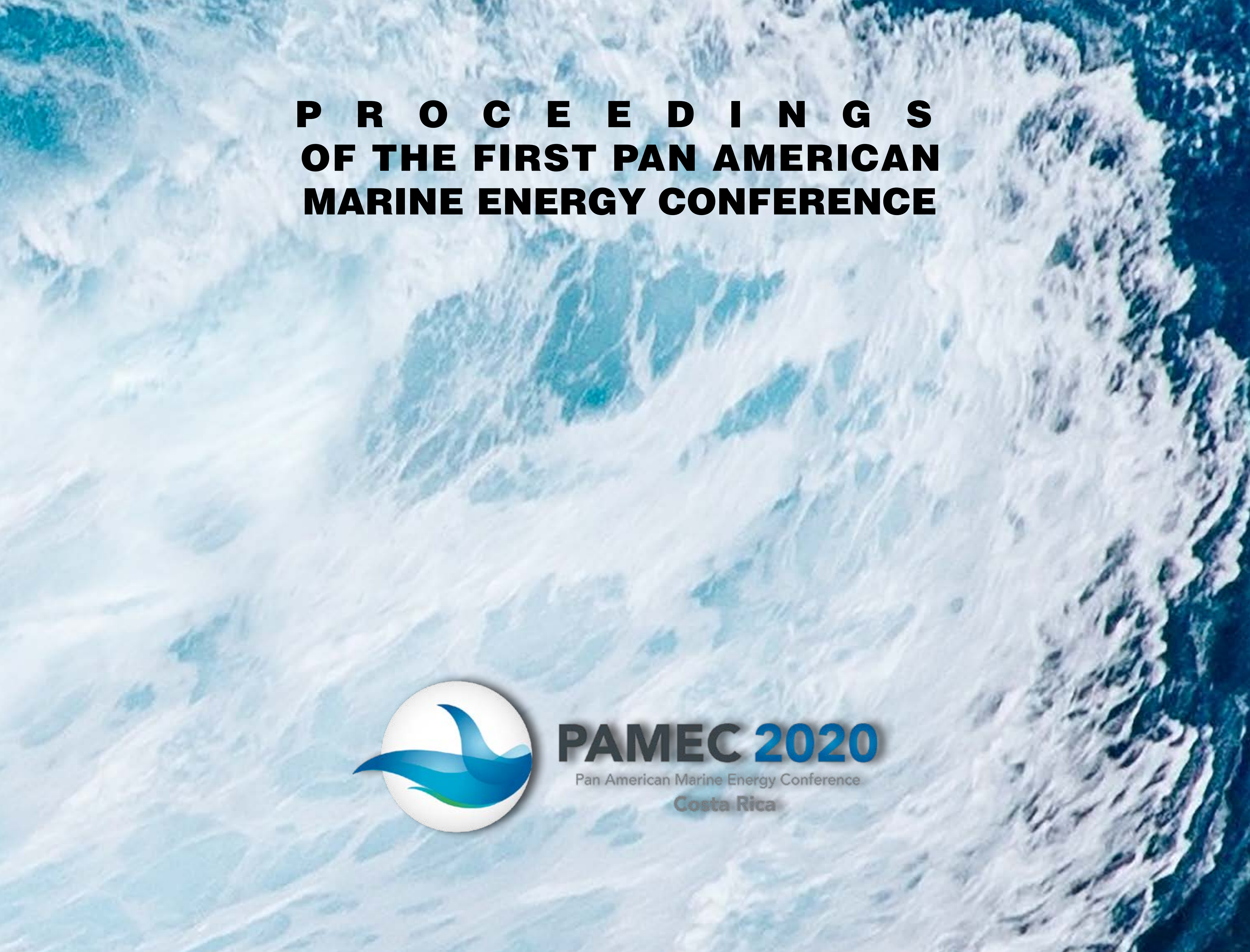
PAN AMERICAN MARINE ENERGY CONFERENCE PAMEC 2020

Book of abstracts

Edited by Dr. José Rodrigo Rojas M and Dr. Carlos Meza

PAMEC 2020
Pan American Marine Energy Conference
Costa Rica

PROCEEDINGS
OF THE FIRST PAN AMERICAN MARINE ENERGY CONFERENCE



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Contenido: Este libro incluye los aportes presentados en la Primera Conferencia Panamericana de Energía Marina que se desarrolló en San José Costa Rica, del 26 al 28 de enero de 2020. PAMEC 2020 tiene como objetivo fomentar el desarrollo de energías renovables marinas mediante la colaboración entre investigadores, desarrolladores y proveedores de América y otros continentes.

1. ENERGÍA MARINA 2. COSTA RICA 3. INVESTIGACIÓN 4. ENERGÍAS RENOVABLES 5. COOPERACIÓN INTERNACIONAL 6. INNOVACIÓN 7. NUEVAS TECNOLOGÍAS 8. LIBRO DIGITAL

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Foreword

Costa Rica is a small country in territory but big in commitment to the environmental future of the planet and has lofty sustainability goals with a running climate change policy, an economy decarbonization strategy, and a long promise to keep producing 99% of clean electricity from hydropower, onshore wind, geothermal, biomass and solar energy. In the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity, the country boost a non-conventional renewable energy portfolio with a road map on offshore energy. We know that ocean energy is still in its infancy, and this sector has to overcome a number or challenges to prove the reliability, affordability and accessibility. Despite this, the oceans represent a source of plentiful energy potential, able to driving a blue economy and provide significant socio-economic opportunities, such as jobs creation, improved livelihoods, local value chains and enhanced synergies between coastal stakeholders.

But before I go further, I have the privilege of presenting the book with the summaries of the first Pan American Marine Energy Conference, PAMEC-2020. An international event, held in last week of January, that we gave high priority from the beginning, not just because it is an important theme for our ministry, it's because we believe in the sustainable use of the ocean as a significant reservoir of renewable energy, resilient to climate change and low in emissions of greenhouse gases effect. In fact, energy is a key component of both the sustainable development and climate goals. PAMEC-2020 served as an effective international vehicle for dialogue, co-operation and coordinated actions to accelerate the uptake of offshore renewable in benefit of the glocal energy transformation. The event provided a forum where those at the forefront of technology development in the sector met, interacted, shared their latest knowledge and debate new ideas and issues related to different perspectives of wave, offshore wind, ocean thermal energy, salinity gradient, currents and tidal energy conversion with a focus on building and strengthening research and development ties in the Americas, and globally.

Finally, I want to re-affirm the Costa Rica government's actual, long-term commitment to ocean energy and the exigency to face, at least, five main bottlenecks: technology development, finance sources, environmental and social acceptance, marine supply chain issues and field data gaps. Now is the time to take actions. Now is the time for bold steps. Now is the moment that we show the planet what can be done. PAMEC-2020 is a great example of governments, academy, NGO´s and private industry running as one to achieve a common ocean energy goal. The progress of the sector we owe to this type of alliance. However, we cannot afford to rest now. The move toward renewable offshore energy is already underway, it is unstoppable and it is inevitable.

Thank you very much for the very kind invitation, which I very much appreciate.

Carlos Manuel Rodríguez E.
Former Minister
Ministry of Environment and
Energy of Costa Rica

During its 71 years of history, the Costa Rican Electricity Institute (ICE) has contributed to the development of Costa Rica bringing electricity and telecommunications services to all corners of the national territory with a focus on social welfare, environmental protection, and creation of economic value.

In terms of electricity, ICE has shown vocation and responsibility by promoting the generation of electricity from various renewable sources, low in greenhouse gas emissions and resilient to climate change, whilst incorporating energy security and sustainability criteria from the planning stages, using the natural resources available in the country. Therefore, identifying and determining the energy potential available to the country is an ongoing task that aims to expand the portfolio of renewable energy projects.

Following this direction, and understanding the role that offshore energies could have in their different forms, ICE collaborates with academia, non-governmental organizations, and private industries to promote the development of research and vocational training initiatives that assess the marine energies' potential in the country, and strengthen networks and technical capacities in this topic.

One of the most evident actions has been co-organizing and hosting the first Pan American Marine Energy Conference, PAMEC 2020, an international event that was attended by leading scientists, researchers, and developers from Europe, America, and the Caribbean. This event facilitated discussion on technological advances, and the main challenges and opportunities presented using ocean energy resources in the future.

This book collects research and experiences developed by different actors worldwide, as well as institutional efforts made to consolidate a blue agenda and a roadmap that places offshore energies as a strategic axis within it.

Irene Cañas D.
President Executive
Costa Rican Electricity Institute

The Costa Rica Institute of Technology (TEC) is committed to the sustainability of the planet, promoting the use of clean energy in the country, through research and the corresponding technology transfer to different sectors of society.

In recent years, the TEC has designed, developed, implemented, and promoted initiatives related to the use of solar energy, water heating, energy efficiency, and general carbon-neutral technology. Such systems have been tested and adopted in our carbon-neutral Central Campus. For instance, to reduce CO_2e *emissions, the Institution adopted the policy of gradual replacement of the vehicle fleet with hybrid and electric cars. We also have more than 1200 solar panels installed on our campuses. The results of these initiatives have not only been used for teaching and research but also are passed on to society through outreach and training programs.*

Wind energy, wave energy and biomass have also been the subject of study in our University. In the case of biomass, TEC has trained small communities in the regions in the production and use of biogas. The conversion of fossil fuel-based vehicles to electric vehicles has been a permanent subject of research in different departments.

At TEC we are aware of the relevance that marine energy will have in the future, that is why we have a group of researchers working towards improving wave energy converters. We are proud and honored to have collaborated in the elaboration of the proceedings of the First Pan American Conference on Marine Energy in Costa Rica and to continue being pioneers in the exploration of new sources of clean energy. Research in the field of marine energy opens a range of opportunities worldwide and Costa Rica must be an active partner in this process.

Luis Paulino Mendez B.
Rector
Costa Rica Institute of Technology

TEC | Tecnológico de Costa Rica

According to the Organization for Economic Cooperation and Development (OECD), more than three billion people depend on marine resources for their livelihood. The vast majority of them are located in developing countries, where situations such as climate change, pollution, and the absence of a social and environmental sustainability strategy put their progress at risk. In this regard, for the well-being of future generations, it is imperative to promote innovative initiatives that mitigate this threat and, in turn, promote sustainable development models.

In the case of Costa Rica, which has a large maritime territory, research, and innovation for sustainable development will be key to the future of the country. The Instituto Costarricense de Electricidad *(ICE), the government-owned power company, has taken the lead in coordinating various national and international stakeholders. This action seeks to promote new forms and opportunities for the sustainable use of our sea, particularly in the generation of marine energy. A reflection of this leadership by ICE is the catalytic role played during the PAMEC 2020 Conference. In this event, world-renowned experts and a diverse global community shared knowledge about the possibilities of use and research of sustainable energy technologies in the Costa Rican maritime territory.*

For the Universidad Estatal a Distancia (*UNED) it has been an honor to participate in PAMEC 2020. This opportunity has allowed us to show our potential contributions in the application of geographic information systems in ocean energy, such as the analysis of the potential effects of marine energy considering the complex situations faced by territories that currently depend on marine resources. UNED ratifies its commitment to the country, particularly to its vulnerable populations, by promoting research and innovation initiatives for the responsible and sustainable use of marine energy, in collaboration with the various actors articulated by ICE.*

Rodrigo Arias Camacho
Rector
Universidad Estatal a Distancia

UNED
UNIVERSIDAD ESTATAL A DISTANCIA
Institución Benemérita de la Educación y la Cultura

Thanks to all national and international experts who attended the Pan American Marine Energy Conference, PAMEC 2020, an initiative to promote the development of renewable marine energy through collaboration between researchers and developers. We know that renewable energies are already enjoying exponential growth. In addition to solar and wind, marine energy shows significant growth and represents an energy source that will reduce greenhouse gas emissions, generate prosperity, and strengthen planetary resilience.

I firmly believe that change of the scale needed to tackle the climate crisis requires all of us to be proactive, whether at the individual level, and/or at the global level, and all levels in between. This is an "everyone in" effort.

Christiana Figueres
World leader on climate change actions
Former Executive Secretary of the United
Nations Framework Convention on
Climate Change

Preface

The Pan American Marine Energy Conference is intended to bring together researchers in marine renewable energy in the Americas (including the Caribbean). This new research conference is part of a global network of conferences that includes the European Wave and Tidal Energy Conference (EWTEC) and the Asian Wave and Tidal Energy Conference (AWTEC).

This book includes the contributions presented at the First Pan American Marine Energy Conference that ran from January 26th to the evening of the 28th. PAMEC is intended to foster the development of marine renewable energy through collaboration among researchers, developers, and suppliers. The contributions are collected in the following topics:

- *Resource assessment*
- *Environment*
- *Current technology*
- *Emerging technology*
- *Storage and integration*
- *Building social and policy support*

The Conference was held under the auspices of the PAMEC.Energy Association and a Local Organizing Committee led by Comité Regional de la CIER para Centroamérica y el Caribe CECACIER, the Costa Rican Electricity Institute, ICE, the University of Costa Rica, Costa Rica Institute of Technology, State University of Distance Education and National University, as well the kind support of the Canadian Embassy in Costa Rica, Costa Rican Institute of Tourism and Marviva Foundation Program oversight is through the PAMEC Technical Program Board, which includes Prof. Richard Karsten, Acadia University Canada, Dr. Andrea Copping, Pacific Northwest National Laboratory, USA, Dr. Rodolfo Silva Casarín, University of Mexico, Luc Martin, General Manager ENERGÍA Marina SpA in Chile, Sandra Farwell, NS Department of Energy and Mines, Canada, Tattiana Hernández-Madrigal, Cardiff University, UK, Dr. José Rodrigo Rojas Morales, ICE, Costa Rica, and Bruce Cameron, Envigour Policy Consulting, Canada.

The Conference was also supported by an Advisory Board that includes Prof. AbuBakr Bahaj from Southampton University and Cameron Johnstone from Strathclyde University, in the UK, on behalf of EWTEC; and Prof. Chul H Jo from Inha University in South Korea, and Prof. Jiahn-Horng Chen from National Taiwan Ocean University, on behalf of AWTEC.

Dr. Rodrigo Rojas
Electric Planning Department
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RESOURCE ASSESSMENT

Field measurements of a floating tidal turbine wake

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***Keywords**: Turbine wake, turbulence, acoustic Doppler current profiler, drifter buoy, field measurements*

Significant effort has been devoted to the study of marine turbine wakes using numerical models and laboratory experiments [1],[2]. These wakes are typically characterized by a velocity deficit and increased turbulence with respect to the surrounding flow [1-3]. Recent deployments of full-scale hydrokinetic turbines in tidal channels provide opportunities to map these wakes in the field. However, efficient field methods that can accurately map the spatial structure of these unsteady turbulent flows need to be applied to quantify the wakes' extent and evolution [4].

In this investigation, a novel technique based on mobile platforms is used to map the flow downstream of Sustainable Marine Energy Canada's PLAT-I floating tidal energy platform [5], [6]. PLAT-I supports four 6.3 m diameter horizontal-axis Schottel turbines with a 4.7 m hub-depth. The platform was deployed in Grand Passage (N 44.2639°; W 66.3369°), one of Bay of Fundy's tidal channels in Nova Scotia, Canada, on September 2018. Tidal flow in Grand Passage runs approximately to the north-south. The channel is about 4 km long and 1.5 km wide at the study site and has been previously selected for tidal energy extraction due to its strong tidal currents (~3 m s-1) [7]. The main objective is to map PLAT-I's combined wake for different stages of the tide.

Two field experiments have been conducted in the vicinity of PLAT-I. The first experiment occurred in November 2018 before turbine blades were installed in the platform. The second experiment was conducted in May 2019, after all four turbines were installed and were (at times) operational.

Measurements of turbulent velocities were collected using two stream-following surface drifters. Each drifter consisted of a disk buoy equipped with one turbulence-resolving Nortek Signature acoustic Doppler current profiler (ADCP). Two ADCPs of different frequencies were used to prevent acoustic contamination, a 500 kHz unit and a 1000 kHz unit respectively. Each ADCP was set to record single-ping along-beam turbulent velocities at different intervals through the water column at the fastest sampling frequency possible when using all five acoustic beams (4 Hz and 8 Hz respectively). Each drifter was also equipped with a fast-sampling GPS tracker, which recorded drifter location and drifting velocity. Both drifters were hand-released immediately downstream of the turbines and recovered about 300 m farther downstream. The data set includes 178 ebb and 86 flood drifts.

Data are quality controlled to remove velocity estimates with low echo amplitude and correlation. Data from the first few seconds of each drift are also removed due to reflection of the ADCP pulse from the platform mooring chain. In addition, velocity data are corrected for buoy motion contamination; velocities induced by buoy “bobbing’ motion are removed from each instantaneous profile of along-beam velocity [8].

All collected data are organized into a local coordinate system centered at PLAT-I’s nominal location and aligned with the principal direction of the flow at this location (-18.8° from true north, flood positive northward). Mean-flow velocities and turbulence parameters are estimated along each drift trajectory to test the performance of the measurement method.

Fig. 1 shows vertical profiles of along-channel velocity and of turbulent kinetic energy dissipation rate (e), from two drifter trajectories taken at the same location; one while turbines were operating and one while they were not. Along-drift data successfully capture the wake; slower velocities are observed around hub-depth (z~-5 m) and higher dissipation rates are observed while turbines are operating.

Maps of mean velocity and turbulence parameters are constructed for different stages of the tide. First, data are organized into 0.5 m s-1 mean velocity bins, using as reference an FVCOM model prediction of near-surface velocity at PLATI nominal location (corresponding to an undisturbed flow condition). Data from each velocity bin are then organized into a horizontal grid of 5 x 5 m2, and ensemble parameters are estimated within each grid-cell.

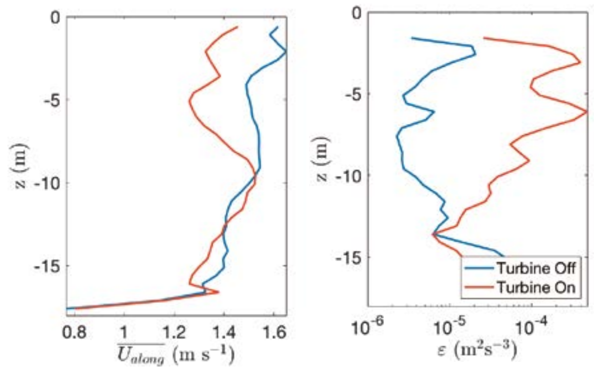

Fig. 1 Comparison between operational and non-operational data: a) Vertical profiles of along-channel velocity averaged over 30 s of a single drifter trajectory, and b) Vertical profiles of turbulent kinetic energy dissipation rate estimated using the first 30 s of data along the same single drifting trajectory.

Fig. 2 shows a map of surface drift velocity for one flood velocity bin when all four turbines were operating. The wake is evident as a deficit in along-channel velocity extending about 200 m downstream of the platform. Similar maps are constructed for along-channel velocity and for turbulence parameters through the water column.

Future work considers extending the data set to improve each flow map and to populate all stages of the tide.

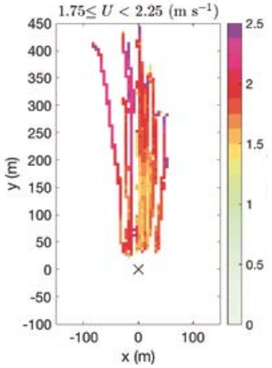

Fig. 2 Map of drift velocity for data collected during flood while ambient flow velocity (from FVCOM model) was between 1.75 and 2.25 m s-1. The X symbol corresponds to the platform nominal location, and turbines are located around y = 40 m during flood.

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Combining observations and simulations into improved assessments of tidal resources

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***Keywords**: Tidal energy; resource assessment; flow measurement; numerical simulation; Bay of Fundy*

Tidal energy is a promising form of renewable energy in which Nova Scotia, Canada, has a distinct advantage since, the Bay of Fundy is one of the world's best tidal resources. However, project development is often hindered due to lack of scientific evidence. To address this gap, the infrastructure specific to the task of characterizing, monitoring and modelling high-energy tidal sites is being continually developed.

An accurate characterization of tidal energy resources and sites requires more than a single measurement of the flow at a specific location or a single numerical simulation of a region. Efficient deployment, operation and maintenance of an array of turbines requires a detailed analysis and prediction of the tidal flow in the entire deployment region. The flow characterization must be sufficiently detailed to provide accurate forecasts of spatial and temporal flow variability, while also being sufficiently long term and broad to make predictions of turbine operation, project energy yields and operational windows.

Field observations from Acoustic Doppler Current Profilers (ADCPs) [e.g 1,2], drifters [3,4], or X-band radar [5,6] can provide accurate measurements of the flow, including the temporal and spatial characteristics of turbulence. But, due to either the limitations of the device or the expense of repeated deployments, the data coverage is limited in either space or time. Numerical models can fill these gaps, providing simulated data over large spatial regions and at any time [e.g. 7,8,9]. However, in order to keep the computational expense reasonable, these simulations must only approximate the real dynamics. For example, the numerical models that can provide month-long or annual simulations do not resolve turbine-scale turbulence or include the effects of waves and winds. On the other hand, numerical models that even begin to resolve turbulence and its impact on turbine operation can only conduct simulations of quasi-steady conditions.

Our research has focused on building a software package that can combine all available data into a comprehensive data set that can be used for both analysis and prediction. The package is built on LunaTide, a phase-learning software package developed by Luna Ocean. LunaTide categorizes flow based on the tide time and tidal range. The phase-learning aspect of LunaTide allows it to make accurate predictions of local flow characteristics, including the asymmetry between flood and ebb tide and the macro-turbulence driven by bathymetric features. As well, LunaTide “learns” the influence of the spring-neap and longer changes in tidal amplitude by determining the relationship between tidal heights and tidal flow, which is unique to each tidal passage.

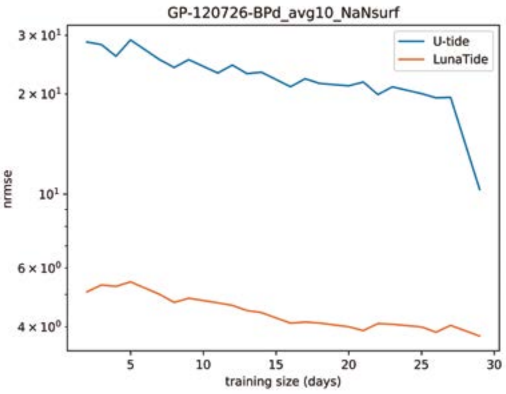

Fig. 1: A plot of the normalized root mean square error (nrmse) of predicted flow speeds as a %, using a log scale, versus length of the training data, using data from an ADCP deployed in Grand Passage. The standard harmonic analysis using U-tide only produces accurate predictions (<10% error) for a full lunar month of data. The phase-learning LunaTide produces more accurate predictions (~5% error) with as little as 2 days of data.

The big advantage of LunaTide is that it can make accurate predictions with short training data sets, as little as two tidal cycles! As Fig. 1 illustrates, LunaTide is more accurate in predicting tidal velocities than 30-day traditional harmonic analysis using [10]—with a time series that is only 2 days long—and overcomes many of the known difficulties in using harmonic analysis to predict tidal currents [11]. As well, since each measurement is treated independently, LunaTide is an ideal tool to use for data that has been gathered over many separate field campaigns, for example data gathered by drifters and X-band radar (see Fig. 2.)

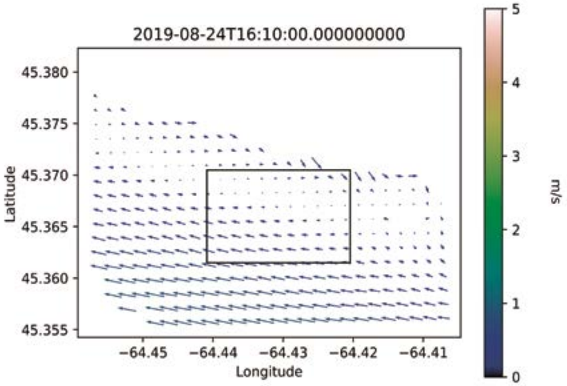

Fig. 2: Prediction of the flow field around the FORCE Crown Lease Area (box) using LunaTide and data from X-band radar. Although the radar data can only be gathered during sporadic, high-wind conditions that occur in winter, LunaTide produces an accurate spatial map of velocities for summer conditions.

Furthermore, LunaTide has been developed to compare and combine data from different sources, including both field measurements and simulated data. Data comparison can be critical to validating both data analysis methods (e.g. getting velocity data from X-Band radar) and numerical models. Usually this would require that the data overlap in time or have sufficiently long time series to allow a comparison of the tidal harmonics.

With LunaTide, we can use data to make accurate predictions for any time series. Therefore, for example, we could validate a single-day, large-eddy simulation of flow through a tidal passage using comparisons to all historic ADCP and other data from the passage.

In order to combine data, LunaTide categorizes and appropriately weights the data based on the accuracy of the measurements and the distance from the location. Machine learning techniques are used to choose weighting factors to best replicate measurements within training data sets. This method is being validated against and applied to tidal currents in Grand Passage and Minas Passage, where we have a large database of field measurements of a wide range of tidal flow conditions.

LunaTide is helping us meet the ever-increasing demands for better characterization of the flow at tidal energy sites. Importantly, it is allowing us to bridge the gap between the disparate forms of data to produce predictions of the flow that incorporate a wider range of time and space scales.

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Evaluation of Wave Energy Extraction in a Sheltered Bay

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***Keywords**: Numerical wave modeling; renewable energy sources; wave energy extraction; wave energy converter; wave farm arrays.*

The extraction of energy from renewable sources is currently envisioned as a possible solution to the global energy crisis [1]. Ocean waves are one of the most promising sources of energy because their high energy density per unit area and because the energy naturally flows to the coast where it can be harvested more easily. The Pacific Coast of North America has one of the most important marine renewable energy resources in the world in terms of waves [2]. However, most Wave Energy Converters (WECs) are designed to work in relatively high seas. This limits their performance in sub-tropical and tropical regions, typically dominated by gentle swell. The present study analyzes and compares the performance of two types of WECs within a sheltered bay in the subtropical zone (Fig. 1).

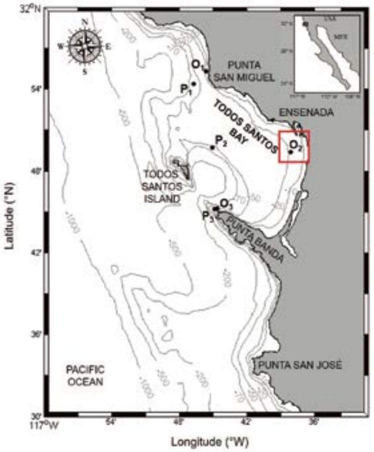

Figure 1. Location of the study site within the Baja California peninsula. The positions for each evaluated points are indicated. Ppoints represent the sited areas for Pelamis devices and the Opoints for the Oyster2 converter. The red lines show the located of nested grids for the WEC arrays analysis area. The solid lines represent the isobaths and their value is expressed in meters.

The spatial and temporal variability of the wave power in the study area were determined from a ten-year hindcast performed for this purpose. The wave hindcast is based on a local implementation of the SWAN spectral model [3] forced at its open boundaries with wave data from the IOWAGA hindcast [4].

The extraction of energy with Pelamis [5] and Oyster2 [6] was simulated based on its power matrix and the effects of the different WEC arrays on the nearshore area were determined with the model SNL-SWAN [7].

In accordance with the results, the studied area has several sites suitable for wave energy extraction. The area has a moderate available wave power with a clear seasonality and a large spatial variability caused by the sheltering effect of Todos Santos Island. Both analyzed devices work better in the southern region; however, Pelamis is more effective than Oyster2 on extracting the available wave power. All the different WEC array configurations examined induced changes near-field and nearshore (e.g. Fig. 2).

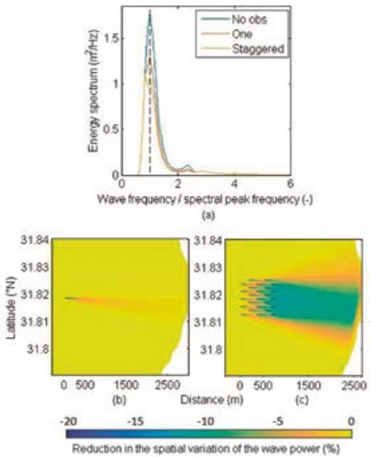

Figure 2. Reduction in wave power (ΔP) in percentage for the various examined Oyster2 arrays configurations: (a) associated wave energy spectrum; (b) single obstacle; (c) staggered array, adding a total of 25 devices with the same spacing distance of devices between rows and columns.

ACKNOWLEDGMENT

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Wave characteristics on the Pacific coast of Costa Rica for energy production

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Keywords: *Wave characteristics, Pacific coast, Costa Rica.*

INTRODUCTION

Costa Rica has a great potential for the production of electricity from waves, especially in the Pacific coast [2]. Currently, 99% of the country's electric energy is produced by renewable sources such as hydropower, wind and geothermal; the extractable energy potential from waves in the Pacific coast equals the combined energy of all these sources [3].

The iMARES group of the University of Costa Rica has carried out a continuous measurement of the Pacific waves of Costa Rica, from which wave characteristics have been determined and how these can influence the production of electrical energy.

The arriving waves at the Pacific Coast of Costa Rica are originated mainly in the east side zone of New Zealand and they travel more than 10000 km through the Pacific Ocean basin to the Central American coast. Due to this long voyage, swell takes the following characteristics:

1. Long period waves

In this transoceanic voyage of more than 10000 km, waves suffer a transfer of energy from their original frequencies to lower ones, increasing the range of frequencies in which a specific storm is distributed. Figure 1 shows the peak period from 2005 to 2018 with a mean value around 15s. During storm condition, a Tp of 20s is easily reached.

2. All year "homogeneous" and no extreme waves

Wave height is very homogenous, varying from 1 m in low energy season to 2 m in the high energy as shown in Figure 2. This can be very convenient for the design of energy harvesting equipment for continuous energy production. Also, there are only few events that exceed the threshold of 3 m and just one over 4 m, so is easy to prevent equipment destruction.

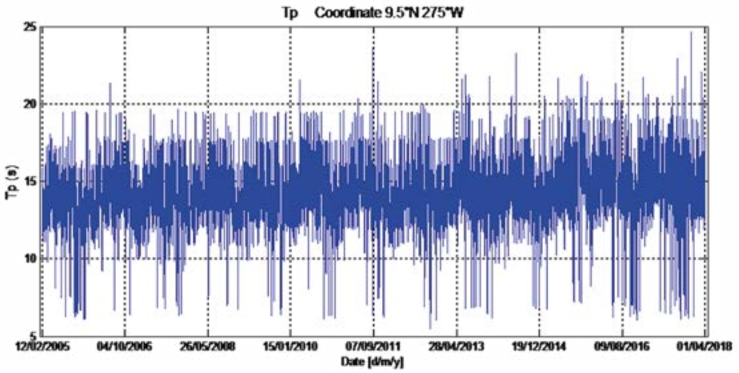

Figure 1. Wave spectra peak period in the Pacific coast of Costa Rica

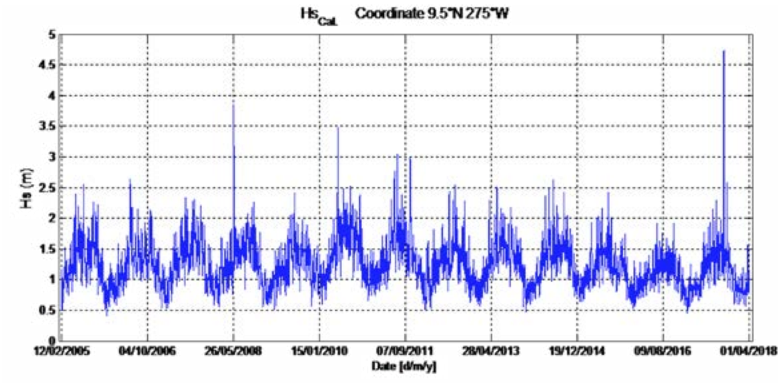

Figure 2. Significant wave in the Pacific coast of Costa Rica

3. Multipeak wave spectra

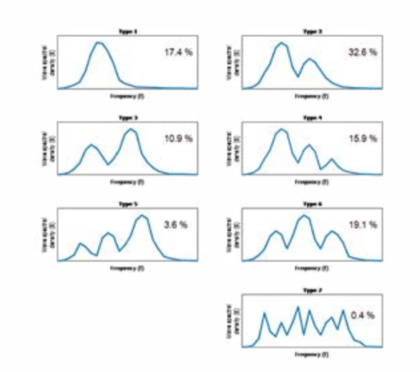

Figure 3. Energy spectra diagrams with their percentage of occurrence [4]

Wave spectra arriving at the coast of Costa Rica have shape distributions as presented in Figure 3. The standard unimodal spectrum shape is present only 17,4% of the time and it was characterized by a JONSWAP spectrum by Lopez [5]. For types 2 (32.6%) and 3 (10.9%), Corrales [4] used a combination of two JONSWAPs.

The effects of multi peak spectra swells over structures and power production equipment must be investigated and taken into account during design.

4. Five to ten days of high predicted waves

Since waves travel several days, we can predict the incident energy with high precision. This is because the swell was already produced, and current propagation software is very accurate. The black isolines in Figure 4 represent the wave travel time to the Pacific coast of Costa Rica.

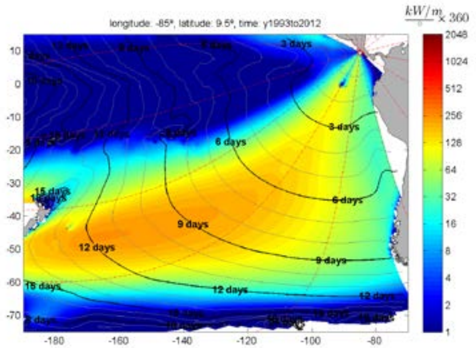

Figure 4 Average energy flow on the Pacific coast of Costa Rica from 1993 to 2012 [1]

5. Diffraction or “shadow” zone of the Galapagos Islands

As most of the energy that arrives at the Pacific coast of Central America is produced near New Zealand, Costa Rica is just in the diffraction or “shadow” zone of the Galapagos Islands. This phenomenon causes the available energy to be less, although it also protects against greater storms.

In addition to this, global wave propagation models such as the NOAAs Wavewatch III [6] are not so accurate in these areas.

CONCLUSIONS

The wave energy potential in the Pacific coast of Costa Rica is very important, nevertheless, the adaptation of technology to the particular swell conditions must be done carefully.

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Approaching the wave energy potential in a coastline section of the Nicoya peninsula

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Keywords: *Wave energy, Pacific coast, swell downscaling*

INTRODUCTION

Costa Rica is a country that generates about 99% of its energy from renewable sources such as hydroelectric, wind, geothermal, solar power and biomass [6]. In addition, its privileged location provides two additional resources in front of its coastlines: the Caribbean Sea and the Pacific Ocean; being the last one an important source for the generation of wave energy [2].

Figure 1 shows, according to preliminary studies, [2] that the zone with the most theoretical potential available for the generation of wave energy is in the northwest of Nicoya peninsula, in the Pacific Ocean. In this zone, the preliminary study identified subzones, where the wave potential (kW/m), seabed geology, nearby power grid infrastructure, marine protected areas, among others, were taken into account.

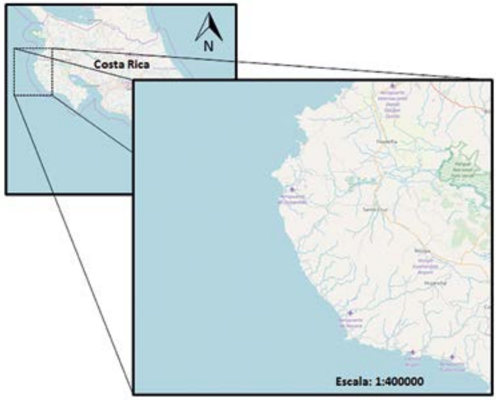

Figure 1. Research zone for the determination of the wave energy potential

The present work aims to generate an additional input to previous studies as well as deepens into the wave energy potential available. To reach this objective, it is projected to apply hybrid downscaling methods which combine numerical and statistics tools, to increase the spatial and temporal resolution in the research zone.

INITIAL DATA

This study, in particular, use different sources of information, such as reanalysis data (wind and wave), satellite measured data (wave), astronomical tide data, and global and local bathymetric surveys.

The wave reanalysis is obtained from the NOAA database, which was generated for the third generation Wavewatch III model [10]. In the study zone, this model uses a grid with a spatial resolution of 0.5° x 0.5°, where relevant wave climate information is obtained for each point of the grid, allowing the characterization of wave climate parameters such as the significant wave height (Hs), wave periods (Tp) and wave direction (Dp). The model has a temporal resolution of 3 hours; besides, and it also has data since 2005 that are constantly updating. The wind information used is magnitude (V) and direction (Dv), which comes from the high-resolution wind reanalysis CFSv2 (Climate Forecast System Version 2) [9]. This reanalysis is generated by the NCEP (National Center for Enviroment Prediction).

Data measured by satellites equipped with altimeter radars issued to calibrate the wave reanalysis. From these satellites the significant wave height can be obtained. The databases for Hs are available from 1991 to 2017. They were generated by several satellites like ESR 1, ESR 2, Envisat, Topex, Poseidon, Jason 1 and Jason 2. The altimetric data were obtained from the "Laboratoire d'Océanographie Physyque et Spatiale" of the French Research Institute IFREMER.

The program TOGA provides the astronomical tide [7] and the General Bathy-metric Chart of the Oceans" (GEBCO) facilitates the global bathymetric information with a 1° spatial resolution, in combination, in available sites, with detailed bathymetric surveys to define shallow areas.

WORK METHODOLOGY

Camus's methodology [5] is followed quasi-similar way to estimate the wave energy potential in the study zone. The methodology followed is presented in Figure 2.

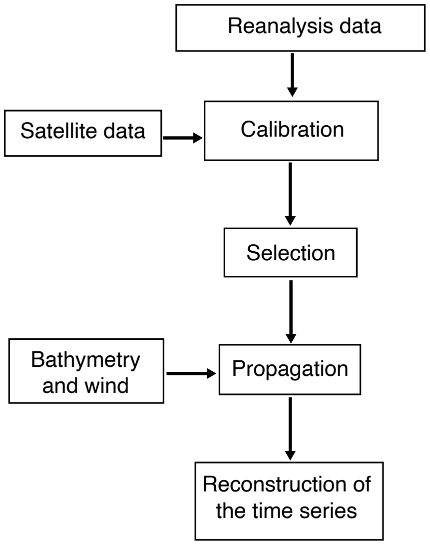

Figure 2. Methodology to estimate the theoretical wave energy potential available

From the wave reanalysis data and with the satellite data [8] the parameter Hs is calibrated. Then applying the maximum dissimilarity algorithm, [3] a selection of representative sea states in deep water is made, in order to spread them into the shallow waters using the waves generation and propagation numeric model SWAN [1]. The SWAN model is forced with the bathymetry, astronomical tide and data from the high-resolution wind reanalysis CFSv2 [9]. To rebuild the time series of Hs, a radial based functions (RBF) [4] interpolation is applied.

RESULTS

Once the wave database is reconstructed in the different points of the SWAN grid, it is possible to estimate the energy potential and the statistics that characterizes it; for example, the average annual energy or the seasonality of the energy throughout the year. Also, among the results, it is expected to produce a series of virtual buoys each kilometer along the 20 m and 50 m depths. Furthermore, by having an increase in the spatial resolution of the surge as a variable, it is possible to obtain climate information of the wave energy potential at different points of the study zone and for different temporal spaces.

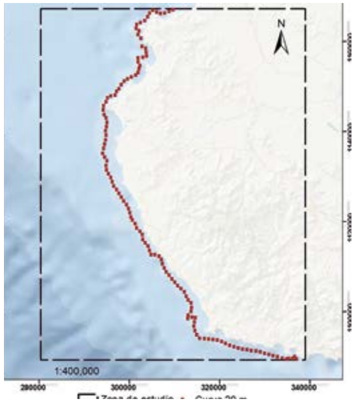

Figure 3. Methodology to estimate the wave energy potential

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Wave power availability in the Pacific of Mexico and Central America

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Keywords: *Wave power assessment; Mexico and Central America; Pacific Ocean; wave energy converter; wave farm arrays.*

The global energy demand increases every day due to population growth and the technification of daily life. It is estimated that between 2020 and 2040 most countries will have an energy deficit. In response, many countries have increased their efforts to promote the use of renewable energy sources and clean technologies to generate electricity. Among the wide variety of renewable energy sources, marine renewable energy has received significant attention in recent decades due to the great potential it represents. It is estimated that only the energy contained in the ocean waves represents between 1 TW and 10 TW. The amount of wave energy available varies according to the geographical area and, mainly, the exposure of the places of interest to the predominant wave regime. In this work an analysis of the spatial and temporal distribution of wave power in the Mexican and Central American Pacific is performed based on numerical wave simulations for the years 1994 to 2012.

The results show that the mean wave power is higher in the northern region of Baja California, where it reaches values of 35 kW/m. In the rest of the Mexican Pacific and Central American Pacific are observed values of 20 kW/m and less than 15 kW/m respectively. In areas close to the coast, wave power varies between 10 kW/m and 20 kW/m (Figure 1).

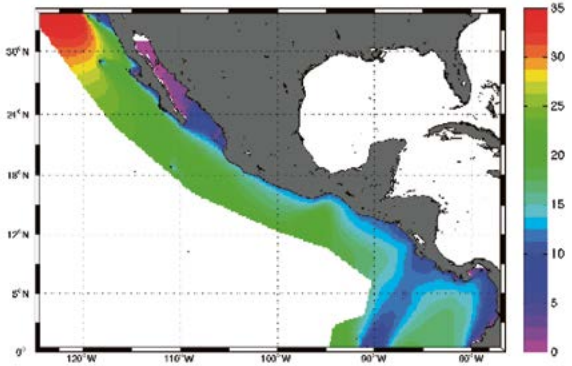

Fig. 1.- Mean wave power of the Pacific of Mexico and Central America.

In general, there is a marked seasonality of wave potential with higher values during the winter in the area of Baja California and during the summer in the rest of the Mexican and Central American Pacific (Fig. 2).

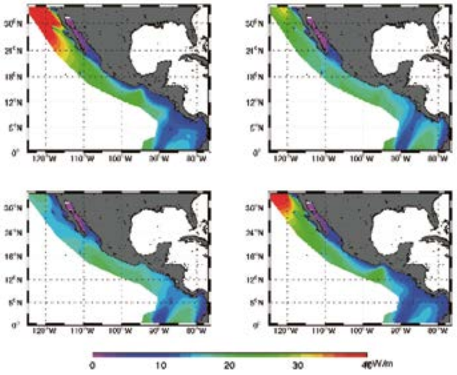

Fig. 2. Seasonal mean wave power of the Pacific of Mexico and Central America.

As part of the results, the characteristics of the prevailing waves are analysed in selected areas to estimate the feasibility of exploiting the resource with current technology (e.g. Fig. 3).

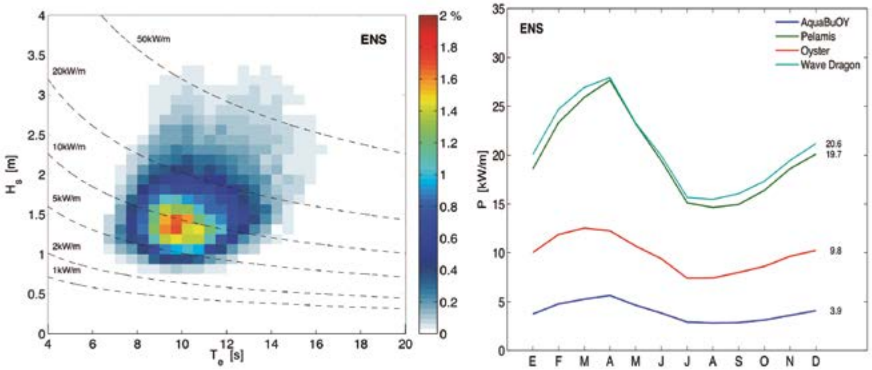

Fig. 3.- Exploitable resource in Ensenada, Baja California, México. a) Available wave power (joint distribution of wave height and period) and b) monthly extractable wave power with different WEC technologies.

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Wave power resource assessment in Northeast México

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Keywords*: Wave energy resource assessment, cold fronts, wave power, shallow water, northeast México.*

Studies of the wave field response to the passage of atmospheric frontal systems (cold fronts) have generally considered individual events [1, 2, 3]. It appears that no studies have been conducted covering a full season. The cold front season in the Gulf of Mexico begins in September and ends in May of the following year, however, it is not unusual for cold off-season fronts to occur in the months of August and June. The mean number of front systems, according to 1981-2010 weather run by the National Weather System of Mexico is 44, although the number of cold fronts per season may be much higher than average [4]. Not all cold fronts enter the waters of the Gulf of Mexico as some of them can dissipate on the continental surface.

This paper describes the generation of wave power pulses coinciding with the spread of cold fronts during the 2017-2018 season in the northwest Gulf of Mexico, and contrasts with the wave power generated under "calm" conditions. As part of the research activities of the Mexican Center for Innovation in Ocean Energy related to identifying and describing sites with potential for clean energy generation from wind-generated waves, there are currently in operation on the southern coast of the State of Tamaulipas and on the north coast of the State of Veracruz, two Nortek Acoustic Wave and Current profilers with a frequency of 1 MHz. A 600 kHz profiler is used for replacement. These profilers have been moored at depths less than 20 m and roughly at 4 km distance from the coast [5]. The distance between the profilers is about 2 km. The internal sample rate of the 1 MHz profiler is 6 Hz and the frequency corresponding to the profiler of 600 Hz is 4 Hz. The three profilers directly measure the free surface using a narrow 1.7° vertical acoustic beam, known as Acoustic Surface Tracking (AST), with a frequency of 4 Hz (1 MHz) and 2 Hz (600 kHz). Wave data are obtained hourly in 17-minute bursts.

The wave power (P), in kW/m, was estimated directly from the wave directional spectrum according to,

$$P = \rho g \int_0^{2\pi} \int_0^{\infty} S(f, h) C_g df d\theta \qquad (1)$$

where ρ is the seawater density, g is the acceleration of gravity, f is the wave frequency in Hz, θ is the wave direction, h is the water depth, $S(f, \theta)$ is the wave directional spectrum, and $Cg(f$, h) is the group velocity given by,

$$C_g(f, h) = \frac{g}{4\pi f}\left(1 + \frac{2kh}{\sinh(2kh)}\right) \qquad (2)$$

where $k = 2\pi/L$, is the wavenumber and L is the wavelength which is estimated with an accurate two-step explicit solution that obtains results with a maximum relative error of less than 8.2 x 10FG % [6].

During the 2017-2018 season, 48 atmospheric frontal systems were officially registered [7]. At the site of southern Tamaulipas, 22 wave power pulses associated with the passage of frontal systems were identified. At the site of northern Veracruz, there were 28 wave power pulses plus one event associated with an off-season unnumbered cold front. The difference from the official number of cold fronts is that the profiler from southern Tamaulipas began collecting data in late November 2017 and the profiler of northern Veracruz in the middle of the same month. In addition, almost three months of wave data were lost in the southern Tamaulipas site due to the incorrect placement of the rubber O-ring that keeps the battery cylinder tight. The most complete wave power time series corresponds to the site in northern Veracruz (Fig. 1).

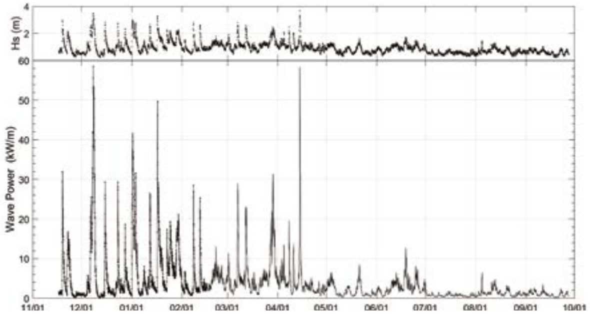


Fig. 1 Time series of the significant height (Hs) and wave power off the north Veracruz coast, México.

In Fig. 1 the wave power obtained from 17 November 2017 to 27 September 2018 is highlighted. This last month corresponds to the 2019-2020 cold front season, however, only three low-intensity cold fronts events occurred in that month [4]. The calculations here presented, unless indicated, do not include the month of September 2018. The cumulative wave power was 110.7 MW/m with a mean power of 16.0 kW/m and a coefficient of variation [8] of 1.4. The cumulative wave power, mean and coefficient of variation during the wave power pulses associated with the cold fronts (November-May), in the respective order, was 95.5 MW/m, 21.2 kW/m and 1.3. During the “calm” period (June-August) it was 15.2 MW/m, 6.3 kW/m, y 0.9, respectively. This emphasizes the importance of the contribution of atmospheric frontal systems to the mean wave power in the Gulf of Mexico, a feature already discussed in extreme events by [9]. Other wave power pulses shown in Fig. 1 have been identified as coinciding with the following meteorological events: south-component winds known locally as “Southerns”, as well as wind gusts associated with tropical waves, the Tropical Depression 4-E and the Tropical Storm Charlotte.

Exploitation of wave energy can be commercially profitable in areas where the wave power is greater than 2 kW/m and the mean annual wave power is greater than 15 kW/m [10,11]. Further, to extract energy from the waves, the Wave Energy Converters (WECs) generally require sites with a wave power between 15 kW/m and 75 kW/m.

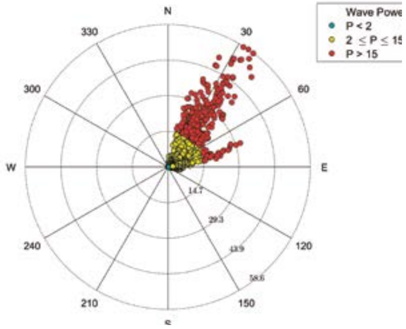
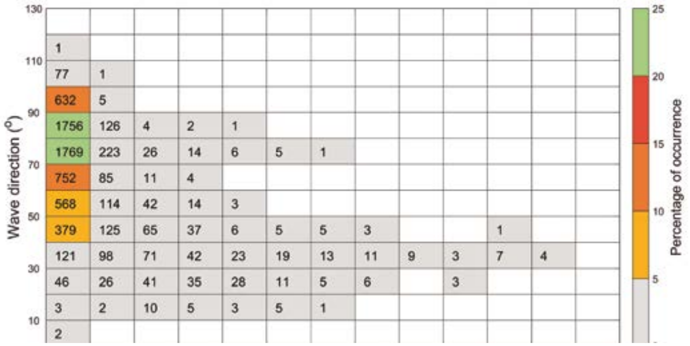


Fig. 2 Wave power rose.

Fig. 2 shows the wave directionality with respect to wave power (includes September 2018). Directionality is important because there are WECs designed to operate in a particular direction or capable of reorienting within certain range of wave directions [12].



1												
77	1											
632	5											
1756	126	4	2	1								
1769	223	26	14	6	5	1						
752	85	11	4									
568	114	42	14	3								
379	125	65	37	6	5	5	3			1		
121	98	71	42	23	19	13	11	9	3	7	4	
46	26	41	35	28	11	5	6		3			
3	2	10	5	3	5	1						
2												

Fig. 3 Bivariate scatter matrix.

Fig. 3 shows the bivariate distribution matrix for wave power and wave direction; a directional interval is observed between 70° y 80° consistent with Fig. 2 where the percentage of occurrence for wave powers less than 20 kW/m is 23.5%. This represents about 1771 h (74 days) out of a total of 7518 h (313 days). Considering now the range of wave directions between 70° y 90° and wave powers less than 20 kW/m, the percentage of occurrence changes to 46.9%, that is, 3528 h (147 days) approximately. The mean wave power, including September 2018, was 15.0 kW/h, with a coefficient of variation of 1.5. From here, the total wave energy per unit area is estimated as $E_T = \left(15.0\ \frac{\text{kW}}{\text{h}}\right) \times 3528\ \text{h}$, that is, 112.8 MWh. By comparison, the Salitrillos wind farm of the Italian company ENEL Green Power located in Reynosa (México), has 30 wind turbines with the capacity to produce 103 MWh. The exploitable wave energy, corresponding to the range of wave directions and wave powers with the 46.9% occurrence, can be estimated as $E_T = \left(15.0\ \frac{\text{kW}}{\text{h}}\right) \times 7518\ \text{h}$, The maximum wave powers were related to the passage of cold fronts No. 14 and 44, in December 2017 and in April 2018 (in the springtime!). For the cold front No. 14, the accumulated wave power was 8.3 MW/m in 83 h, while for the cold front No. 44, the accumulated wave power was 2.6 MW/m in 25 h. Thus, a seasonal characterization of wave energy may be inadequate in the Gulf of Mexico. In contrast, the nominal power from wind turbines is about 3.5 MW.

About 80% of the rainfall in México drains in the southeast of the country in 90 days. The availability and storage of water resources is not a problem but its distribution. Wind farms in México face a similar problem because of the lack of transmission lines and power cables for interconnection with the National Electricity Grid. It is uncertain at this stage whether WECs can extract energy from short-duration, high energy events, as devices can change the way operate to a survival mode in which no energy is extracted. The result is an intermittent resource for users, in addition to the WEC being reviewed and repaired in case of damage. One possible solution is the design and construction of an electrical energy storage system to meet local demand, so that the extracted wave energy is generated and consumed on the site, as an antidote to the intermittency of supply and saturation of transmission nodes (bottle necks).

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High-resolution Wave Hindcasts for Resource Characterization in the U.S. Pacific Regions

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Keywords: *Wave Resource Characterization, Regional Wave Modeling, Unstructured-grid, WWIII, SWAN.*

The U.S. Pacific regions, which include the states of Washington, Oregon, and California along the Pacific Coast and the state of Hawaii in the Pacific Ocean, consist of most of the U.S. wave energy resource [1]. Wave resource characterization is an essential step for Wave Energy Converter (WEC) project siting and deployment. An accurate resource assessment requires long-term wave climate data with sufficient spatial coverage. This paper provides an overview of a modeling effort on high-resolution, long-term wave hindcast for resource characterization in the U.S. Pacific regions.

A modelling approach with nested WaveWatchIII (WW3) [2] and unstructured-grid Simulating WAves Nearshore (SWAN) [3] is presented. The SWAN domains cover the entire U.S. Exclusive Economic Zone (EEZ). The nearshore wave climate was simulated with SWAN at 300 m spatial resolution, driven by WW3 model output. The wave hindcasts were forced by NOAA's global Climate Forecast System Reanalysis (CFSR) wind field at 0.5 degree spatial resolution and hourly interval [4]. Model hindcasts cover a 32-year period from 1979 to 2010. Model configurations closely follow the International Electrotechnical Commission [IEC] Technical Specification [5]. Model hindcasts of the six IEC recommended resource parameters were validated with extensive wave buoy data maintained by the National Data Buoy Center (NDBC) and the Coastal Data Information Program (CDIP). Model skills are assessed with a set of standard model performance metrics. The challenges of high spatial resolution simulations at regional scale, directional resolution around complex islands and high per force computing requirement are also addressed.

The present study demonstrates that the multiscale nested grid modeling approach with WW3 and SWAN can efficiently generate multi-decadal and high-resolution wave climate data to support accurate resource characterization at regional scales.

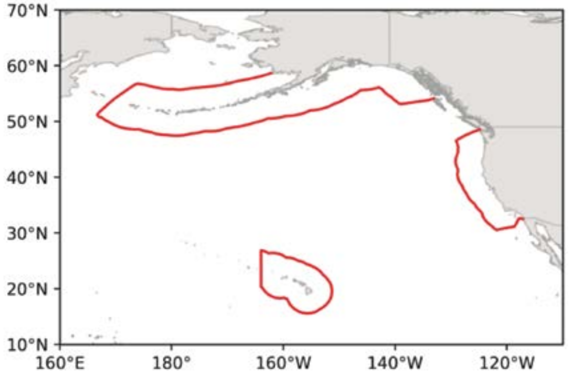

Fig. 1 Wave hindcast model domain for the U.S. Pacific Regions, including the West Coast, Alaska, and Hawaii Islands. The model domain covers the entire US. EEZ

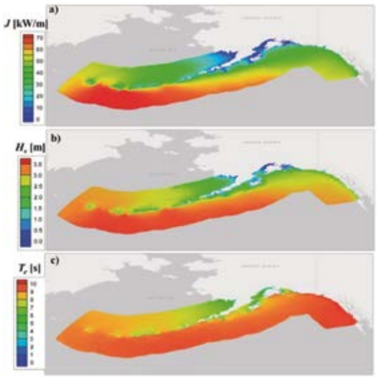

Fig. 2 Simulated annual averages of (a) omnidirectional wave power; (b) significant wave height; (c) energy period in Alaska region

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GIS based multicriteria analysis for offshore wind power potentials sites in Costa Rica's North Pacific

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Keywords: *GIS, Wind, Offshore, Marine Energy, Multicriteria.*

The purpose of this study is to design and execute a Multicriteria Analysis methodology based on a Geographic Information System in such a way that it allows a determination of Costa Rica's offshore wind potential for electricity generation. This study was conducted in the North Pacific region of Costa Rica, area where the highest wind speeds in Costa Rica are presented (Figure N°1).

With this study one more phase is completed in the knowledge chain of the national energy resource for electricity generation, a basic element in any planning and management process of a country's natural resources. From this, the portfolio of energy possibilities that Costa Rica has for the satisfaction of the electricity demand with non-conventional renewable energies is expanded.

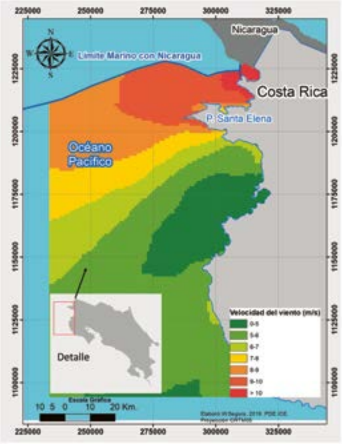

Figure N°1. Wind speed in the study area.

In the same way as the development of offshore wind energy projects around the world has increased, the use of GIS based multicriteria analysis applied to these types of studies has also increased. Here we present the first multicriteria analysis based on GIS conducted in Costa Rica to determine the areas with the greatest potential for offshore wind energy.

PRIORITIZATION OF ZONES

The multicriteria prioritization will identify the best areas for the development of wind farms in the North Pacific, based on physical, technical-economic and socio-environmental information of the study area. As a first step, a series of criteria were established with relative weights assigned, as shown with details in Table 1.

Table 1. Criteria and weights for multicriteria analysis.

Criteria	Unit	Description	Relative weight (%)
Average annual wind speed at 120 meters high	m/s	Identifies the wind speed at the site, measured at hub height (120 meters).	20
Bathymetry	m	It seeks to differentiate sites by the depth of the seabed, considering this as a relevant factor for the ease or constructive difficulty of the project.	40
Distance to the nearest site on the coast with enabling conditions for the development of the project.	km	It establishes differences between “pixels” according to its distance to the site closest to the coast and that has conditions to establish infrastructure that favors the construction and operation of the project.	5
Environmental criterion		Differentiate “pixels” according to their environmental importance or socio-productive interest.	20
Visibility of the project from the coast (landscape aspect)	km	It establishes differences between “pixels” according to the level of visibility of the project that exists from the point closest to the coast.	15
Total			100

The relative weights shown in table 1 were determined based on the expert criteria of the team members, averaging the individual values provided by each professional. For each criteria value rules were defined that allowed to grant a grade in each point or pixel of the area.

For the prioritization the method known as “Scoring” or “pesos” was used, which is based on the following formula:

$$\text{ValorAMC} = \frac{\sum \text{Notas} \times \text{Pesos relativos}}{\sum \text{Pesos relativos}}$$

Where the variable “Notas” refers to the multi-criteria rating that each “pixel” obtains by means of the determined value rule. The variable “Pesos” indicates the relative weight of each criterion used.

The creation of the model required the development of raster maps for each of the selected variables, for which a series of algorithms of the ARCGIS software were used. They were integrated into only one, for which the RASTER CALCULATOR algorithm was used. The formula used for integration was:

$$\text{Peso} = (CB \cdot 0.4) + (CA \cdot 0.20) + (CVis \cdot 0.15) + (CD \cdot 0.05) + (Vel \cdot 0.2)$$

Where CB represents bathimetry, CA represents environmental criteria, CVis represents visibility, CD represents distance to coast, and CVel is the wind speed. In order to analyze the robustness of the model a sensitivity analysis was developed considering four alternative scenarios. The sensitivity analysis consisted of changing the weights of the variables.

RESULTS

The multicriteria analysis performed contemplated a baseline scenario, developed from the weights and value rules described. The result of this modeling, which classifies the area with priority levels between 1 and 5, is presented in Figure 2. This figure shows two areas with priority 1 (dark green color), at depths less than 50 meters for systems anchored to the seabed. One is located at the north end of the study area, next to the border with Nicaragua, at the exit of Salinas Bay, with an extension of 1 180 hectares. The other is located north of the Santa Elena Peninsula, opposite the port of Guajiniquil, with an area of 555 hectares.

Another sector with priority 1 is located in to the northwest of the study area, but quite far from the coast, at depths much greater than 50 meters, which would undoubtedly involve floating systems. This sector has an extension of 72 201 hectares.

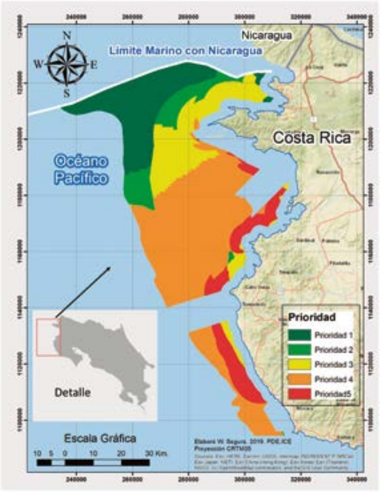

Figure 2. Multi-criteria prioritization for offshore wind development.

CONCLUSIONS

The baseline scenario of this study identified three priority 1 zones for offshore wind developments. These are the areas where attention should be focused for future studies, both for the measurement of offshore wind resources and for possible project identification studies.

There are priority 2 areas in the study, which should not be neglected when selecting sites for future studies or developments.

The results of the multicriteria analysis reflect alternative scenarios. From the sensitivity analysis, it is concluded that the model is sensitive to the variation in the weights of the wind speed and bathymetry criteria.

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Determination of offshore wind power potential in Costa Rica

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Keywords: *Wind, Offshore, Marine Energy, Costa Rica, Electricity.*

In 2009, the Geophysics Research Center of the University of Costa Rica (CIGEFI) developed a study to develop maps with wind speed and power density values, contemplating both annual and monthly averages of each variable (CIGEFI, 2009). This study is the basis of the present investigation.

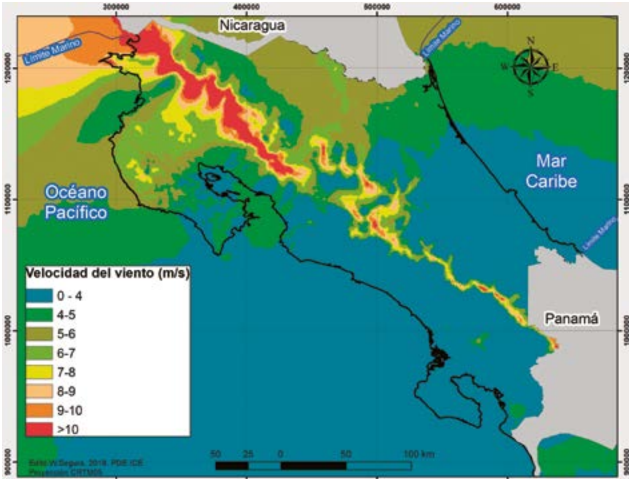

Figure N°1. Annual Average wind velocities at 120 m elevation.
Source: Adapted from CIGEFI, 2009.

The purpose of this study is to determine Costa Rica's marine wind potential for power generation, centered in the North Pacific region, the area of the country where the highest speeds of this resource are presented.

The evaluation shows a marine area of great natural wealth, in biodiversity and ecosystems, under different conservation regimes, ranging from protected marine extensions that are national parks to responsible fishing areas. In social terms, along the coast there are several communities that use marine resources as their way of survival, through fishing or tourism.

The results of the study show that Costa Rica has marine wind potential for electricity generation in a commercial scale. A technical potential of 14 400 MW and an energy prediction of 59 058 GWh/year was determined for areas with a plant factor greater than 34%. This can be considered as the profitable technical potential of Costa Rica with offshore wind energy.

Of the total, 14 200 MW are obtained through floating generation systems and 200 MW with systems anchored to the seabed (in depths lower than 50 m).

There is an area that presents plant factors greater than 50%, with a potential of 4 780 W and an annual production of 21 519 MW. Of these, 4 640 MW is through floating systems and 140 MW with systems anchored to the seabed.

The investigation determines that the country has a reduced marine platform below 50 m, most of it is between 50 and 200 m. The total usable area in the study area covers a space of 3 721 km2.

ECONOMICALLY FEASIBLE TECHNICAL POTENTIAL

Environmental and separation restrictions are considered to determine the economically feasible technical potential, and work is done with systems that can exceed 3 000 hours of full annual load (34% of plant factor). This restricts the area of exploitation of offshore wind energy and therefore the corresponding potential.

For the study area, a technical potential of 14 400 MW, an annual generation of 59 058 GWh and an average annual density of 37 GWh/km2 were determined. These results are shown in Table 1. In this case, the anchored potential is reduced to 200 MW and the floating potential to 14 200 MW.

Table 1. Technical potential, plant factor greater than 34%.

Offshore Wind Technology	Power (MW)	Energy GWh/year	Annual Average Energy Density (GWh/km2)
Anchored	200	830	37.4
Floating	14200	58 228	36.9
Total	14400	59 058	37

To quantify this potential, it should be noted that in energy terms the value of 59 058 GWh/year represents more than 5 times the current annual electricity demand, which is in the order of 11 000 GWh. This reinforces the relevance and magnitude of the marine wind potential obtained for Costa Rica.

Within the resource characterization, it was found that there are areas that exceed 4 380 hours of full annual load (50% plant factor), which would produce a technical potential of 4 780 MW, with an annual generation of 21 519 GWh and an energy density of 41 GWh/km2.

Table 2. Technical potential with a plant factor greater than 50%

Offshore Wind Technology	Power (MW)	Energy GWh/year	Annual Average Energy Density (GWh/km2)
Anchored	140	661	43
Floating	4640	20858	40
Total	4780	21519	41

In table 2 we can see this technical potential corresponding to a power factor greater than 50% for each technology. For this condition, the anchored potential turns out to be 140 MW and the floating of 4 640 MW.

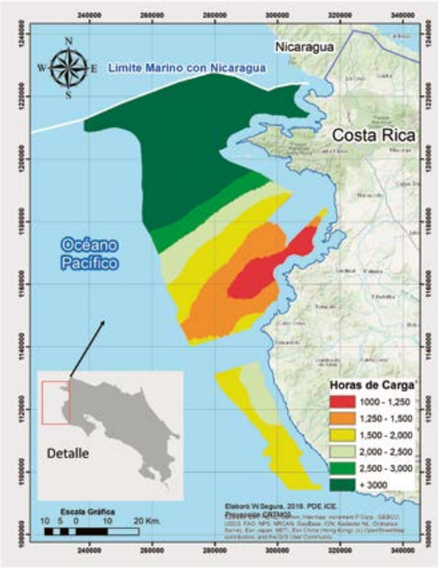

Figure 2. Distribution of the hours of full charge in the study area.

CONCLUSIONS

Costa Rica has the resource availability to produce electricity using offshore wind energy. The results of this study reflect a technical potential of 14 400 MW and an energy of 59 058 GWh/year for areas with a power factor greater than 34%. Of this potential, 98.6% (14 200 MW) results with floating generation systems and about 200 MW with systems anchored.

It is concluded that the national offshore wind potential is highly conditioned by the reduced continental shelf of depths below 50 m, which clearly tilts the landscape towards floating systems that are continuously evolving and improving technologically and economically and will constitute a feasible solution in the near future.

It is determined that there is an offshore wind potential of 4 780 MW in areas with power factors greater than 50, with an annual production of 21 519 MWh. Of these, 4 640 MW with floating systems and 140 MW with systems anchored.

It is concluded that power factors greater than 50% for wind farms represent a special condition worldwide, so that the potential identified constitutes an energy resource of great value, which must be evaluated technically, economically and environmentally in the future, to consider its eventual incorporation into the national energy matrix.

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Evaluation of the Oceanic Thermal Potential on the Coasts of Panama

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Keywords: *OTEC, Oceanic Thermal Energy, Energy Security, Efficiency.*

Energy represents an indispensable resource for the development, success, and economic stability of any nation [1]. Therefore, the dependence on fossil fuels represents a global issue [2]. Currently, an increase in energy demand has been reflected due to social dependence on technology and a high quality of life, particularly in developed countries. Besides this, most of the activities still rely on fossil fuels, releasing CO2, a major contributor to global warming [3]. Topics such as global warming, various types of pollution, lack of oil supplies, shortage of drinking water, among others, are associated with the generation of electrical energy, and its dependence on fossil fuels. [1], [2].

The scientific society has contributed to the search for alternatives that aim to produce clean energy while supplying the growing energy demand and mitigate the environmental impact induced by the use of traditional fuels for power generation. Implement renewable energies sources and the continuous improvement of these projects themselves as potential represent alternatives to solve such problems [3].

Electricity generation from renewable sources has achieved acceptable production levels due to their increasing technological development in recent years [5]. They represent a promising alternative to meet energy demands without inducing irreversible impacts on the environment. Ocean energy (tidal, thermal differential, salinity differential), is a promising alternative to supply future energy demands [4].

The oceans retain approximately 15% of the total solar energy as thermal energy [5]. Roughly, ninety-percent of the global ocean resource corresponds to Ocean Thermal Energy Conversion (OTEC), 300 [3].

The OTEC is a process that can generate electrical energy using the temperature differential between warm surface seawater and deep cold seawater that can operate an Organic Rankine Cycle [9]. The OTEC process can be used to produce hydrogen, drinking water, cold water for air conditioning, in addition to promoting tourism, aqua-cultural activities, and creating jobs for the neighboring cities [3], [5]. OTEC represents the highest potential for the use of ocean energy. Studies have found that implementing OTEC might not induce a significant impact on the thermal structure of the ocean [1].

The availability of this resource is estimated to range up to 30, and the deployments of 7 would produce little noticeable effects on ocean temperature fields [3].

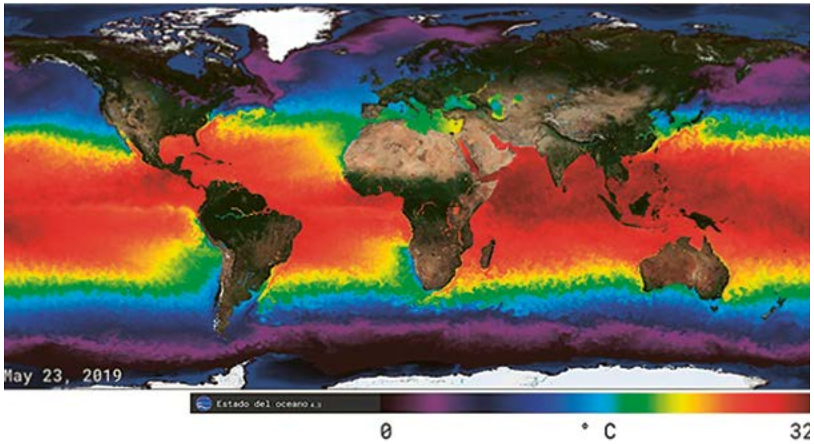

Fig. 1 Global distribution of oceanic thermal energy. [6]

The global thermal energy of the oceans is estimated to be [7]. The operating temperature differential required by OTEC must be at least 25 ° C for this technology to operate with representative results or levels of efficiencies. Without the use of other thermal sources, these differentials are achieved between latitudes 201 and 241 north and south of the equator, respectively, as can be seen in Fig. 1.

The oceans cover more than 70% of the earth's surface [5], [8], making them the largest solar energy collector and energy storage system in the world [8]. It is estimated that on an average day, tropical seas absorb an amount of solar radiation equivalent in heat content to a few barrels of oil [3], [5], [8].

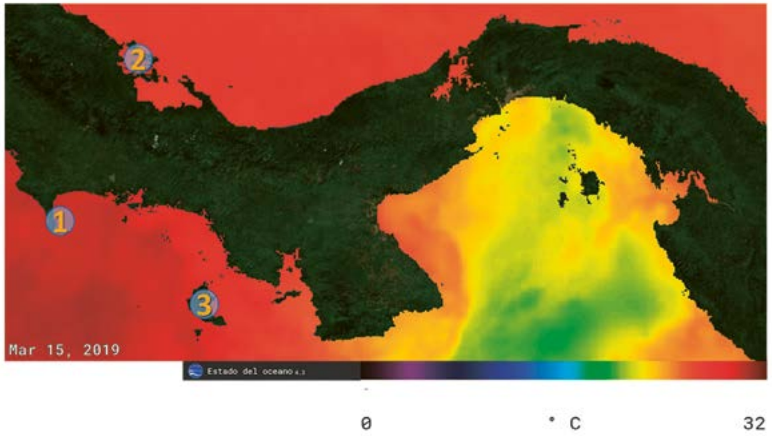

Fig. 2. Panama's Ocean Thermal Potential [6]

Fig. 1 locates the Republic of Panama in the intertropical zone near the equator. The country has coastal limits in the Caribbean Sea and the Pacific Ocean. From this figure, it can be observed that the oceanic territory of Panama reflects a oceanic thermal potential. The three sites of interest were considered for this study, as shown in Fig. 2. Some anomalies in the Sea Surface Temperature (SST) can be observed, as well in this figure.

In Fig. 3, the bathymetry of the oceanic territory of Panama is observed. Several locations can be identified with acceptable depths that might store water at low temperatures. In this document, the SST for the year 2018 for Isla Coiba, Punta Burica, and Punta Mariato is shown. The data was obtained from the Physical Oceanography Distributed Active Archive Center (PODAAC) database; all measurements were taken with an error of 0.05 °C. The deep-sea water temperature (DST) is estimated to be 4–5 °C at a depth of approximately

700–1000 m. However, throughout the oceanographic territory of Panama, several points of interest are identified where it would be possible to reach these depths. The Caribbean Sea shows shallow regions compared to the Pacific Ocean, therefore the selection of our interest in this region.

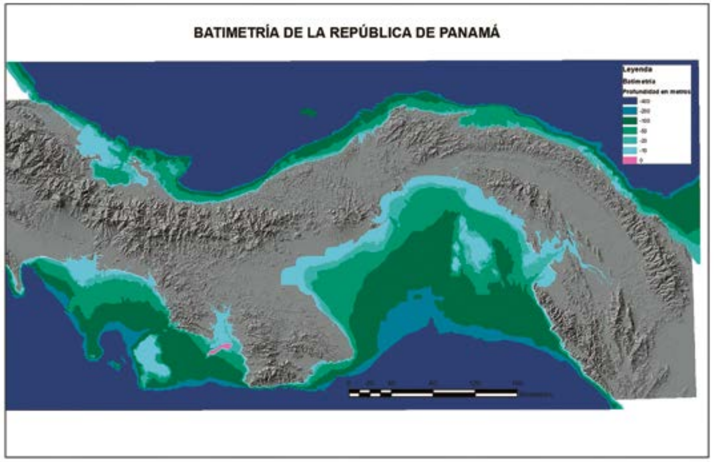

Fig. 3. Map. Bathymetry of Panama [10]

To evaluate the Oceanic Thermal potential for the implementation of OTEC, the SST was used because it represents a key indicator of the thermal potential that can be obtained based on the sea surface temperature of the identified sites. This is important because the temperature differential between warm surface seawaters and deep cold seawaters governs the OTEC operability and its efficiency [1-5,7-9]. To evaluate this potential, we carry out a comparative analysis between the selected sites. In this analysis, the daily SST corresponding to the year 2018 was considered, at each point, using the PODACC database.

RESULTS

In Fig 4., we can observe the monthly average SST corresponding to the three sites. Even though there are some variabilities, these were not representative. The minimum SST was close to 28 ° C, occurring in October, where the rainy season is more intense.

Even under these climatic circumstances, The SST reflected acceptable values for OTEC operability [2]. These results evidenced that the oceanic territory of Panama presents a low variation of the surface seawater temperature. As a result, the implementation of OTEC could be stable. However, other variables need to be considered. Furthermore, in Table 1, we have synthesized the annual minimum and maximum SST for each site of interest.

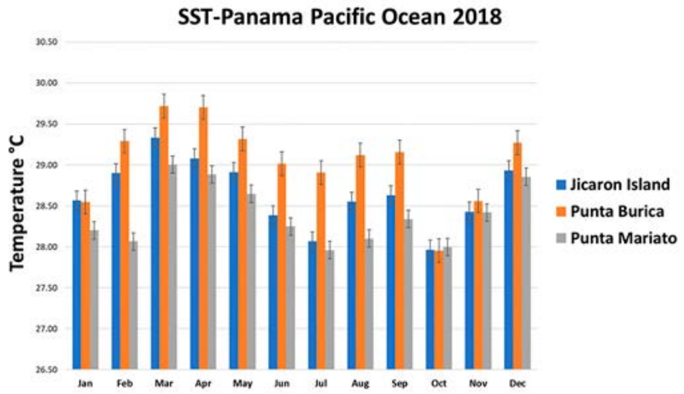

Fig. 4. Monthly SSTmax of the year 2018 corresponding to the sites under study. [6]

Then, we can imply that Punta Burica showed the best conditions in terms of SST, presenting the most attractive conditions to take advantage of the oceanic thermal potential.

Table 1. Minimum and maximum SST corresponding to the study sites.

Interest site	$\text{SST}_{\text{mín}}$ (°C)	$\text{SST}_{\text{máx}}$ (°C)
Punta Burica	27.15±0.328	30.60±0.328
Punta Mariato	26.55±0.305	30.45±0.305
Jicaron Island	27.30±0.295	30.00±0.295

Moreover, the small variation in the SST, coupled with the proximity of these sites to the costs, could allow the implementation of new actions or technologies that can be exploited as ocean energies, such as OTEC. The geographical location of Panama could benefit this country with the use of the ocean's thermal resources. However, more studies should be carried out to investigate the temperature difference and the coastal bathymetry that allow fair use of this resource.

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ENVIRONMENT

Multidisciplinary investigations of environmental effects of 1.2 MW Tidal Power plant in the Eastern Scheldt storm surge barrier

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Keywords: *Marine energy, tidal energy, environmental effects, marine mammals, seabed morphology.*

The Oosterschelde storm surge barrier is a dam that contains 62 gates that can be closed during storm surges. In 2015, the Dutch company Tocardo Tidal Power installed a 1.2MW tidal power plant in one of the gates comprising an array of 5 turbines.

Fig. 1 Tocardo Tidal Power 1.2 MW dam-integrated array

This paper discusses the methods and results of a unique two-year monitoring program to assess impacts on both the biotic and abiotic ecosystem as well as effects on the reliability of the storm surge barrier itself [1]. The collaborative research was undertaken by four research institutes. Changes in flow patterns were monitored and modelled, the decrease in tidal amplitude, impact on sedimentation processes, the development of numbers of porpoises and seals in the Oosterschelde and possible collisions between these mammals and the turbines were all part of the study.

The observations of the flow field in the gate with turbines suggest that the turbine contribution to the drag of the storm surge barrier is limited for the current design in the observed cases, hence possible effects on the tide and seabed protection are expected to be small. The turbines' presence in the barrier may have affected the flow separation downstream of the barrier piers and sill, possibly suppressing energy losses in the separation zone locally.

An effect of the tidal power plant on tidal amplitudes in the Oosterschelde could not be established. Water level data on either side of the barrier were compared with long-term water level measurements. Results show that the measuring period is too short to relate any changes in water levels to the presence of the tidal power plant. Coincidental variations in tidal range in combination with the long-term variation of 18.6 years are observed anyway.

Trends in numbers of seals and porpoises were analyzed, based on data collected in on-going monitoring programs (seals: 1995-June 2017 including porpoises 2009-2018).

Numbers of both seals and porpoises at either side of the barrier have increased during the last 25 years. Numbers of marine mammals do not show any noticeable, unexplainable deviations from the trend lines after the turbines were installed. However, given the small number of post-installation data points, such an effect should have been very strong in order to stand out.

Post-mortem research on seals and porpoises found dead in the Oosterschelde and on the seaward side of the barrier (post- installation) identified two porpoises that had died from blunt trauma. However, the cause of the blunt traumas could not be identified, and these two cases could therefore not be related to the presence of the tidal power plant.

The research presented in this paper was shared during a number of interactive stakeholder meetings. The process of stakeholder engagement will also be reported on.

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Coastal Energy Development–Recent Canadian Experiences

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***Keywords**: Tidal Power, Marine Noise, Electromagnetic Fields, Environmental Impacts, Underwater, Cables.*

Canada has relevant experience in assessment of environmental impacts associated with coastal electric power development. While development of offshore wind power is far behind that in Europe, undersea power cables, tidal power turbines, and marine noise are major environmental issues in Canada's coastal zone. Atlantic Canada is conducting research into tidal power development in areaws with among the highest tidal currents in the world. A new underwater cable is carrying 500-megawatt (MW), +/- 200 to 250-kilovolt high voltage direct current (HVDC) and high voltage alternating current (HVAC) between the Island of Newfoundland and Cape Breton, Nova Scotia. Fundy Ocean Research Center for Energy (FORCE) has been studying tidal power development in extreme high current coastal areas for a decade, including prototype installations of turbines and undersea cables. On Canada's West Coast, marine noise has become a major issue with concern about impacts on an endangered population of killer whales, which live in areas near the busy port of Vancouver.

Bailey et al. (2014) provided a review of impacts from offshore wind farms. They note the large profusion of coastal wind farms in Europe and their tendency to increase in size and move further from the coast. As with other recent studies of biological impacts, emphasis is on the population level, connectivity and effect on ecological systems, especially feeding and reproduction. In addition to the construction impacts, particularly pile driving, operational impacts are associated with underwater noise and the electromagnetic radiation from undersea power cables. These issues are common with most, if not all, offshore power developments.

In its review of underwater noise, the US National Oceanic and Atmospheric Administration (NOAA) identified renewable energy sources (e.g., wind, wave, and tidal farms) as one of many sources of human introduced sounds. The NOAA roadmap explicitly mentions environmental monitoring of pile driving at offshore wind farms in Europe. The report also notes that unlike marine mammal studies on temporary threshold shifts that are typically published in peer-reviewed journals, marine mammal behavioral data are found in a variety of published and unpublished documents (e.g., monitoring reports, technical reports), with varying levels of quality.

The lack of peer-reviewed scientific studies also applies to the impacts from electromagnetic fields from undersea power cables. Using state-of-the-art telemetry, the impacts of movements of snow crab were studied in relation to the 500 MW undersea electrical cable in Eastern Canada. Recent advances in technology allow improved data collection from acoustic transmitters using sensing gliders that can collect data remotely but in real time (Cote et al. 2019). It is recognized that these undersea cables may create a barrier to normal Snow Crab movement through static magnetic fields, increased temperature, and induced electrical fields or the physical barriers created as a result of trenching activities and substrate disturbance (DFO 2018). At present, there is no information that can be presented to definitively describe their effects upon Snow Crab. The power utility will be conducting studies of snow crab movements when power is flowing through the cable (Figure 1).

In terms of noise, all levels of government, academic and public groups are engaged in trying to reduce impacts on the Southern Resident Killer Whale population. The primary foraging area has been identified and a number of measures are being implemented (see Figure 2).

The research and mitigation carried out to reduce impacts of marine noise and electromagnetic radiation demonstrate the complexity of the issues. There is a tendency to place the knowledge of engineering and technology ahead of the uncertainties of biology and ecology — an appropriate balance is important but not easy to achieve. The recent experience in Canada can be applied generally to coastal energy developments and provides important priorities for research and mitigation. Some of the key issues include enhanced consultation and community involvement for increased effectiveness, a broader focus on ecological systems and pathways, and use of new technologies in monitoring.

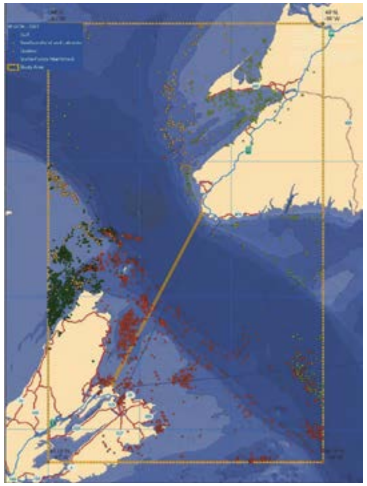

Figure 1: Distribution of snow crab in relation to the Emera-Newfoundland power cable.

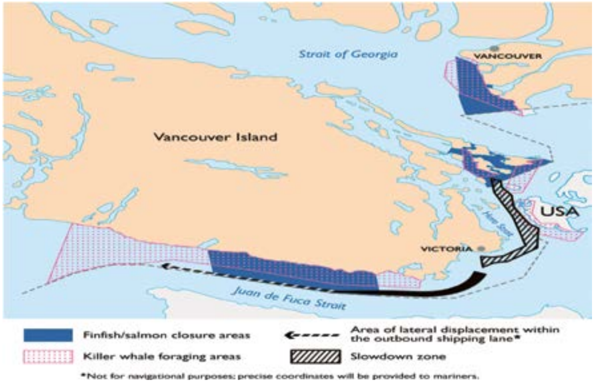

Figure 2: Mitigation initiatives relative to the killer whale foraging area around Vancouver Island.

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SEA Wave: Addressing the long-term environmental concerns associated with the development of wave energy technology

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Keywords: *Environmental impact, wave energy technology, de-risking consenting, multi-device type monitoring, SEA Wave.*

The potential environmental impacts associated with deploying wave and tidal energy converters, coupled with the novel nature of their infrastructure, has led regulators to adopt a precautionary approach which often requires developers to undertake substantial environmental monitoring. Regulators from across jurisdictions require reassurance from evidence-based monitoring to be able to adopt a risk-based consenting procedure in the future. Led by the European Marine Energy Centre (EMEC), a consortium of technology device developers, policy and academic experts, data managers and key stakeholders have launched the SEA Wave project. The project has been devised to address the long-term environmental concerns around the development of this emerging technology, particularly focused on wave energy. As a European Commission funded project, SEA Wave builds on existing EU funded initiatives to streamline future site development and further de-risk the development of the sector. As a successor to the H2020 Clean Energy from Ocean Waves (CEFOW) project with Wello, the SEA Wave project incorporates environmental monitoring campaigns around the CorPower Ocean, Ocean Energy and Laminaria wave energy converters, as well as Wello's Penguin device. The data collected will be analyzed and used within ecological models to provide deeper insight into the response of host environments to the presence of this emergent technology.

Targeted research effort across multiple device types, for the first time, will address the lack of understanding about the direction and magnitude of environmental response, hence further de-risking the deployment of ocean energy convertors across Europe. Device-specific environmental demonstration strategies have been developed for each technology within the SEA Wave project, ensuring robust, consistent, and comparable sampling strategies are used throughout the project. The sampling strategies employed by SEA Wave project partners have been informed by undertaking a gap analysis of current knowledge and risks followed by a critical analysis of mitigation and monitoring techniques.

The gap analysis was informed by a number of previous studies, in particular the Offshore Renewables Joint Industry Programme Ocean Energy's Forward Look and Ocean Energy Systems Environment's (formerly known as Annex IV) State of the Science Report. Following the review, SEA Wave issued a call for evidence to key stakeholders to allow the project consortium to the reach a consensus on the priority knowledge gaps and consenting issues upon which coordinated strategic data collection and research efforts should focus on in the project and across the sector, ensuring improved efficiencies in the allocation of resources and distribution of effort. A broad consensus was reached between industry, regulators, stakeholders, and wider research community on a number of high priorities consenting issues and risks, these are summarized in Table 1.

Table. 1 Key strategic consenting issues and risks – wave and tidal current

Topic	**EIA/HRA issue and knowledge gap(s)**
Ecological	
Collision risk	Nature of potential interaction
	Possible physical consequences
	Suitable instrumentation and methodologies for monitoring behavior and detection of event
Underwater noise	Lack of available data from operational devices
	Array effects on marine mammals
Electromagnetic fields (EMF)	Data on effects on fish would improve confidence
Displacement	Birds, marine mammal, shark displacement of essential activity
General	Strategic baseline data
	Agreed approach to undertaking site characterization and baseline surveys
	Further data of mobile species populations
	Population level impacts and methods to assess the significance of population level impacts
Human environment	
Impacts on commercial fisheries	Lack of standardized approach to assessing the availability of alternative fishing grounds
Impacts on shipping and navigation	Difficulties with assessing and mitigating the potential cumulative impacts on shipping and navigation
Social and economic impacts on local communities	Difficulty with identifying, assessing, mitigating, and managing potential cumulative social and economic impacts

Topic	EIA/HRA issue and knowledge gap(s)
Physical environment	
Impacts on physical processes	Development of hydrographic models to predict the effects of changes in water flow and energy removal
	Validation of hydrographic models
Regulatory processes	Methods/processes are required to help manage perceived and identified environmental risks
	Methods/processes are required to predict and measure potential cumulative impacts around clusters of development
	Agreement is required on the approach to applying a design envelope approach
	Agreement is required on the approach to developing Project Environmental Monitoring Programmes and incorporating adaptive management strategies
	Guidance is required as to how best to consider decommissioning

Following the identification of current industry knowledge and consenting risks, a critical analysis of monitoring and mitigation measures employed in completed or planned wave and tidal energy projects was performed. The aim of the task was to inform industry with knowledge of successes and lessons learnt in relation to these measures but also to inform the development on the environmental demonstration strategies undertaken in the SEA Wave project. As part of the analysis, extensive stakeholder consultation was undertaken in order to gather a comprehensive list of management measures designed to manage the environmental effects of wave and tidal projects during construction, operation, and decommissioning/removal. Environmental management measures are considered in relation to the relevant potential environmental impact, these were as follows:

- Barrier to movement
- Change in sediment dynamics
- Changes in tidal flow, flux, and turbulence
- Collision Risk
- Displacement
- Dissipation of wave energy
- Electromagnetic fields
- Entanglement
- Entrapment
- Habitat creation
- Introduction of marine non-native species
- Lighting
- Loss of seabed habitat
- Pollution
- Underwater noise
- Vessel disturbance

Key experts in the management of the impacts and potential effects of wave and tidal energy developments on the marine environment were engaged in interview style meetings to review the lists presented alongside the advantages and disadvantages of each environmental management measure. Remarks regarding specific user experience were recorded including any challenges encountered.

The methodologies employed in the environmental demonstration strategies have been devised utilizing the expertise and user-experiences divulged during the critical analysis. The proposed methodologies for use include high-definition towed camera array survey for seabed biodiversity and integrity monitoring (see Figure 1), non-destructive baited and un-baited static video camera surveillance for cryptic, mobile and larger species behavior, fisheries biomass response monitoring using static and mobile fisheries echosounders, and underwater noise characterization to understand implications on the local soundscape.

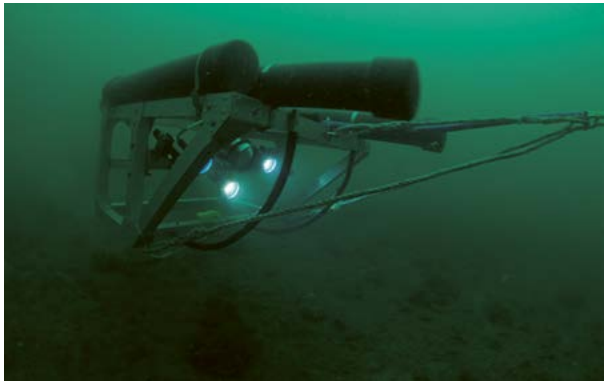

Fig. 1 High-definition towed camera array (Source: University of Plymouth)

During the data campaigns, a review of environmental monitoring equipment used for data surveys will assess their effectiveness, with variations in the equipment for different WECs to allow further optimization. For each relevant impact pathway, the multitude of data collection streams will be combined to model, temporally and spatially, the extent of ecosystem changes. The receptors assessed in the models will include seabed, birds, fish, and marine mammals. To ensure the robustness of models, control sites will also be surveyed to allow consideration of natural variation and wider anthropogenic pressures.

The presentation will discuss the all-inclusive review and gap analysis conducted regarding environmental impacts, remaining uncertainties, and current consenting risks to gain a consensus on the priority knowledge gaps relevant to the industry. The paper will then discuss the environmental monitoring strategy design process adopted within the SEA Wave project, to address the identified knowledge gaps. An overview of the selected monitoring methodologies and survey design process will also be reported.

The Road to Risk Retirement: Evaluating and Communicating Environmental Risks that Affect Consenting

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Keywords: *Marine renewable energy; risk retirement; environmental effects; wave energy; tidal energy.*

Concerns about the potential effects of marine renewable energy (MRE) devices on the marine animals, habitats, and ecosystem processes continue to slow down siting and consenting/permitting of wave and tidal devices worldwide. Regulators must apply laws and regulations that are not well suited to this new ocean sector. The challenges facing regulators include assessing potential environmental effects with new types of technologies that are installed in high- energy ocean environments that are not well studied; potential conflicts of MRE development with existing ocean users; and the reality that many of the marine animal populations considered at risk from MRE devices are already under stress from other anthropogenic activities. Stakeholders, including environmental conservation groups, may welcome the advent of a low-carbon energy source, but remain concerned that marine animals, especially marine mammals, fish, seabirds, and sea turtles, may be harmed. Although the MRE industry is young, there is a considerable body of knowledge that has been acquired to understand the risks posed by each portion of an MRE system that might harm the marine environment (“stressors”) and the specific animals, habitats, or processes in the ocean that might be harmed (“receptors”).

The collective efforts of researchers, MRE device developers, regulators, and other stakeholders over the past decade have reached a consensus on the most critical stressor/receptor relationships that affect consenting/permitting [1]. These risks include: possibility of animals colliding with turbines; effects of underwater noise from installation and operation of MRE devices on marine animals; effects of electromagnetic fields from cables and other device components on marine animals; changes in seabed and water column habitats from MRE systems; attraction of animals to MRE devices and balance of station; avoidance or barrier effects of MRE arrays; changes in circulation and sediment transport from MRE operations; and entanglement of marine animals in mooring lines of MRE projects [2]. For these stressor/receptor interactions, information from other industries may resolve risks and provide mitigation strategies if needed.

Through two related efforts (OES-Environmental and Triton Initiative), issues associated with environmental effects of MRE technologies are being addressed to further move the consenting process towards “retirement” of certain risks, which in turn simplify and shorten regulatory requirements and timelines. A key part of the process for retiring risk includes ensuring that regulators, and the stakeholders they support, understand what is known scientifically; that the appropriate level of risk is assigned to each stressor/

receptor interaction; and that data collection efforts required for consenting and licensing are proportionate to and inform that risk. This process of “data transferability” and “data collection consistency” is aimed at ensuring that existing data and information are readily available to regulators and interested stakeholders, and that there are accessible descriptions of preferred data collection methods and appropriate data collection instruments.

Under the international consortium Ocean Energy Systems (OES), 15 participating nations work together to understand and disseminate information on environmental effects of the MRE industry. The OES-Environmental task has developed a risk retirement process that examines data from already consented/permitted projects to determine whether there is reason to forgo extensive data collection and analysis for every small MRE development. Inherent in examining the pathway to risk retirement is the application of a data transferability process consisting of three components: (1) a data transferability framework; (2) a process for data discoverability; and (3) a set of best management practices for data transferability and data collection consistency (Figure 1).

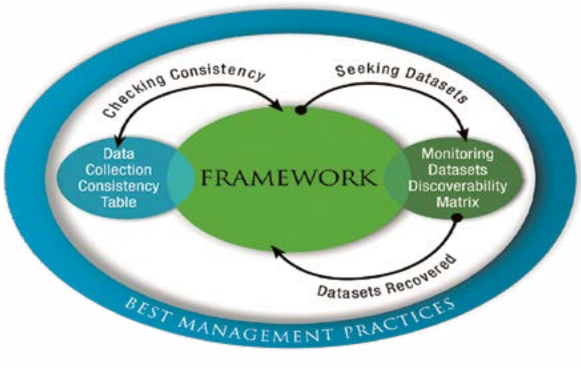

Fig. 1 Data transferability process that support risk retirement of environmental effects of marine renewable energy development.

In order to carry analyses for risk retirement, datasets need to be collected in a consistent manner. Under the US Department of Energy *Triton* program, methodologies and instrumentation for optimal data collection are being field-tested to create a catalogue of consistent and accurate means to measure key stressor/receptor relationships. These field trials include methodologies for measuring and analyzing the collision risk of fish and marine mammals with turbines; effects of underwater noise from devices on marine animals; effects of EMF from export cables and inter-array cables on marine animals; and effects of habitat changes in the benthic and pelagic ecosystems.

This presentation will describe examples of consented/permitted projects from various OES nations as case studies to illustrate and test the data transferability and data collection consistency process. Additionally, results of methods development and analysis for key stressor-receptor interactions, including fundamental research examining the interaction between resident fish and underwater environmental monitoring systems, will be discussed.

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How international standardization and certification accelerate commercial uptake of marine energy convertors

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Keywords: *Marine energy, tidal energy, standards, certification, experimental trial, test protocol, IEC, IECRE, conformity assessment.*

Conformity assessment can mitigate technical and financial risks of the technologies in terms of performance and structural integrity, which in turn attracts finance and encourages international trade. As Marine Energy is an emerging industry, International Standards are yet to be published and consistently adopted. A conformity assessment system is still under development. The implementation of international standards and certification schemes de-risks the technology providing a good level of confidence to insurers, investors, and licensing authorities. This is one of the main recommendations from the Ocean Energy Forum Strategic Roadmap [1].

MET-CERTIFIED (Marine Energy Technologies – Certified), is an Interreg 2 Seas funded project [2]. The aim of the project is to accelerate the development of standards and certification schemes for marine energy technologies under the umbrella of the IEC [3].

The project enables the application of International Electrotechnical Commission (IEC) technical specifications 62600 for marine energy convertors to pilot projects and tank testing. The Technical Specifications are currently under development or revision. To date experimental campaigns and three of the pilot projects have been completed. The pilot project includes the Eastern Scheldt Tidal Power plant, the Texel Floating Platform installed at EMEC and the SME Plat- I installed in Connel near Oban.

To support the above project, along with other marine energy related technologies, a new technical standard of assessment is being developed. Referred to as the 62600-4 standard, this document aims to provide a globally accepted consistency in the way such technologies are assessed both from the technology and risk perspectives.

The benefits are twofold. Firstly, the developer's device is assessed to applicable technical specifications. Secondly, feedback on practicality based upon its deployment on real projects is provided to the IEC Technical Committee 114, so the data-driven learning can be incorporated into future editions of the relevant International Standards.

It is the objective of this paper to present the learnings to date in the MET-CERTIFIED project, Including:

- how test facilities can provide services under the new certification system
- how we interacted with finance and insurance community on the role of certification in financing commercial projects
- results and recommendations from test and experiments to date
- recommendations and developments in conformity assessment.

The Technical Specifications applied and recommendation for changes will be discussed, covering the IEC 62600 -2 for design Requirements, -10 for moorings, -30 for electrical power quality, -40 for acoustics, -200 for tidal power performance assessment, -201 for tidal resource assessment and -202 for scale testing. Underlying the above, an overview of the application of the 62600-4 technical specification for technology qualification will also be provided.

The process of certification against the IECRE certification system will be explained: from concept to construction and installation of a full-scale tidal array developed by Tocardo Tidal Power [4].

The project is funded by Interreg 2 Seas, the Dutch ministry of Economic Affairs, the Provinces of South Holland, North Holland & West-Flanders.

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Large scale model investigation for monopile decommissioning of offshore wind turbines

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Keywords: *Monopile, offshore foundation, decommissioning, offshore wind, life cycle*

The German offshore wind industry has historically grown since the first offshore wind farm (OWF) “alpha ventus” was completed in 2010. Since the end of 2017, a total number of 18 OWF with a capacity of about 5 GW have been operating in the German Exclusive Economic Zone (EEZ) [1]. While the majority of the population and the industry focus on new projects, it appears the life cycle observation and especially the decommissioning phase remain largely unattended. This narrow view can lead to unexpected and expensive consequences in the future. The German authorities have set a maximum lifetime of an OWF to 25 years. The decommissioning of a complex structure as an offshore wind turbine (OWT) needs to be planned well in advance. There are numerous aspects that make the decommissioning a challenge, such as the federal regulations, the marine environment, and the technical limitations of offshore operations.

The Institute of Foundation Engineering and Soil Mechanics of the Technische Universität Braunschweig (IGB- TUBS) got the funding for the research program on technical solutions with large scale tests for decommissioning of offshore monopiles named DeCoMP.

This article gives an overview of the problematic matter of dealing with monopiles after the predicted lifetime, the geotechnical condition, analyses of the current decommissioning options and identification of issues in regard to the decommissioning method.

Large scale tests of decommissioning methods for a complete removal of offshore monopiles, such as vibratory extraction, internal dredging, external jet drilling and the use of buoyancy force, are presented and compared concerning a possible combination. First test results of overpressure pile extractions (Fig. 1) and a variation of vibratory extractions (Fig. 2) are presented.

Some of the presented methods are highly experimental, others are commonly used in other industries.

Fig. 1 Decommissioning with overpressure – sealed pile head equipped with pressure and strain sensors

Fig. 2 Vibratory extraction with an Ape Model 3 vibrator of Cape Holland

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Environmental impacts of ocean energy devices: Life Cycle Analysis

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***Keywords**: Life Cycle Assessment, Ocean energy, environmental impacts.*

INTRODUCTION

Up to date, population growth and global industrial development have sustained an increase in energy demand. Fossil fuels are the most widely used source of energy. Nevertheless, the reserves of these fuels are limited and their use on a large scale contributes significantly to the Climate Change (CC), through the Greenhouse Gases (GHG) emissions [1]. In that regard, global energy policy has developed strategies for energy generation from renewable sources. Among these is ocean energy, which in recent years has seen a considerable increase in research development and application. In this sense, it is of great importance to evaluate these technologies under an environmental approach, taking into consideration the possible environmental impacts that these systems can generate throughout their life cycle. Life Cycle Assessment (LCA) is a methodology designed to quantify the environmental impacts of a technological system during its life cycle [2]. Therefore, the objective of this study is to evaluate the environmental impacts of ocean-based power generation technology systems applying LCA methodology. As an outcome, critical stages of the systems evaluated are identified, along with areas of opportunity for ocean energy technologies.

METHODOLOGY

LCA is a methodology that allows the identification of global environmental impacts generated by a process or system, considering since the raw material extraction until the end of its useful life cycle, considering the final disposal of the technology. Figure 1 shows the stages that conform an LCA, all of which are interrelated. The main objectives of LCA are to reduce the use of resources and emissions into the environment, as well as to improve the social/environmental/economic performance of a system and/or service throughout its entire life cycle. This can enable the relationship between the economic, social and environmental dimensions within an organization and along the entire value chain [3]. The study of the possible environmental impacts generated by the different ocean energy technologies is still limited at this moment, as well as their likely magnitude. Moreover, possible impacts on the environment can be associated with different stages throughout its life cycle (manufacturing, operation, and maintenance, dismantling and final disposal).

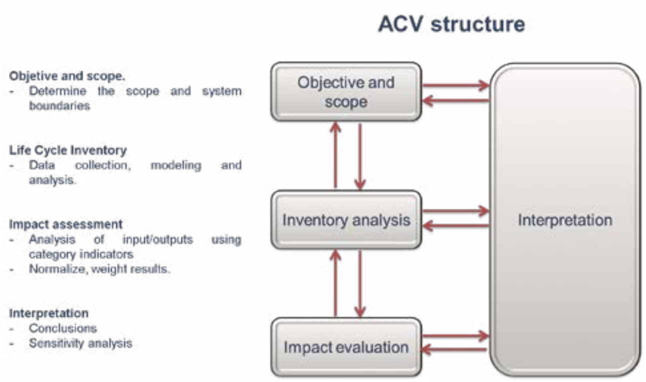

Fig. 1. LCA methodology approach [2].

A general diagram of an LCA study for ocean energies can be seen in Figure 2. However, other LCA studies may have variations in their stages. During the dismantling stage, the waste can follow different paths, including incineration, landfill, recycling, or a combination of them [4]. At this moment, LCA studies for ocean energy systems are limited, analyses have been developed mainly for wave and tidal energy converters, with a focus on field devices [5].

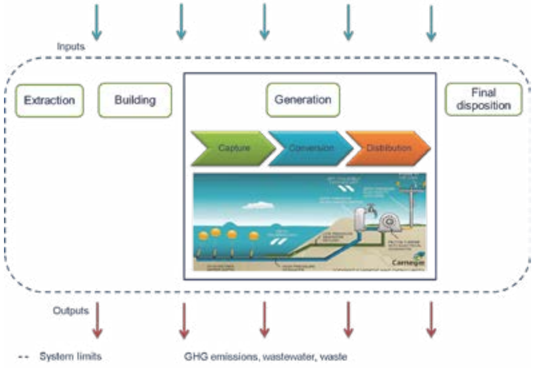

Fig. 2 General scheme of ocean energy LCA.

RESULTS AND DISCUSSION

Considerations for studies of ocean device LCAs were as follows:

- Definition and scope. Developing an LCA for the production of 1kWh of electrical energy from energy technologies: ocean currents and wave energy, under a Mexican context
- System function. Electric power generation.
- System evaluated. ocean current and tidal devices: Impulsa Hydrogenerator and SeaGen Generator.
- System limits. In all the ocean energy technologies evaluated their complete life cycle was considered, from the raw materials extraction, construction, generation and dismantling.
- Time limits. A time limit between 10-20 years of energy production was considered, which corresponds to the operating horizon of ocean power plants.
- Geographical limits. The stages of plant construction and power generation are delimited for the Mexican national territory.
- Impact categories. Climate change, ozone depletion, acidification, marine eutrophication, human toxicity, particulate matter formation, marine ecotoxicity, metal depletion, fossil fuel depletion

LIFE CYCLE INVENTORIES (LCI)

Table 1 shows the materials for the manufacture of the SeaGen Generator and Impulse Hydrogenator. Steel is used for the rotors, concrete for the anchoring system, aluminum is used for the blades and fiberglass for the casing.

Table. 1 LCI of Ocean Energy Technologies

Materials	Amount per device	Unit	Amount per UF	Unit
Impulsa Hidrogenator				
Fiberglass	100	kg	0.0023	kg/kWh
Aluminium	200	kg	0.0045	kg/kWh
Steel	1200	kg	0.0274	kg/kWh
Concrete	1000	Kg	2.289E-05	kg/kWh
SeaGen Generator				
Steel	3954370	kg	0.0417	kg/kWh
Fiberglass	1683	kg	1.776E-05	kg/kWh
Copper	1255.8	kg	1.325E-05	kg/kWh
Epoxi	600.426	kg	6.338E-06	kg/kWh
Foam	120.22	kg	1.269E-06	kg/kWh
Polyethylene	0.1749	kg	1.846E-09	kg/kWh

ENVIRONMENTAL IMPACT ASSESSMENT (EIA)

The Impulsa Hydrogenerator device (marine currents) presents the greatest environmental impacts in the construction stage for five impact categories: human toxicity, marine ecotoxicity, marine eutrophication, ozone depletion, formation of particulate matter and acidification. It is worth mentioning that the blades are the components with the greatest impact (Figure 3). Meanwhile, for the SeaGen device (Figure 4) in its construction stage, the tower is the element that requires the greatest amount of material, which is why most of the impacts are related to this element, followed by the upper part of the tower (Top). Interconnection and cabling are especially important in the human toxicity category, due to the manufacture of copper as the main material and the special coatings that it requires. As can be seen, the construction stage is the one with the highest environmental contribution in most of the categories evaluated, this is mainly due to the type of materials used to manufacture the device components. Therefore, the search for alternative materials presents a potential for environmental improvement for these devices, in order to increase their competitiveness in the market.

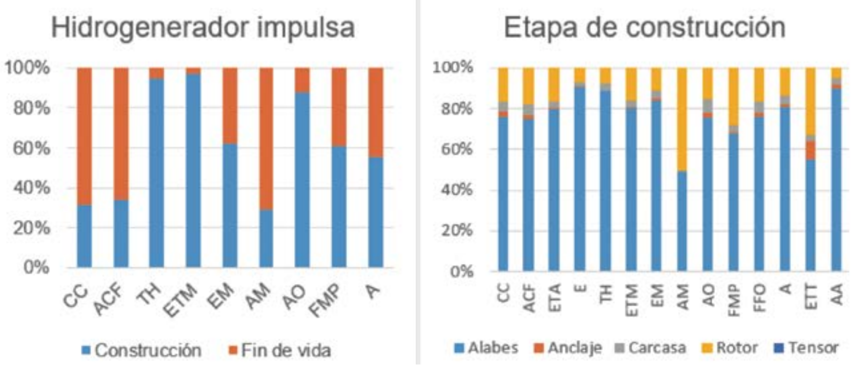

Fig. 3 Normalized environmental impacts for the Impulsa Hydrogenator

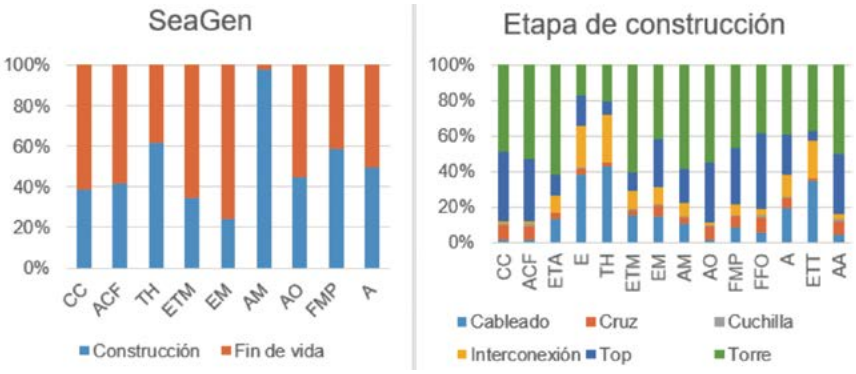

Fig. 4 3 Normalized environmental impacts for the SeaGen Generator

CONCLUSIONS

Ocean energy devices are still in an early stage of development compared to other renewable energy technologies. Wave energy systems will be an important source of renewable energy because it offers an attractive alternative conventional energy (fossil fuels). However, the success of these systems will depend on their availability at low costs, their environmental impact and the ability to generate electricity.

ACKNOWLEDGEMENTS

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TECHNOLOGY: PRESENT

Development and Testing of a Tidal Turbine Blade

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Keywords: *Tidal Turbine, Blade, Testing, Model-Scale, Full-Scale*

The development of a tidal turbine blade includes hydrodynamic [1] and structural design, load simulations, testing model-scale rotors e.g. in a towing tank, manufacturing a full-scale blade, static and possibly fatigue testing on a blade test rig and finally validating its performance in the field. The rotor design of the horizontal axis fixed-pitch SIT250 turbine from SCHOTTEL HYDRO aims for a passive-adaptive deformation – in particular torsion – to reduce the thrust loads in off-design conditions (cp. [2] and [3]). The effect of blade deformation on the performance of horizontal axis tidal turbines is focusing on blades made from fiber reinforced composite materials. For example, NICHOLLS-LEE et al. presented a numerical investigation of the performance of a 20 m diameter three-bladed horizontal axis tidal current turbine [4]. MURRAY et al. developed a FSI tool, which utilizes a blade-element-momentum (BEM) model coupled to a FEM model to design a blade for a 1:20 scale model of a horizontal axis tidal turbine from composite material [5].

SCHOTTEL HYDRO has developed the SCHOTTEL Instream Turbines (SIT), which utilise 4m or 6.3m diameter rotors, depending on the flow regime of a specific site, mounted on the same SIT250 drivetrain. For high resource sites, the smaller diameter rotor is used to minimise loads on the overall system, whilst maximising power output. At lower resource sites, the longer blades can be used since they can withstand the loading and produce higher power at lower speeds. The SIT250 drive train is rated at a mechanical shaft power of Prated = 85 kW which corresponds to a grid ready power of Pel = 70 kW. The blades of the full-scale turbines are made from fiber-reinforced composite. The elasticity of these blades provides an additional load reduction at high inflow velocities (“passive-adaptive pitch”) through an elastic pitch-to-feather. An overspeed strategy using speed control limits the power output to rated power.

This paper presents the hydrodynamic and structural design process of a fixed pitch 6.3m tidal turbine rotor for the SIT250 drivetrain. Experimental results are obtained in model scale towing tank tests, on a full-scale blade test rig and during full-scale field tests on Sustainable Marine Energy’s floating tidal energy platform PLAT-I. The overall objectives of this work are:

- To describe a design procedure for a tidal turbine blade
- Present results from a full-scale blade test rig
- Present performance data from both model-scale and full-scale testing.

Special attention was given to the hydrodynamic design of the turbine blades. A novel multi-objective optimizing scheme, as described in [1], was used to target the best compromise between maximum power output, minimum thrust load and shallowest immersion depth for operation without cavitation. To support the passive-adaptive pitching, the skew of the blade has been designed to provide a sufficient moment around the radial axis. Thus, not only the bend-twist properties of the material but also the design of the stacking line contributes to the passive-adaptive pitch (to feather).

A fluid-structure-interaction (FSI) model is used to predict the performance characteristics of horizontal free-flow turbines considering the load related deformation of the blades and also to inform the laminate layout. The key components of the model are:

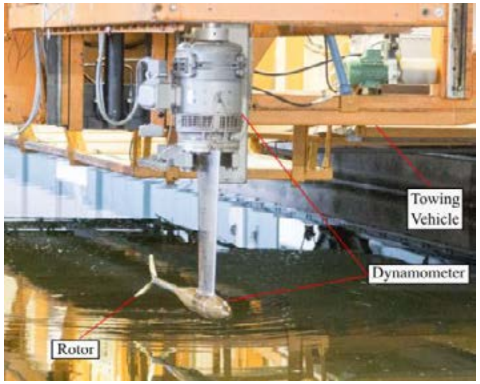
- an extended performance prediction model based on the BEM theory
- a structural model describing the laminate layout of the blade.

To initialize the simulation, the BEM model is used to predict the spanwise load distribution for a given operating point. The loads are applied to the structural model, which is then solved to predict the deformation of the blade due to the loads acting on the blade. Subsequently, the induced torsion along the blade span is calculated based on the displacements of specified points along the leading edge (LE) and trailing edge (TE), respectively. Considering the changed pitch angle distribution, the BEM model predicts the altered performance and the updated loads are passed to the structural model to actualize the deformation.

A 1:12.6 brass model of the horizontal axis fixed-pitch turbine was manufactured, Fig. 1, and its non-dimensional dimensional performance characteristics are measured in a towing tank. The experiments are performed at the ship model basin in Potsdam, Germany, Fig. 2. Unsteady time domain simulations are conducted using DNV GL's Tidal Bladed software to predict both ultimate and fatigue loads for the blade, Fig. 4. These loads are used to inform a static and dynamic blade test at NUI Galway ´s structural lab Fig. 5. Finally, the blades have undergone field testing on Sustainable Marine Energy's floating tidal energy platform PLAT-I, Fig. 6. The platform is installed at Grand Passage at the southern tip of Digby Neck. Digby Neck is a strip of land located at the mouth of the Bay of Fundy in Nova Scotia, Canada. Experimental results are collected to IEC TS 62600-200 where applicable or suitable and compared to the predicted performance, Fig. 7.

(Starzmann_fig1.png)

Fig. 1 12.6 model of the 6.3 m rotor of the SIT250 tidal turbine utilized for the model tests



(Starzmann_fig2.png)
Fig. 2 Towing tank setup at SVA Potsdam, Germany

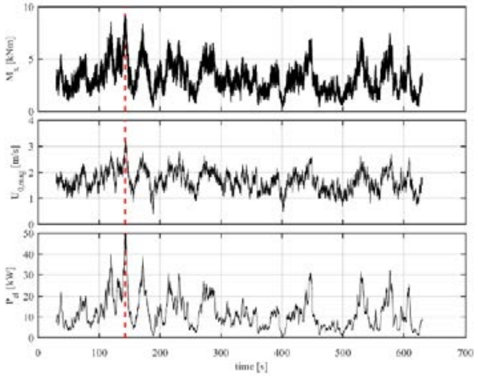


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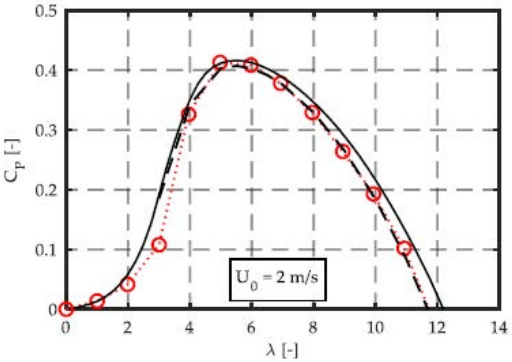
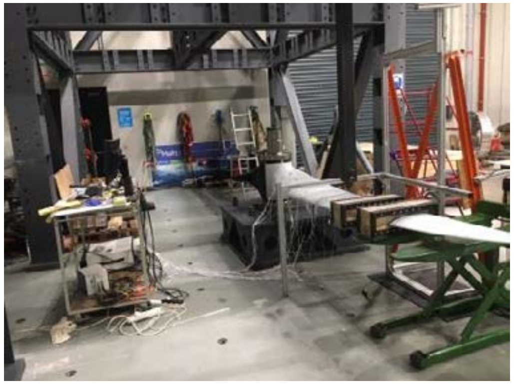
Fig. 4 Sample time domain simulation using Tidal Bladed

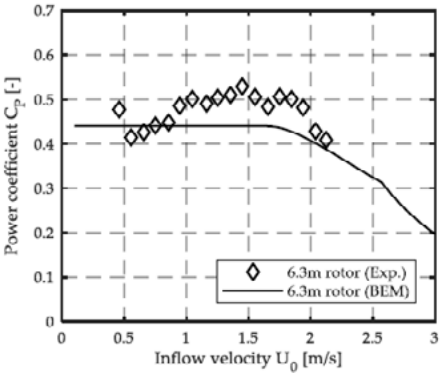


(Starzmann_fig3.png)
Fig. 3 Comparison of BEM predicted performance coefficient with model-scale experimental data (towing tank)



(Starzmann_fig5.png)
Fig. 5 Experimental setup at NUI Galway’s blade test rig (Ireland)

(Starzmann_fig6.png)
Fig. 6 Blade installation (6.3m rotors) on the PLAT-I platform in Grand Passage, Nova Scotia, Canada



(Starzmann_fig7.png)
Fig. 7 Comparison of predicted and measured rotor performance coefficient during the field test in Grand Passage, Nova Scotia, Canada

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Marine HydroKinetic Tools – MHKiT

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Keywords: *MHKiT, Marine Energy Data Processing, Marine Energy, Data Analysis, IEC Standards.*

Field and laboratory validation, testing, demonstration, and operation are critical steps for increasing the technology readiness level of marine energy converters because they provide high-quality testing and performance data. These data are critical information used to feed all aspects of technology development as shown in Figure 1. Without quality test data, technologies may move forward with insufficient feedback on their design. This leads to design revisions at higher TRLs to correct mistakes, thus increasing project costs and development timelines. Additionally, lack of quality data may require use of higher safety factors to account for uncertainty. In the worst case, poor quality data can lead to false conclusions and faulty designs that do not work as predicted or result in a failure or personal injury.

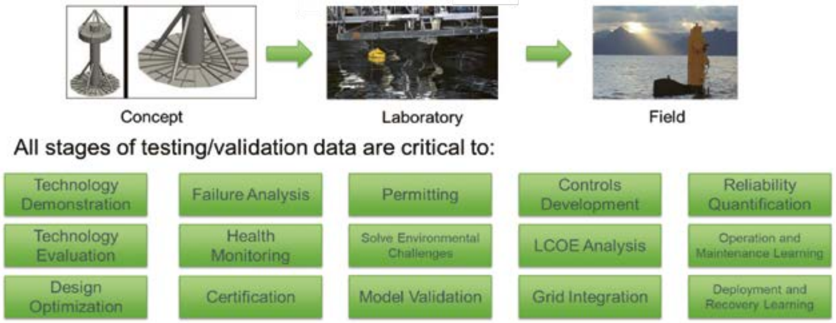

Fig. 1. Data are the foundation of understanding and knowledge gained in validation and testing

Obtaining quality data for marine energy systems is challenging because it requires knowledge and hands-on experience with many types of measurements, an intuition for expected device operation, as well as a strong understanding of sensors and instrumentation; signal conditioning, protection and routing; data processing; similitude; testing; accepted practices and standards; and sensor operation and protection in marine environments. Even with adequate sensors and instruments that have been appropriately selected and installed, quality assurance and control (QA/QC) is needed to ensure data are fit for their intended use, and to flag data that do not meet quality standards.

This project focuses on the data processing (data ingestion, reduction, conditioning, manipulation, calculation and visualization) and QC. It leverages prior investments by the US Department of Energy, the offshore engineering and measurement community, the MRE sector, and the

Navy to empower the MRE community with Standardized, opensource, turnkey extensible data processing and QC software solutions that are discoverable and accessible and that have been verified by relevant experts.

MHKiT consists of the following three parts: 1) MHKiT Code Catalog, 2) MHKiT Code Hub, and 3) MHKiT Matlab/Python. MHKiT Code Catalog and MHKiT Code Hub are part of DOE's Portal and Repository for Information on Marine Renewable Energy (PRIMRE, https://primre.org), and sits at the same level as Tethys and the MHK Data Repository (MHKDR).

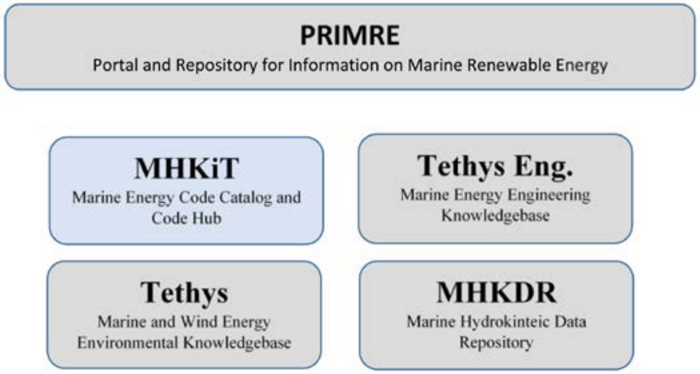

Figure 2 MHKiT is part of PRIMRE and augments Tethys, Tethys Engineering, and MHKDR

The MHKiT Code Catalog is a searchable online software discovery platform and knowledge base that allows users to perform faceted searches to identify software tools, codes and other software products that they can use for MRE related tasks. In addition to providing information on existing software tools, the MHKiT software discovery platform also hosts the MHKiT Code Hub. The MHKiT Code Hub is a collection of MRE code repositories. It is designed to host open-source software tools developed by the National Labs and the broader MRE community. MHKiT Code Hub includes DOE developed codes for data acquisition, data processing and visualization, simulation and modeling, and resource analysis. It also mirrors other Git based software sites so that a wide range of open-source MRE software tools can be found at one location. MHKiT Matlab/Python is a set of toolboxes with functions that are intended to supplement existing software languages (e.g MATLAB, Python) and public repositories (e.g. WAFO, Pecos). MHKiT Matlab/Python provides data processing and visualization toolboxes that are needed by the MRE community but are not available, or existing code does not meet verification requirements. The first versions (2018-2020) leverage software developed at the National Labs and include toolboxes that are based on IEC technical specifications and other guidelines and include power performance, power quality, mechanical loads, resource tools and data QC.

MHKIT CODE CATALOG

The MHKiT Code Catalog was designed and built to be an online, searchable, public software discovery platform and knowledge base that allows easy access and discovery of existing MRE relevant codes, scripots, and software tools; promotes reuse of existing codes and software tools; and provides mechanisms that support active community software development, engagement, and feedback. The MHKiT Code Catalog is searchable from PRIMRE and is developed as an intuitive, interactive and user-friendly catalog designed to:

- be a repository of metadata and other information needed for users to quickly identify software that meets the needs of their MRE-related task(s)s
- facilitate easy discoverability and access to software for MRE tasks through a faceted search
- allow authenticated OpenEI users to add and modify content
- create mechanisms for active community engagement and feedback
- automatically dual-list DOE-funded codes in the MHKDR for greater exposure

To enable rapid identification of software tools within the MHKiT Code Catalog, the user interface uses a faceted search design, Figure 3. This design allows users to narrow down search results by applying multiple filters based on classification of the software into specified categories (facets) such as MRE technology, license, and programming language.

MHKIT CODE HUB

The MHKiT Code Hub is a collection of MRE code repositories. It is designed to host open-source software tools developed by the National Labs and the broader MRE community. MHKiT now includes several repositories of DOE sponsored MRE software. Existing codes such as WECSim and Pecos are be mirrored while codes such as MHKiT Matlab/Python are directly hosted. MHKiT Code Hub uses the open-source GitLab platform which provides the following capabilities:

- Role-based security, private or public repositories
- Code versioning and branching
- Code review
- Release tagging
- Issue tracking
- Code download via git clone or zip file
- Pull Merge requests (i.e., users can submit a proposed code modification to a project they don’t own, which will be vetted by the project team)
- Forking (i.e., users can create a custom version of an existing project and still merge changes from the parent project)
- Code documentation and wikis
- Code rating
- Code aggregation using submodules
- Remote mirrors

MHKIT CODE CATALOG

As previously stated, MHKiT Matlab/Python is a set of toolboxes with functions that are intended to supplement existing software languages (e.g MATLAB, Python) and public repositories (e.g. WAFO, Pecos). It provides data processing and visualization that are needed by the MRE community but are not available, or existing code does not meet verification requirements set forth within the MHKiT Code Guidelinese–all HKiT Matlab/Python codes are robust and be thoroughly tested prior to release to ensure accuracy and confidence in use. In FY19 alpha version of six toolboxes were developed, Table 1. These toolboxes include an initial set of functions needed to perform the primary data QC, processing, analysis, and visualization. All codes are developed following a framework, format, and conventions that are defined in the Code Guildelines. All codes are also rigorously tested using a continuous integration framework that is applied every time files are uploaded to the MHKiT Code Hub. These tests check functionality and accuracy.

MHKiT Matlab/Python will also use the HDF5 and JSON file formats to store data to ensure compatibility and usability by the broader MRE community and beyond. These formats also help ensure that adequate metadata is collected.

Module	Description
Wave Power Performance	Functions that support wave power performance calculation. Calculations are based on IEC TS 62600-100:2012
Tidal and River Power Performance	Functions that support tidal and current power performance calculation. Calculations are based on IEC TS 62600- 200:2013 and IEC TS 62600-300 ED1
Wave Resource Assessment	Functions that focus on the resource assessment for a wave energy site based on IEC TS 62600-101:2015
Tidal Resource Assessment	Functions that focus on the resource assessment for a tidal energy site based on IEC TS 62600-201:2015 and IEC TS 62600-301 ED1
Data Quality Control and Assurance	Functions that support data quality control and assurance. These functions are based on those developed in ARM and Pecos.
File Utilities	Functions that provide general utilities that include loading data, converting data, and writing data from files produced by MRE specific instruments and from files commonly used by the MRE community.

ACKNOWLEDGEMENTS

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Floating Tidal Energy Platform PLAT-I

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Keywords*: Tidal energy, Floating, Performance, Field trials, Full-scale testing*

Tidal platforms have been developed for sites in: the UK, for example at EMEC [1]; in Canada, such as FORCE [2]; and around the world. These sites, whilst similar in many ways, also vary for conditions such as turbulence intensity, bed conditions, range and wave height. Tidal energy systems must be flexible enough to be deployed in a variety of areas and Sea Acceptance Tests (SATs) must be diverse enough to allow systems to be tested for different commercial opportunities. Additionally, tests must be conducted in areas dissimilar to the technologies' intended deployment area, such as SATs in the UK for a system due to be used in South East Asia; this is due to cost of access and availability of specialized infrastructure and vessels.

Sustainable Marine Energy (SME) have developed a surface variant of their tidal platforms to support tidal turbines, called PLAT-I. The platform is a trimaran structure with a center hull which houses the mooring turret, power conditioning, and communications equipment. The outer hulls provide additional buoyancy, roll stability, and an operational access point. The cross deck hosts the SIT Deployment Modules (SDMs) and lifting mechanisms. The mooring system is interchangeable depending on the flow conditions, wave characteristics, bed composition, and tidal range; this means that the system is suitable for deployment in a range of environmental conditions, as would be experienced at tidal sites around the world.

Fig. 1 PLAT-I deployed at Connel, UK

SCHOTTEL HYDRO have developed their current commercial SCHOTTEL Instream Turbines (SIT), which utilise 4m or 6.3m diameter rotors, depending on the flow regime of a specific site, mounted on the same SIT250 drivetrain. The combination of these technologies leads to many commercially viable deployment sites. PLAT-I can be deployed in high resource sites, such as EMEC or FORCE, using the smaller diameter rotor to minimize blade forces such as bending moment, whilst maximizing power output. At lower resource sites the longer blades can be used, since they can withstand the loading and produce higher power at lower speeds.

PLAT-I has undergone Sea Acceptance Tests (SATs) in the UK, at a site with strong tidal currents, high turbulence and low wave conditions [4][5]. At Connel, UK the system used 4m diameter rotors to withstand the high instantaneous velocities, with a four-point mooring spread and rock anchors, due to the bathymetry and bed composition (Fig. 2).

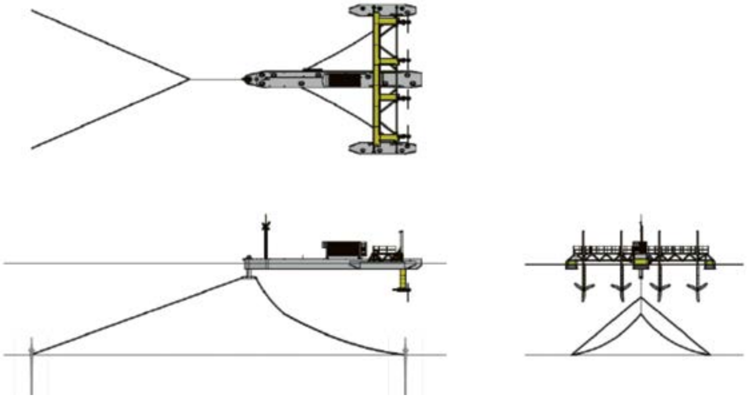

Fig. 2 PLAT-I configuration at Connel, UK with four-point mooring and 4m diameter rotors (note component size is indicative)

The system has also been tested in Nova Scotia, where there are similar flow speeds but larger wave conditions and different bed composition. In Grand Passage, Nova Scotia, the site has lower peak velocity, so 6.3m rotors can be deployed, and the flat, glacial till bed suits a two-point spread with drag embedment anchors (Fig. 3).

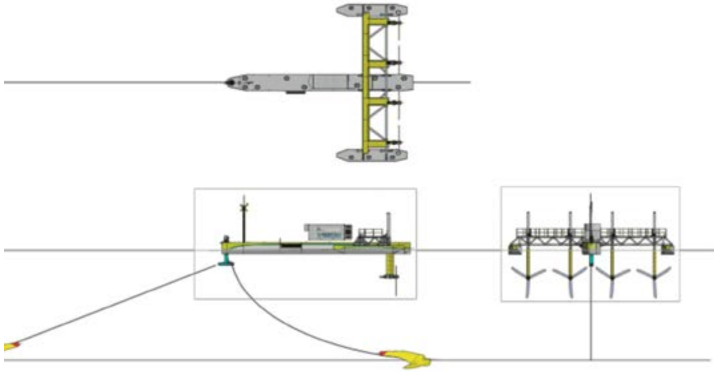

Fig. 3 PLAT-I configuration at Grand Passage, Nova Scotia, with two-point mooring and 6.3m diameter rotors (note component size is indicative)

PLAT-I, and the SITs, have undergone SAT testing to IEC TS 62600 standards where applicable or suitable. These standards cover the mooring system design and load cases for review (62600-2, -10), site information required (62600-201) and tidal energy converter performance testing (62600-200). The equipment used for performance measurement is shown in Table 1 and Fig. 4.

Table 1: PLAT-I Instrument Locations

Parameter	Instrument	Location	No.
Power, Torques, Speed	S120 SIEMENS Inverter	Control Container	3
Velocity	Electromagnetic Current Meter	SIT2 (UK) or SIT3 (NS)	2
Reaction force at pins (Thrust)	LCM Load Pin	Lower connection point between SDM and cross deck structure	1
Mooring line load	Strainstall Load Shackle	Mooring point to turret	4
Mooring line load	LCM Annular Load Cell	Mooring chain clacker plate	5
Position	GPS	Communications mast	6

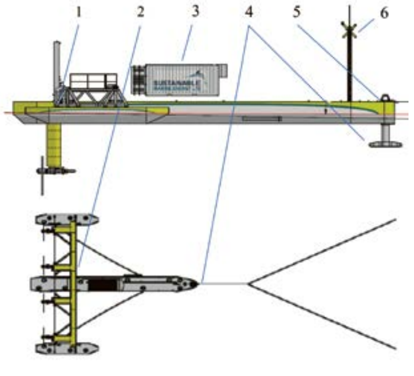

Fig. 4 PLAT with instrumentation locations

The platform position is analyzed for the different PLAT-I states, including SDMs up (raised in maintenance position), SDMs down (normal, non-generating state), and SITs operating. The position of the platform during operational testing in Connel is shown in Fig. 5 [5]. This shows that as the velocity increases the rotor thrust and platform drag increase, so the platform moves away from the mooring centre spread as the moorings stretch out. The movement remains within the predicted excursion, shown by the mooring ellipse for low water and high water.

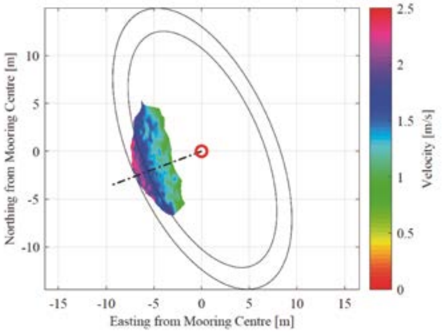

Fig. 5 PLAT-I turret position with Operating turbines, with Velocity

The mooring line loads are also assessed to compare the measured load to those predicted using Ansys AQWA modelling. An example comparison between the predicted load and the measured (both IEC compliant and non-IEC) load for PLAT-I in different modes is given in Fig. 6 [5].

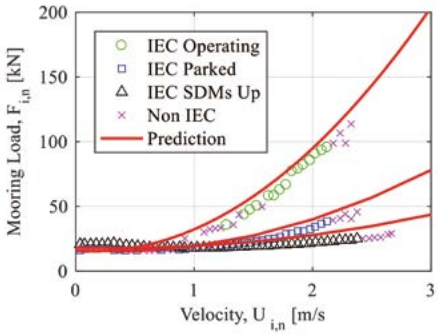

Fig. 6 Load Shackle Mooring Load against Velocity

The performance of PLAT-I in both Connel and Nova Scotia will be presented, with the applicability of the standards and the methods of testing a full-scale tidal device. The system suitability and adaptability for other environments will also be demonstrated.

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ANDRITZ Mk1 Tidal Turbine Operating Experience

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Keywords: *Tidal turbine, Operation Experience Validation*

ANDRITZ supplied 3 of its Mk1 1.5MW tidal turbines to the MeyGen Phase 1A tidal energy project located in the Pentland Firth, Caithness, Scotland. To date the turbines have generated in excess of 22GWh of energy, and accumulated tens of thousands of operating hours in a variety of sea states and fault conditions such as grid loss events. The aim of this presentation is to share some of the observations, and outcome of model validation activities, which have taken place to date.

Over the past twenty years, ANDRITZ has developed and tested three generations of tidal turbines

- 300kW turbine in Kvalsundet, Norway
- 1MW turbine at EMEC, Scotland
- 1.5MW turbine at MeyGen, Scotland

In addition, ANDRITZ has been selected by DP Energy to supply 3x 1.5MW turbines to their Uisce Tapa tidal Energy project located at the FORCE test site, Nova Scotia, Canada

Fig. 1 CAD image of turbine for Uisce Tapa project

In summary the turbine performance, and measured loading is in line with predictions from Tidal Bladed, and other simulation software used by ANDRITZ.

PERFORMANCE

Of particular interest is of course the predictability of the energy generation – such predictions are made by combining the predicted flow speeds from a channel model created in a software package such as Mike 21, Theits or FVCOM with the predicted power curve from Tidal Bladed. Figure 2 below shows the predicted versus measured output of the 3x Mk1 tidal turbines in operation over the course of 2019.

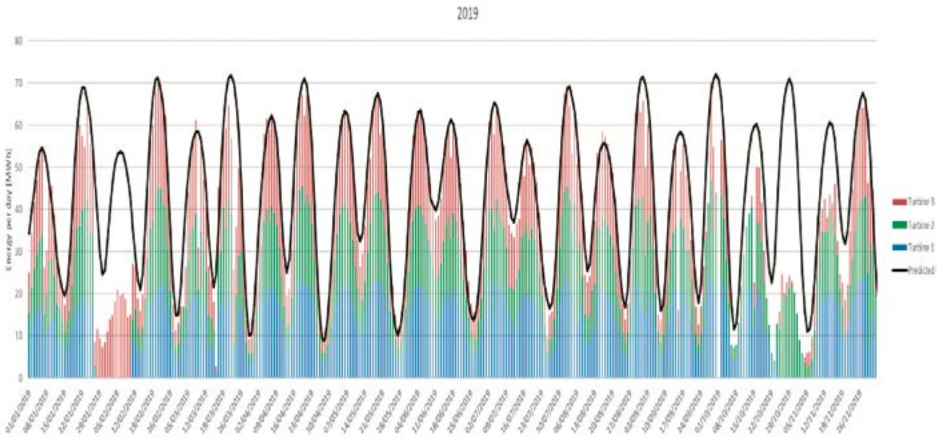

Fig. 2: Daily energy export versus predictions

LOADING

In addition to the performance of the turbines, it is important to validate that the structural and mechanical loading experienced by the turbines is in line with the loads predicted at design time and used to calculate the strength and design life of turbine components. Several key areas are presented here;

- Blade bending moment
- Blade pitching moment
- Rotational speed stability
- Structural vibrations

BLADE BENDING MOMENT

The turbine rotor blades are one of the most highly loaded components. Due to the low torque to thrust ratio in comparison to a wind turbine (due to high density low speed fluid) the blade bending moments are extremely high, and thus fatigue loading is critical.

BLADE PITCHING MOMENT

The high-speed pitch control of the turbine allows for management of the blade bending moments discussed above. The Mk1 turbine controller has independent control of the pitch angle of each blade.

ROTATIONAL SPEED STABILITY

Stable control of the turbine rotational speed is essential for management of the loading on all mechanical and structural components. In addition, good speed control is important to manage the export power level, and meeting grid code.

STRUCTURAL VIBRATION

Structural vibrations are a significant source of fatigue loading for tidal turbines. During the design phase, such vibrations are estimated by calculating the natural frequency of the structure components.

Vancouver Wave Energy Testing Station: Continuous electricity output verification from waves of various sizes, Development history and Transparent policies for industrial wave energy power plants

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It is urgent to bring new “zero emission” power systems online immediately. The effects of greenhouse gases and water consumption from using steam for creating electricity is directly causing the serious environmental problems facing humanity.

Wave energy has long been identified as a renewable energy source at least a large as solar and wind combined, but up until now this has not been made available in a commercially viable system.

ADVANCES IN ENERGY RESEARCH

A wave energy engine has been developed and tested that produces continuous electricity for at least 8,000 hrs/yr (91%) hence qualifies as a “Firm Power” producer like nuclear and fossil fuel plants = carbon reduction, & more sustainable power.

DEVELOPMENT HISTORY

The 10 year development history of this wave engine is presented from: (a) the simple linear generator attached directly to a float, to ((b) the patented direct drive PTO which enables a power stroke from both the up and down reciprocating movements of variable height waves to be converted into one way rotational motion to directly drive a generator, to (c) a tidal compensator patent to, (d) failed attempts to create a dis-harmony of movement between the device float part and the motive float (energy) part, to (e) the failed floats on lever arms to, (f) the working and available for verification testing, “donut on a stick stuck in the seabed” (pile) that produces continuous electricity for approximately 8,000 hours per year, even in very small waves, to, (f) the 24 float-piston power plants as an add-on to an offshore Wind turbine mon-piles as presented to otary.be for their feasibility study request.

LATEST RESEARCH DEVELOPMENTS

Optimization research made possible by modelling, the entire mechanical process from wave height & period moving the point absorber to generator output, by Johan Fourie. The *“theoretical model and calculation spreadsheet determines critical design parameters and predict the functional performance of the wave power generation system. The model is based on the principle of simultaneous conservation of energy and conservation of momentum.*

Constant angular acceleration and deceleration of the generator is assumed in the model.”

This model has enabled the wave engine to solve the “last wave energy problem” which is to produce continuous “firm” electricity from the variable height and variable period prime mover waves.

This modelling design aid tool, has been used for building a full size unit in the shop. This unit has been tested to produce continuous electricity and to prove the model is correct in predicting the electrical outputs. After numerous re-modelling and shop tests a final system will be deployed for verification at the Vancouver Wave Energy Testing Station (deployment at sea is scheduled for June 2020).

RECENT PROGRESS

Our test location, under a 5-year Investigative Use Licence from the Province of BC, in the Strait of Georgia, has small, near shore, waves, (0.1 m to 2.0 m) which we have concentrated our research on utilizing.

The existing tested unit, expanded to include 24 float-pistons is projected to produce 24 kWh per hour in waves of .1 m high by 3 s period. On an 8,000 hour annual basis this would produce 192,000 kWh of continuous electricity at a minimum, and, when the waves are 1.1 m high by 4.5 s the expanded testbed engine is projected to produce 290 kWh per hour, which, for the expected 385 hours in a year these wave are available in the test bed location, would be (projected) to be 112,000 kWh (during the year). The Vancouver Wave Energy Testing Station will be deployed by Vancouver Pile Company and will allow others to visit, verify and showcase the advances in wave energy research we have made. The testing station will receive DC power from the wave engine’s 3 phase AC generator-rectifier deployed 25 m away using 1 float-piston.

NEW TRANSPARENT POLICIES

Standardized methods of transparency are needed as the wave industry finally emerges from the research theory and development stage to the industry power plant stage.

The main reason for this need is because wave energy, like solar, wind and tidal, has a natural variable energy input from the prime mover, whereas, the traditional energy sources, coal, gas, oil, nuclear, hydro and run of the river, have continuous flow sources and the flow of energy can be controlled by humans.

The following 3 items are presented as “plans for discussion” it is our design method to make a plan and have it criticized, especially by experts in the field, so the plan can be made more suitable.

1. Predicting power plant output from available (NOAA et al) wave height and wave period data is essential to a viable transparent wave energy industry for all the stakeholders.

The scatter chart will facilitate a natural variable energy flow. In the interest of transparency, scatter charts should be standardized to display wave energy commercial power predictions for project development proposals and updated to display the actual waves and power produced from the projects. The available wave data is based on the use of Hs (Significant wave height) which is a statistical value, designed to be used for marine safety and immediate future wave condition predictions, is not created to be used for wave energy calculations. This is discussed and a proposal to calculate H(average) = Hs *.7071 [root 2] is proposed in detail.

2. & 3. The natural variable energy flow systems require a new Name Plate Rating (NPRv) and a new Capacity Factor (CFv) metric.

The currently used NPR & CF metrics are based on human controllable "continuous" energy source systems and are not applicable to natural "variable" energy source systems.

A plan for a new method to determine a consistent standardized Name Plate Rating (variable) [NPRv] for this variable prime mover renewable energy systems is proposed in detail.

A plan for a new method to determine a consistent standardized Capacity Factor (CFv) for variable prime mover renewable energy systems is also proposed in detail.

RESEARCH FROM OTHERS

The objective of the current research project is to explore novice wave generation systems using an evidence-based approach. To allow for the unbiased innovation of these systems, it was decided that their development should not to be guided or influenced by historic achievements in the field. Hence, no former research was used referentially nor directly in the development of the wave engine.

Neptune Test Scatter Chart 1

Neptune Wave Scatter Diagram shows: (a) hours per year for each Avg. Period & Avg. Height cell; (b) projected kWh / h; (c) Actual kWh / h

Nep Engine Model Test-11019

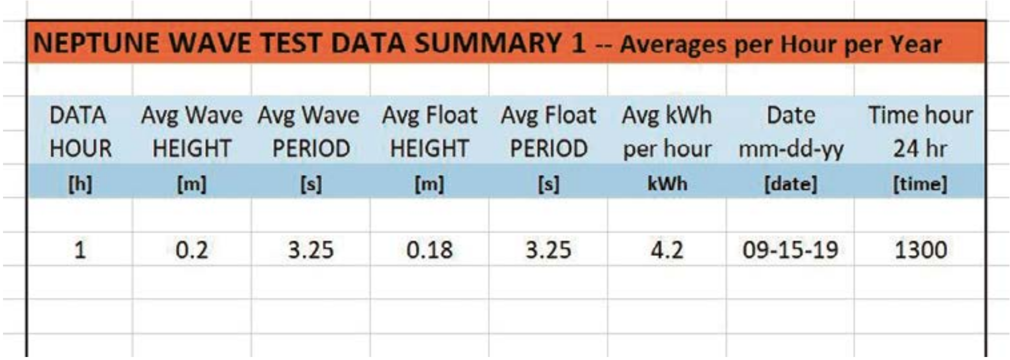
ACTUAL VALUES FROM HALIBUT BANK STATION GOVERNMENT DATA FOR 2016 Conversion Formula used: Havg = Hs*.83 Average W. Periods from Times in Data

Hrs/ yr = 8766

Wave Data Avg Period [s] Avg Height [m]	2.22	2.74	2.95	3.24	3.33	3.74	4.1	4.27	4.79	5.33	5.89	6.4	6.92	7.42	SUM of Hours	Percent of T. Hrs/ year
0.1 Hrs / yr.	212	146		94		24	667	86	24	12	108	177			1550	18%
0.1 Proj. kWh/hr	2.2	1.8		1.5		1.3	1.2	1.1	1.0	0.9	0.8	0.8				
0.1 Actual kWh/hr																
0.2 Hrs / yr.	296	401		159	789	36		60	13	8	82	67	7	3	1921	22%
0.2 Proj. kWh/hr	4.4	3.6		3.0	2.9	2.6		2.3	2.0	1.8	1.7	1.5	1.4	1.3		
0.2 Actual kWh/hr																
0.3 Hrs / yr.	94	510	319	215		48		19	8	3	2	3	3		1224	14%
0.3 Proj. kWh/hr	6.6	5.4	5.0	4.5		3.9		3.4	3.1	2.8	2.5	2.3	2.1			
0.3 Actual kWh/hr																
0.4 Hrs / yr.	27	496	187	509		89		11	15	4		2			1340	15%
0.4 Proj. kWh/hr	8.8	7.2	6.7	6.1		5.2		4.6	4.1	3.7		3.1				
0.4 Actual kWh/hr																
0.5 Hrs / yr.		26		389	60	94		11	7	4					591	7%
0.5 Proj. kWh/hr		9.0		7.6	7.4	6.6		5.7	5.1	4.6						
0.5 Actual kWh/hr																
0.62 Hrs / yr.		28		559	73	419		64	9	8					1160	13%
0.62 Proj. kWh/hr		11.1		9.4	9.1	8.1		7.1	6.3	5.7						
0.62 Actual kWh/hr																
0.84 Hrs / yr.				68		353	18	168	21	10	3		1		642	7%
0.84 Proj. kWh/hr				12.7		11.0	10.0	9.6	8.6	7.7	7.0		6.0			
0.84 Actual kWh/hr																
1.1 Hrs / yr.						10		73	24	1	1				109	1%
1.1 Proj. kWh/hr						14.4		12.6	11.3	10.1	9.2					
1.1 Actual kWh/hr																
1.2 Hrs / yr.						5		50	26	1	1				83	1%
1.2 Proj. kWh/hr						15.7		13.8	12.3	11.0	10.0					
1.2 Actual kW/hr																
1.6 Hrs / yr.						1		14	47	25	12	2			101	1%
1.6 Proj. kWh/hr						21.0		18.4	16.4	14.7	13.3	12.3				
1.6 Actual kWh/hr																
SUM of Hours	629	1607	506	1993	922	1079	685	556	194	76	209	251	11	3	8721 8721	99%

Note: *the Neptune Wave Engine used in this test has 1 small piston. Commercial models would have larger pistons & have at least 24 pistons per engine.*

Fig. 1 Scatter Chart showing Wave Height & Period with NOAA type Data, Projected Electrical power produced in KWh and MWh compared to Actual Electricity produced from Testbed



NEPTUNE WAVE TEST DATA SUMMARY 1 -- Averages per Hour per Year

DATA HOUR [h]	Avg Wave HEIGHT [m]	Avg Wave PERIOD [s]	Avg Float HEIGHT [m]	Avg Float PERIOD [s]	Avg kWh per hour kWh	Date mm-dd-yy [date]	Time hour 24 hr [time]
1	0.2	3.25	0.18	3.25	4.2	09-15-19	1300

Fig. 2 Chart of averages per hour based on actual data from wave energy testbed data recorded at 10 ms per data point

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Assessment of the INWAVE WEC-Hybrid PTO Technology in the Canadian Pacific Coast

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Keywords*: Wave energy, Wave Energy Converter (WEC), hybrid power-take-off (PTO), mooring dynamics, numerical model*

INTRODUCTION

Ocean waves provide a substantial source of renewable energy which can be extracted for electricity production. Wave energy convertors (Hereafter WECs) are devices which are potentially able to extract significant amounts of wave energy in connection with appropriate power take off (PTO) systems. The aim of this paper is to provide a high-fidelity assessment of INWAVE [1,2] WEC-Hybrid PTO performance in Canadian Pacific Coast.

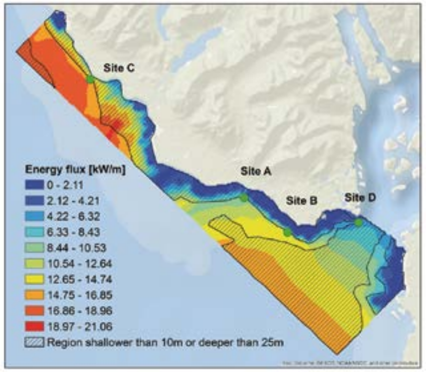

Fig. 1 Frequency screened wave energy transport in the MMFN traditional territory averaged over 2004-2014. The four candidate deployment sites are marked as Sites A, B, C and D.

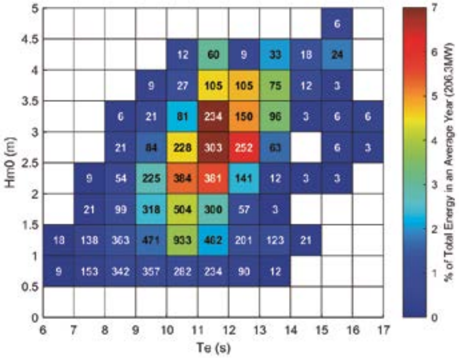

Fig. 2 The 2016 Hs-Te sea state histogram at Site 'B'

The INWAVE system is considered to be deployed as the source of clean renewable energy for the village of Yuquot, an off-grid area located in the territory of the Mowachaht-Muchalaht First Nation (MMFN) on the West Coast of Vancouver Island. Base on the resource assessment performed by PRIMED [3], the performance assessment will be carried out at four candidate deployment sites. Among the candidate sites presented in Fig.1, site B (see Fig. 2) has been initially found to be the most appropriate site to deploy the INWAVE technology [3]. The INWAVE WEC-PTO system consists of the disk-shaped WEC connected to the onshore PTO system through a system of pulleys and connecting ropes [1,2]. A schematic representation of INWAVE system is shown below:

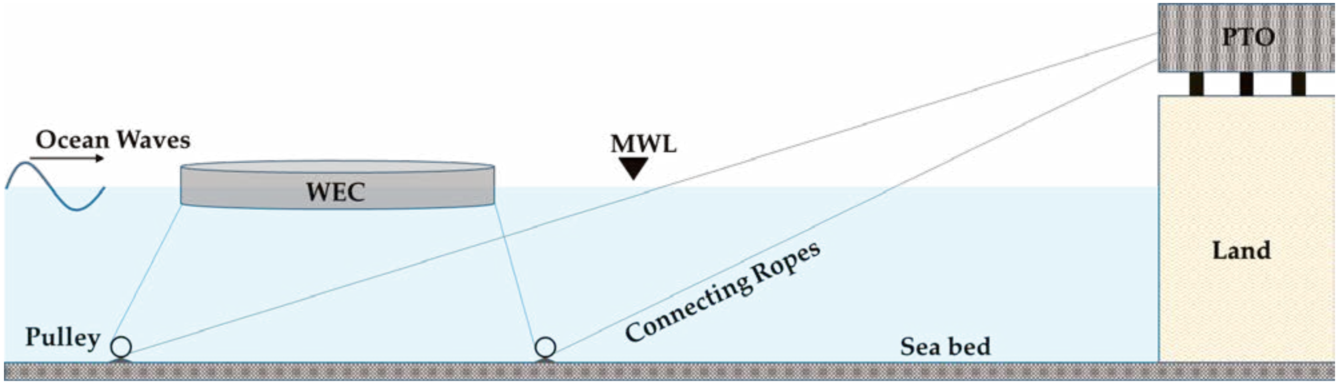

Fig. 3 Schematic description of the INWAVE WEC-PTO system

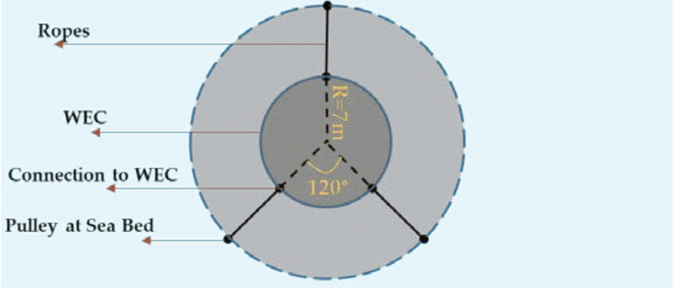

Fig. 4 Plan view of the Connection Ropes arrangement at the WEC

NUMERICAL MODELLING

The connecting ropes play a crucial role in power generation by the INWAVE system described in Fig. 3 and Fig.4. Therefore, in this study, a high-fidelity finite element cable model is utilized to simulate connecting ropes. The numerical model consists of two parts, namely the WEC which is modelled as disk-shaped moored float using PROTEUS DS (Hereafter PDS) [4], and the dynamic model of the Hybrid PTO system which is developed in MathWork's Simulink. These two software packages are coupled to provide a single modelling platform that generates time series data on the power output. The numerical simulation in this work builds on the work previously presented by [1,2] in that: i) A dynamic model of the hybrid PTO is developed. ii) The high-fidelity finite element model is utilized to simulate mooring lines. iii) The non-linear viscous drag forces are taken into account.

The time-domain dynamic equation of the float motion solved by PDS can be expressed as:

$$(M + M_\infty)\ddot{x} = F_E + F_R + F_H + F_D + F_M + F \qquad (1)$$

where M is the mass of the float, the subscript stands for the infinite frequency, is $\ddot{x}$ the float acceleration, F_E is the excitation force, $Frad$, is the radiation force, F_H is the hydrostatic force, F_D is the drag force and F_M is the mooring force calculated by the finite element cable module. The finite element cable module, which is available as an integral part of PDS, is based on the approach developed by [5]. The non-linear viscous drag force modelling in PDS is also based on integrating discrete drag forces calculated by "Morison's approach" at the panelized surface of the float [6].

The Hybrid PTO involves a system of counterweights and a hydraulic circuit. The counterweight, and the accumulator pressure in the hydraulic circuit consistently maintain tension in the rope (see Fig. 3). A ratchet gear mechanism in the Hybrid PTO converts bi-directional winding motions of ropes into the unidirectional rotation required by the hydraulic pump.

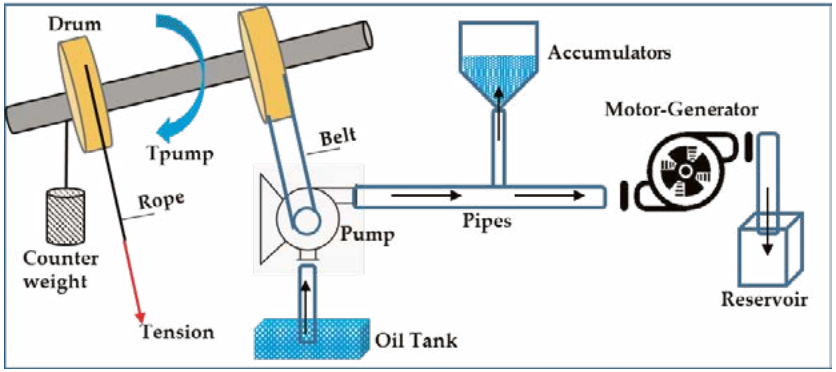

Fig. 5 Schematic description of the Hybrid PTO system

The ratchet gear mechanism is represented by a virtual torsional spring which in this study kinematically connects / disconnects the rope drum with the hydraulic pump (see Fig. 4.) which maintain the oil flow in the hydraulic circuit.

$$q_{\text{pump}} = \frac{D_{\text{pump}}\,\omega_{\text{pump}}}{\eta_{\text{pump}}} \qquad (2)$$

$$T_{\text{pump}} = \eta_{\text{pump}}\, p_{acc} D_{\text{pump}} \qquad (3)$$

Here, q_{pump} is the pump discharge flow, D_{pump} is the pump displacement, ω_{pump} is the pump rotational speed and η_{pump} is the pump efficiency Due to the action of hydraulic pump, high-pressure hydraulic oil is reserved in the hydraulic accumulator, resulting in the increase of pressure in the accumulator:

$$q_{\text{motor}} = \frac{D_{\text{motor}}\,\omega_{\text{motor}}}{\eta_{\text{motor}}} \qquad (4)$$

$$dq = q_{pump} - q_{motor} \tag{5}$$

$$\Delta V = \int dq \cdot dt \tag{6}$$

$$P_i = \frac{P_0 V_0^{\gamma}}{(V_0 - \Delta V)^{\gamma}} \tag{7}$$

q_{moto_r} is the motor flow, D_{motor} is the motor displacement, ω_{motor} is the motor rotational speed, η_{motor} is the motor efficiency, P_{acc} is the accumulator pressure, P_0 is the pre-charge pressure in accumulator, V_0 is the total volume of the accumulator, and γ is the gas specific heat ratio. When the pressure in the accumulator reaches a threshold value P_{open} ($p_{acc} \geq p_{open}$), the control valve will be opened and high-pressure oil will be released and rotate the hydraulic motor with high speed, resulting in power generation.

$$\dot{\omega}_{motor} = \frac{1}{J_{motor}}(D_{motor}P_{acc} - b_{motor}\omega_{motor})$$

Where ω_{motor} is the motor rotational velocity, J_{motor} is the inertia of the motor, and b_{motor} is the motor dissipation. When the oil pressure decreases below the threshold level, the control valve will be closed and pressure in accumulator starts o build up again. In other word, when the PTO system captures enough wave energy and reaches the threshold point, the hydraulic motor starts to generate power When wave energy is not enough, the energy stored in the accumulator can continue to drive power generation process for some time until the pressure in accumulator drops again below the threshold value.

RESULTS

The following figures represent sample outputs from the INWAVE model, which are selected on the basis of the sea state at Site B (see Fig. 2), featuring the connection/ disconnection function of ratchet gear mechanism, smoothening the motor flow due to accumulator effect, and power generation by hydraulic motor

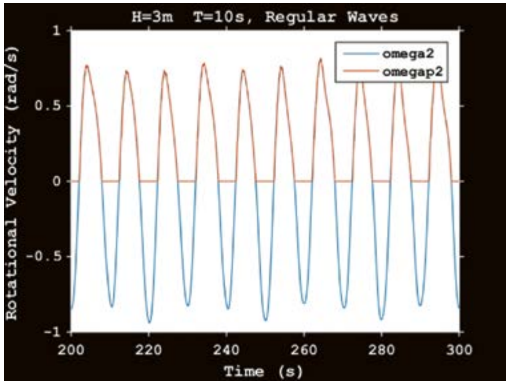

Fig. 6 Conversion of bi-directional rotation of the drum (blue lines) to the unidirectional rotation of the pump (red lines) by ratchet gear mechanism

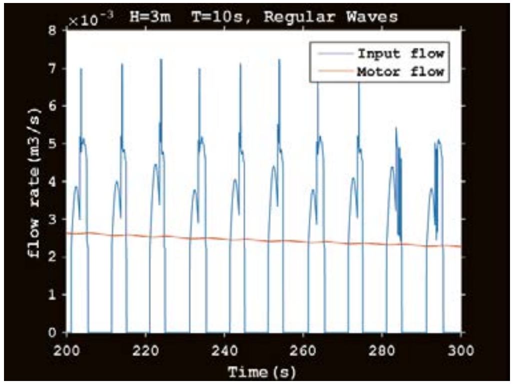

Fig. 7 The variations of motor flow (red line) is noticeably smoother than that of input flow(Pump flow, blue line)

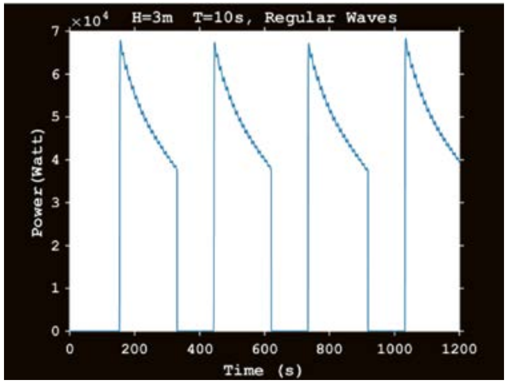

Fig. 8 Time series of the power output, featuring frequent cut-off periods

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Understanding Transient Load on Turbine Blades to Reduce Risks and Assist Design

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Keywords: *Transient Blade Loading, Fatigue, Horizontal Axis Tidal Turbine (HATT), CFD, Risk/Cost Reduction.*

INTRODUCTION

Due in large part by its density being a thousand times higher, water exerts forces (loads) on a tidal turbine that are orders of magnitudes greater than loads produced by air on wind turbine. Tidal companies still do not have accurate and validated ways of determining expected loads on their turbine during the design stages. This leads to unresolved questions and risks which leads to either poorly built systems that fail prematurely, or overdesigned/overbuilt systems that exponentially increase costs. It is now well understood, from tidal turbine developers, that one major unquantified risk is the determination of expected loads on the turbine (primarily on the blades, but on the entire structure as well). For the marine energy industries, particularly in-stream tidal, reliability will be the key. Without proper knowledge of those loads, and the spatio-temporal variations of those loads, the best design of the turbine (the one that would lead to an optimum between turbine performance and longevity, at the lowest allowable built and maintenance cost) is impossible. The long-term risk of the entire operation is also higher, affecting developers' ability to raise funds and obtained any type of insurance coverage. One just has to think of the first failure in the Bay of Fundy by OpenHydro (under designed of the turbine due to the lack of proper knowledge of local tidal velocities and expected loads on that turbine) to their latest design iteration that worked properly but resulted in a massive structure at a fairly high cost (those high cost, and correspondingly lower return on investment might have played a role in DCNS shutting down OpenHydro in 2018). When it comes to determining expected loads on a turbine during their design, tidal developers today use for the most part codes (some validated, some not) based on blade momentum element theories (BEMT) [1]. BEMT codes are lighter to use and provide results rapidly, but by neglecting some 3D effect of the flow on the turbine blades [2]. Most simulations are also performed under steady-state condition; constant inlet flow velocity on the turbine. This provides the maximum average expected load on the turbine, load that varies extremely slowly following the time scale of tides. It's been shown that tidal flows are extremely transient in nature, varying in amplitudes on time scale of seconds or less [3], leading to large variations in loads following the same time scale. These fast variations of loads lead to a different mode of failure of the blades (and other turbine components): fatigue. Those load variations are not currently accounted for in most simulations since using real-tidal flow data is not common practice still today. The knowledge of those loads, and their variations, can be used to study long-term fatigue of the turbine blades and determine real estimate of the blade lifetime as a function of: their design, the material selection, and the tidal site in which the turbine is operating.

This presentation will discuss work previously done in the author's lab loading at various parts of this problem: turbine CFD modelling, transient studies, load variations and the use of real tidal flow data. In essence presenting all the components studied individually that will need to be put together moving forward to predict real tidal flow induced load variations on the turbine.

III. MODELLING WORK Initial work in the author's lab used a quasi-steady modelling approach using ANSYS CFX. Various projects looked at modelling the performance of turbines for which experimental data was available for validation [4-6]. Figure 1 shows a rendering of one of the turbines using an NREL S814 blade profile while Fig. 2 shows the Cp relationship obtained numerically and compared to experimental results.

Fig. 1 Turbine rendering from [7]

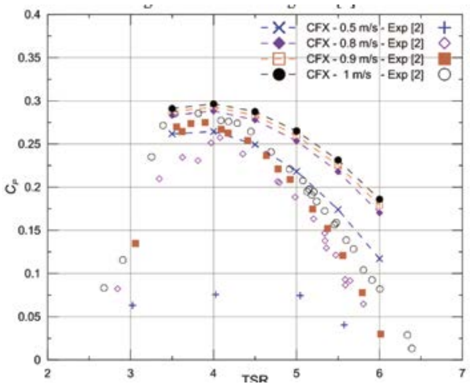

Fig. 2 Numerical CP as a function of TSR for four test velocity compared to experimental measurements [7].

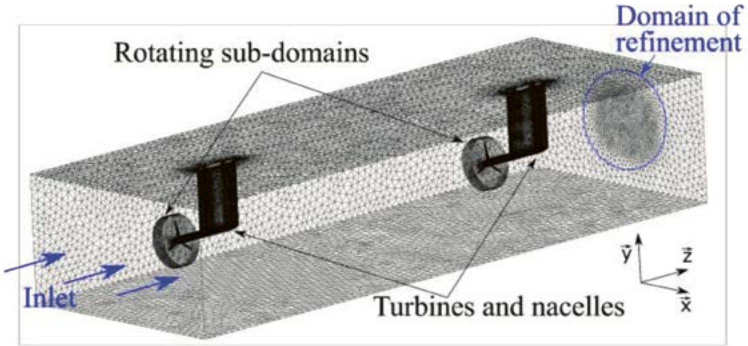

Fig. 3 Numerical domain used to study the interaction of a downstream turbine with the wake generated from an upstream one [8].

To get a better understanding of the spatial and temporal variations of loads on turbine blades, fully transient simulation with RANS-SST turbulence physics were run again using ANSYS CFX of flow over a second turbine placed in the wake of a first one [8]. Three different setups were considered: i) a downstream turbine aligned with the upstream one, ii) with an offset of half the turbine diameter (0.5D), iii) with an offset of 1D. A 10D clearance between both turbines was used. The results showed that the Cp and CT of the downstream turbine fluctuated with a frequency corresponding to the rotational rate of the turbine, and with a noteworthy amplitude of 30% and 12% of the Cp and CT mean values, respectively. The power deficit reaches a value of approximately 70% when both turbines were in-line. More importantly, this study led to the creation of spatial load maps, as well as load temporal variation maps, as shown in Fig. 4. These shows that a position on the turbine blade can see variations in load of up to 50% during its rotation, as well as temporal variations up to 13.3% at a given position (in this case, close to the blade root). Those results are for a constant inlet velocity in the system but show that a methodology can be implemented to extract the local load values on blades. Finally, a transient study was performed looking at the turbine performance when subjected to representative tidal flow velocities (Fig. 5a); flow data taken from Grand Passage in the southern portion of the Bay of Fundy [9]. Under these conditions, Cp fluctuated by up to 25%; but still, the overall amount of power produced over a period of time longer than the fluctuation equated what a constant flow at a similar average velocity would have produced.

Of greater interest, the overall thrust on the turbine (CT) varied by up to 100%, clearly showing that the natural turbulence and flow fluctuation in real tidal flow will have a great impact on the spatial and temporal loads on turbines blades.

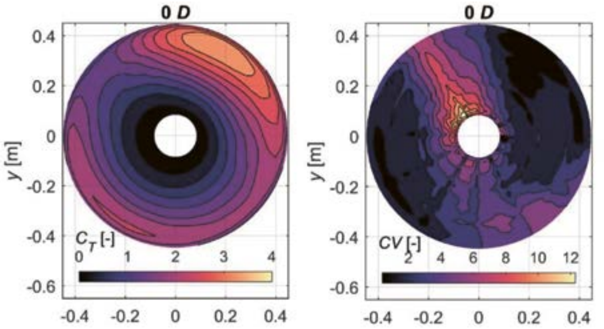

Fig. 4 Left: Dimensionless local load (CT) as a function of position on the turbine blade and through its rotation. Right: Percentage variation of local load over time at any position on the blade and through its rotation [8].

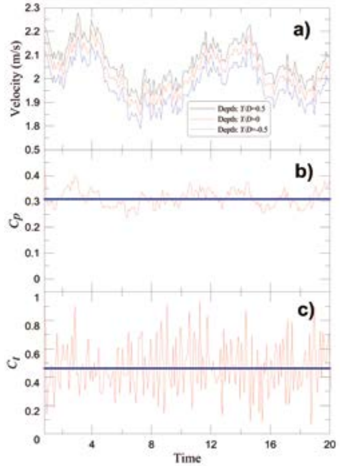

Fig. 5 a) Inlet velocity as a function of time for 3 different depths, b) Cp, as a function of time and c) Ct as a function of time (blue: coefficient from the steady simulation, red from the transient one) [9].

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Conversion System of Undimotriz Energy to Electricity

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***Keywords**: System, converter, generator, single, potential, kinetic, simultaneous.*

Wave energy is the only one that manifests itself in a pulsating, irregular and random way in the time domain (seconds), while its total energy is available in two variants: potential and kinetic in equal proportions. Developing a method or mechanism flexible enough to handle all the characteristics of the resource, is what we will try to achieve by deploying a System of Wave Energy Converter Modules.

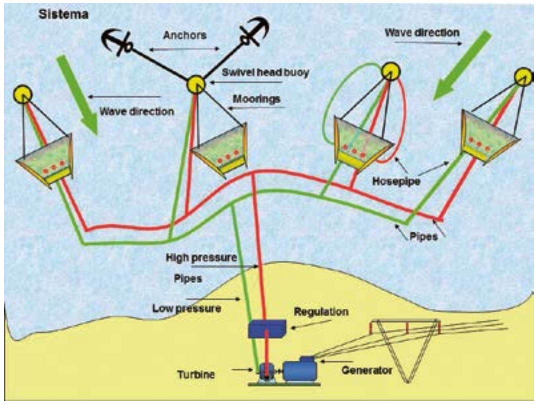

Fig. 1 Wave energy conversion system

The system shown in Fig 1 simultaneously captures the potential and kinetic energies of the waves and converts them in pressure of a fluid in a large diameter pipe of a hydraulic circuit, maintaining an almost constant pressure in the high-pressure line, regardless of how variable the energy (volume of fluid) that each module may provide; by regulating the flow in a turbine or hydraulic motor coupled to a generator.

The generator set (unique for the entire park) and the technology endowment that complements it are not in contact with the water, nor are there submerged complex mechanisms that need attention except for the anchorages and mooring of the modules.

The location of the generating park depending on the distance to the coast can be located on the coast or on a floating platform.

MODULE

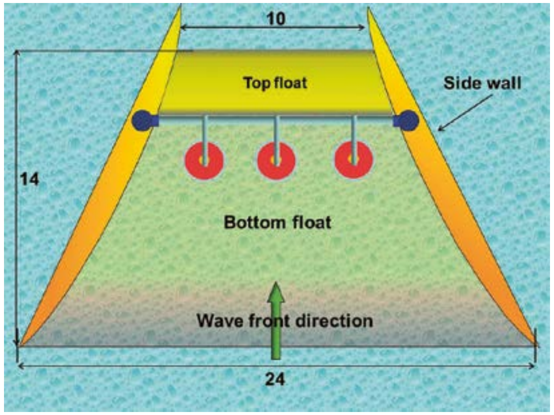

Fig. 2 Plan view of the converter module. Approximate measurements in meters.

The converter module Fig. 2 fulfills the function of energy into pressure. The second stage, the generation of electricity, in this case takes place on the coast but it is also possible to do it off shore on a floating platform.

SYSTEM CARACTERISTICS

Fully mature technologies employed

All the works related to this system are possible to carry out in our Country: Argentine Republic.

Capture Potential and Kinetic energies simultaneously

Worldwide, most wave energy projects are focused on harnessing potential energy, few on kinetic energy and even less the combination of both.

A generator running dry for the entire park

A single generator is powered by the energy collected from all the converter modules in the park. Almost all of the wave energy converters of many projects worldwide have an electric generator mounted, this implies that the number of generators is equal to that of converters. In addition, the generators are in contact with water on the surface or submerged, due to this (the generators) must be encapsulated, making service or replacement difficult, this configuration has an associated potential for generator failure multiplied by the number of generators.

No complex installations under the surface

There are no underwater moving mechanisms, nor complex electrical installations under the sea surface.

Closed or open hydraulic circuit with air or liquid

The closed hydraulic circuit has the advantage of being able to work with a dosed fluid with anticorrosive treatment, for internal protection of the pipe, or as an open circuit with air or sea water. In the open circuit, the low-pressure branch is removed, at a lower project cost, but the fluid is not treated. In both, cathodic protection mitigates corrosion.

Anchorage and mooring system in accordance with standards of the offshore oil industry

It allows a stable position of the modules with respect to the mean sea level (tidal range) and an autonomous orientation of the axis of symmetry of them with respect to the wave front.

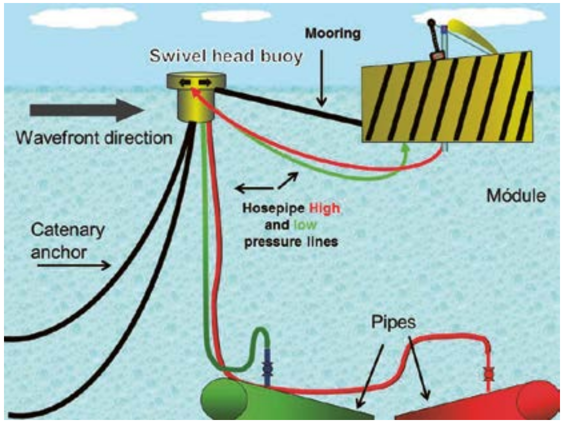

Fig. 3 Module, mooring buoy with swivel head and pipes.

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TECHNOLOGY: EMERGING

e.Wave: Maximization of wave energy harvesting through the integration of an adaptive mechanical system regulated by sea conditions for point absorber wave energy converters

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***Keywords**: Ocean energy, Wave Energy Converter, Wave-to-Wire, Maximization, Efficiency Optimization.*

Ocean wave energy is one of the richest renewable energy sources, and its potential is very significant in many countries around the globe [1]. The estimated worldwide potential of ocean wave power is 32000 TWh [2], which exceeds the worldwide electricity consumption of about 25721 TWh [3].

The development and implementation of wave energy converters have several advantages and benefits, especially for those countries with abundant wave energy resources. Examples range from local benefits for the country in terms of increase in the renewable energy matrix and guarantee of energy supply diversity [1], to global benefits, as a contribution towards confrontation of the problems of climate change and the difficult challenge of reducing the dependence on conventional energy resources such as fossils or nuclear energy.

In contrast to solar or wind energy, wave energy cannot be considered a mature technology [4, 5, 6, 7, 8]. To date, wave energy technologies are extensive, resulting from the different ways in which wave energy can be extracted, and depending on the water depth and on the location. Despite that many variants for wave energy converters (WECs) exist, all of them can be sorted in four main classes, according to: location, size, working principle of the absorber or the working principle of power take-off (PTO) system [6, 9, 10].

Up to now ocean wave energy conversion faces several challenges, ranging from economic problems and technical obstacles to issues affecting its operation and maintenance in the severe ocean environment, mainly due to ocean salinity and extreme weather conditions [7].

Waves are irregular, which cause another challenge for extraction of their energy, as there is a problem of randomness in amplitude, phase and direction. This makes it difficult to optimize the device efficiency over the entire range of excitation frequencies [1].

In addition, wave energy converters should be able to operate (efficiently) on normal sea state weather, but also outlast extreme sea state conditions, in which the exerted peak forces can be as high as 100 times the average forces [8].

One of the main challenges for the development of successful WECs is to reduce the levelized cost of energy (LCOE) [12]. The LCOE of different technologies is shown in Fig. 1. The WECs are, comparatively, the most expensive clean energy producers among the technologies evaluated [13]. According to Ulazia et al. [11], a comprehensive improvement of the WECs systems must be carried out considering aspects such as the optimization of the control for the maximization of energy, improving the PTO and reducing construction, installation and maintenance costs.

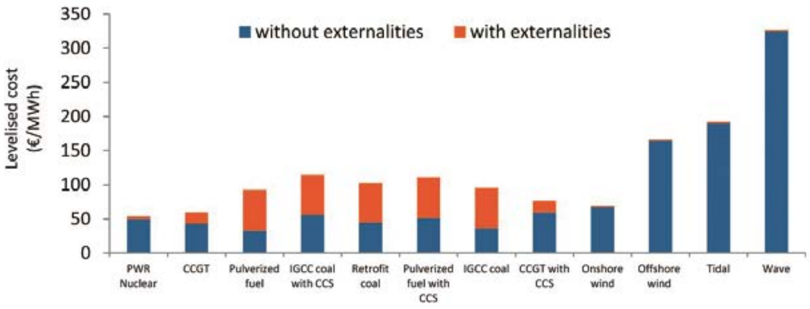

Fig. 1. Levelized costs (LCOE) of different technologies including external costs [5]. The reader should observe that the wave energy represents the highest LCOE.

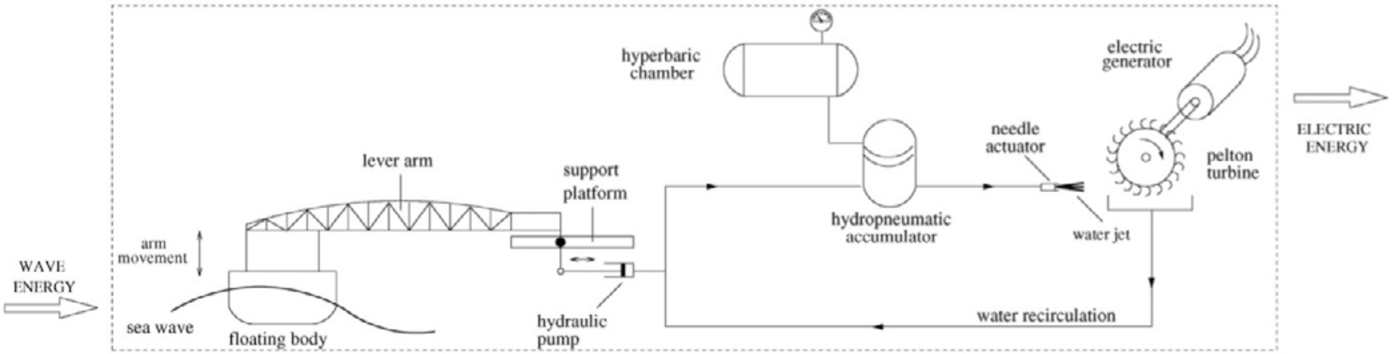

Fig. 2 Scheme of a floating body WEC attached to a rigid lever arm [16].

This research focuses on improving the PTO of a point absorber WEC attached to a rigid lever arm (see Fig. 2). In these systems, each pump module has a floating body connected to a hydraulic piston pump which pressurizes a closed water system that is used to load a hydropneumatics accumulator. Then, a needle actuator produces a water jet which drives a Pelton turbine coupled to an electric generator.

These WECs are simple and can be installed on the coast or offshore. However, like other WECs systems, its efficiency is associated with the specific wave regime [14]. Normally, these mechanisms are designed and optimized in terms of efficiency assuming a fixed length of the lever arm and a single point of connection between the hydraulic pump and the arm [15]. Consequently, when the wave has small amplitude, the displacement of fluid in the hydraulic system is smaller and, therefore, the electricity generation is low. This represents an obstacle in conditions with fluctuating wave amplitudes [16], which affects the overall system efficiency and, therefore, elevates the LCOE.

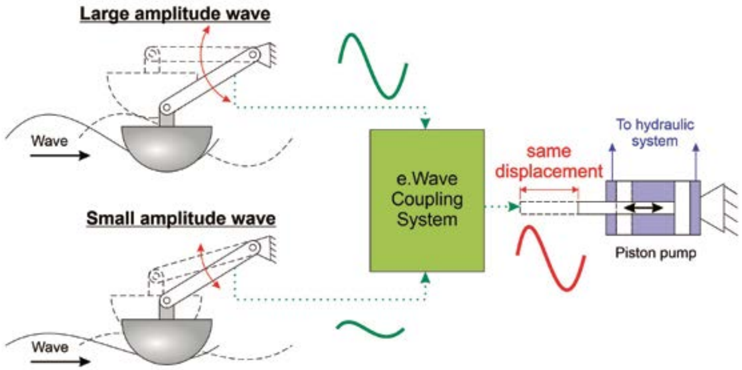

Fig. 3 Scheme of the e.Wave system to guarantee the same displacement in the piston pump regardless of the amplitude of the wave.

e.Wave has overcome this limitation by including within the mechanical design of the WEC an accessory system that guarantees a uniform displacement of the hydraulic pump, regardless of the wave conditions (see Fig. 3). The foregoing is valid if enough buoyant force is available at the point of absorption of the wave. The novel mechanical system modulates the action of the arm on the hydraulic pump based on the amplitude of the wave and, therefore, maximizes the harvesting of the energy available in the wave. The concept of the system is shown in Fig. 3.

The results of this research contribute significantly to the development of more efficient WECs and, consequently, could reduce the LCOE of this type of technology, making it more accessible and commercially attractive. The authors consider that the design proposed here can be used in other WECs that have to deal with time-varying reciprocating movement of mechanical elements for the conversion or accumulation of energy.

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Numerical study of the effect of a flap-type Wave Energy Converter in the wave field analyzing the directional wave spectrum

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Keywords: *Wave Energy Converter, Wave Modeling, SWAN, Relative Capture Width, Directional Wave Spectrum.*

Part of the energy transferred from the atmosphere to the sea surface is carried by the wave field along great distances. Some of this wave energy can be collected using devices known as Wave Energy Converters (WEC), which ability to extract energy from the wave field can be highly dependent on the wave frequency and direction, particularly those that are single axis devices like a flap-type WEC [1].

The most common approach to estimate the power absorbed by a WEC is considering bulk parameters as a representation of the wave directional spectrum. This approximation is not completely accurate, particularly at regions with complex and variable wave systems [2]. For such cases, the evaluation of the directional wave spectrum is more convenient.

In this work, the results of numerical simulations of the directional wave spectrum under the presence of WEC arrays are presented. The work was carried out through the implementation of the third-generation spectral wave model SWAN in the Todos Santos Bay, Ensenada, BC, Mexico. The results were validated by using data from Acoustic Doppler Current Profilers (ADCP), deployed at three different sites for a period of two years. Results from the model showed significant wave height (H_s) Root Mean Square Error (RMSE) from 0.21 to 0.24 m and a linear correlation coefficient (R) of from 0.73 to 0.94. For the peak period, the RMSE was about 2.45 to 2.71 s, and the R values were about 0.64 to 0.72. From the simulation results time series, the most common combinations of significant wave height and peak period for winter and summer were identified and considered as boundary conditions as selected events to carry out five different experiments: one without WEC as a reference run, and four with configurations of one, five, ten and twenty-five WECs, the latter as a staggered array.

The WEC devices were represented in SWAN as energy absorption obstacles. The obstacles are introduced by the coefficient transmission, K_t, which is defined as the ratio between the incident and transmitted wave height [3].

SNL-SWAN (Sandia National Laboratories–SWAN) is a version of SWAN that incorporates a WEC module, which allows us to compute K_t for specific WEC analysis and performance studies [4]. In this work, the performance function known as Relative Capture Width (RCW) was used in SNL-SWAN to simulate WECs behavior and their effect on the wave field. The RCW is defined as the relative amount of power absorbed by the WEC in relation to the available power in the width of the device [5]. A frequency dependent RCW (f) associated with a flap-type WEC device characteristics [6] was used in this work to simulate the presence of WECs.

From the numerical simulations considering the presence of WECs, it has been found that the maximum dissipation of energy occurred in the lee of the devices, as expected. The difference of significant wave height ΔH s was obtained from subtracting the results from experiments with WECs arrays from those from the experiment without WECs. As it is shown in Figure 1, a shadow zone is present indicating a reduction in H s where the difference is more significant for the staggered experiment. In O'Dea et al., (2018) it is argued that when the WECs arrays are closer to shore, the waves have less distance to spatially redistribute their energy which means that the reduction of H s is more noticeable.

From the results, it is also shown that the amount of dissipation of energy due to white-capping and to bottom friction, is reduced under the presence of WECs. Therefore, the momentum flux due to the wave energy dissipation, τ ds , (equation 1) in the staggered array was reduced by 37%, which means that the presence of WEC could reduce the turbulent kinetic energy injection to the water column [7].

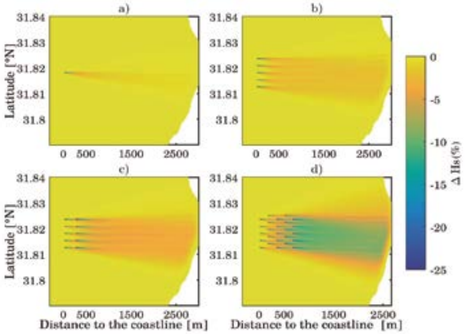


Fig. 1. Results of ΔH s in percentage from the numerical simulations including different WEC configurations, with a) one, b) five, c) ten and d) twenty-five staggered array with flap-type WEC characteristics.

$$\pi_{ds} = \rho g \iint \frac{1}{c} S_{ds}(f,\theta)\, df d\theta \qquad (1)$$

where S ds (f,θ) is the energy dissipation due to white-capping and the induced by bottom friction, ρ is the density of the water, g is acceleration due to gravity, and c the phase speed.

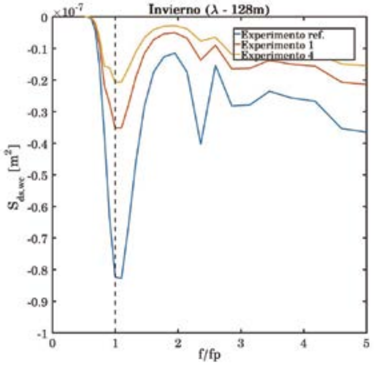


Fig. 2. Results of wave energy dissipation associated with whitecapping and bottom friction. Reference experimental run is without WEC (blue line), and the two additional experimental results correspond to 1 WEC (red line) and a 25 staggered WEC array (yellow line).

Additionally, to analyze the power that might be extracted by the flap-type WECs when considering the incident directional wave spectrum, a frequency-direction dependent performance function was proposed as RCW (f , θ), which is given by,

$$RCW(f,\theta) = RCW(f)D(\theta)$$

,

where D (θ) is a function that represents the ability of the flap-type WEC to absorb energy as a function of direction,

$$D(\theta) = \cos(\theta - \theta_0)^{2m}$$

Two cases were analyzed: when directional absorbance ability of WEC is relatively low ($m = 10$) and when is relatively high (m = 2). To estimate the absorbed power, RCW is applied as,

$$P_{\text{absorbed}} = RCW(f,\theta)P$$

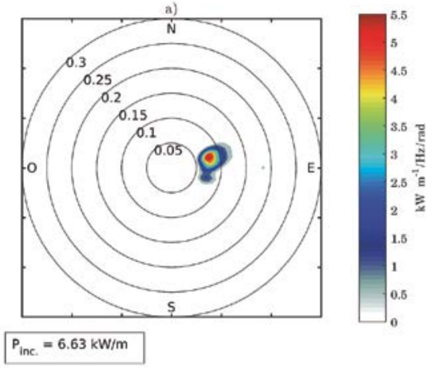
,

where P is the incident wave power, as given by,

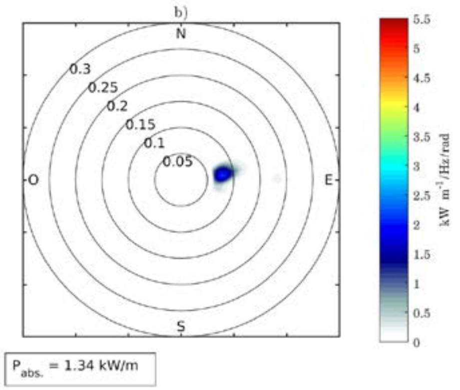
$$P = \rho g C_g(k,h)S(f,\theta)$$

and Cg is the group velocity, while S (f, θ) is the directional wave spectrum.

The results of the experiments using the proposed RCW(f, θ), suggest that using m= 10 the estimated power absorbed is up to 60% less than the case when considering RCW(f), and about 22% less when m=2 is used. In Figure 3, the incident wave field is shown in terms of the wave power (top) and the resultant power absorbed is also given (bottom) for the case of m= 10.



(a)



(b)

Fig. 3. a) The incident wave power going towards the east and the b) result of the absorbed power when using RCW(f, θ), with m=10. The integrated values are 6.63 kW/m for the incident wave power and the power absorbed is 1.34 kW/m.

In this work, numerical simulations experiments were carried out to analyze the effect of single axis flap-type WECs by analyzing the directional spectrum of waves. The dissipation of energy due to the presences of WECs causes a reduction in H s and τ ds. Finally, it is demonstrated the importance of considering the direction in the performance function to evaluate the power absorbed by the WECs.

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Electrohydrodynamics for a point absorber WEC: theoretical foundation

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***Keywords**: Wave Energy, Variational Method, Wave Energy Converter.*

In this work, we introduce a methodology, based on Lagrangian dynamics, to understand the composition of a wave energy converter (WEC) like an only system. The idea of a coupled representation of a system that shapes a WEC is not new, [1] tell that treating the systems what shape a WEC like a systems independent, as such leads to inaccuracies in the prediction of power output and reliability, and can erode confidence in numerical modeling tools. The idea of study systems coupled with Lagrangian dynamics in interaction structure and fluid is development in other works [2], where they present a Lagrangian strategy for solving fluid-structure interaction (FSI) problems. Uppsala University has experimented with point devices in the ocean since 2006; it continues to research on them. The reason is that the concept of point absorbent devices is simple, which ensures a robust and efficient system [3].

In the design of the point absorber device, many power take-off (PTO) systems have been tested, standing out for their direct drive, structural simplicity, high-efficiency PTO known as a linear generator. There are many ways to analyze a WEC device through experiments or simulations. From which much information would be obtained, which also requires a complicated analysis which can result in having unwanted or poorly understood information. On the other hand, the derivation of a mathematical model that is useful and realistic is complicated, but if it is found, information can be obtained economically and with acceptable precision [4].

In this paper, we study the voltage obtained from a linear generator in a WEC with a degree of freedom in its movement, when a wave induces movement on it. To do a mathematical model is developed considering a Lagrangian dynamics, that is a variational formulation of the dynamics, which allows describing the mechanical and electromagnetic part as a single mathematical model. This formulation has been considered previously in the design of microphones and speakers [5, 6].

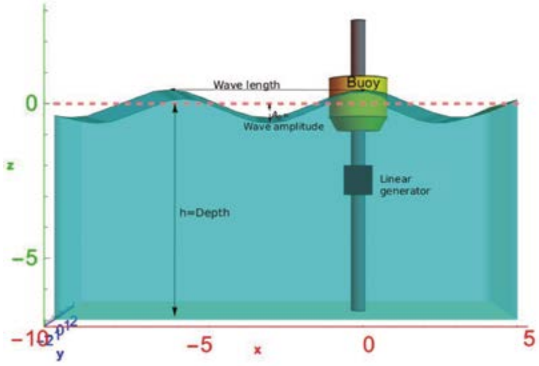

Fig. 1. Scheme of a WEC device with one degree of freedom of motion. The average level of the sea, in orange, you can appreciate the waves in turquoise. The WEC is constituted by a buoy in yellow, coupled with an electric generator, in black, and can move freely on the vertical axis, in gray, because the waves induce movement in it.

But at the moment its application in WEC devices is unknown. In this work, we use a particular variational method named Euler-Lagrange equations. With this, we derived a coupled system of equations that contain the energy of the systems and dissipative terms.Solving, we obtain an equation of motion for a mechanics system of a wave energy converter. For another hand, we get an equation of motion for an electric system based on a linear generator used like PTO.

$$\begin{aligned} \frac{d}{dt}\frac{\partial L}{\partial \dot{z}} - \frac{\partial L}{\partial z} + \frac{\partial P_d}{\partial \dot{z}} &= \quad F(t) \\ \frac{d}{dt}\frac{\partial L}{\partial \dot{q}} - \frac{\partial L}{\partial q} + \frac{\partial P_d}{\partial \dot{q}} &= \quad V_\epsilon(t) \end{aligned} \qquad (1)$$

In equation 1, L represents a Lagrangian that contains conservatives forces of study, mainly kinetics and potential energy. Pd, represents dissipative energy, like a friction F(t) is the wave force over a WEC, and Vε(t) the voltage obtains of a linear generator. For another hand, z and ż were the coordinates of the mechanical system; q and q were the coordinates of the electrics system. This work is based in a WEC kind absorber point, see figure 1, with one degree of motion. Therefore, we have one linear generator. The variational formulation has the advantage of what works with electric systems too. Then we can consider two systems, the mechanical system, and the electromagnetic system, in one [6, 5], this can see in equation 1, where both equations are coupled. Solving equation 1, we obtain a coupled system of two equations. This couple is more approximate to the reality of a wave energy converter that represents systems that are not independent. The couple made through a factor T, named transducer, and in this mathematic model represents the form in what is transmit the energy of systems. For simplicity, the solutions were obtained by Laplace transforms.

After solving equation 1, with the solutions, we can obtain a transfer function, (see equation 2) between the input, the force waves and the output, the voltage given by a linear generator.

$$V(s) = Rs\frac{-TsF(s)}{(ms^2 + k_d s + k_f) - (Ts)^2} \qquad (2)$$

In equation 2, the variable s tells us that the variables are in the Laplace transform space. V(s) is the voltage, T is the transducer constant, R is electric resistance, m is the mass and kd is the dissipative term, and kf is the buoyancy constant.

From the transfer function, we can analyze the behavior of the systems. In the literature plots of the transfer function is named Bode plot. Some of the most relevant aspects that we can get of these graphs; is the peak associated with the resonance of the system like the response to a perturbation. In this case, a WEC as a response to the incident wave (see fig. 2).

For validity equation 1 and 2 were tested, by comparing data with others works in wave tank experiments with a scale model. From output voltage, it can be estimated by Ohm's law the current in the terminals and then estimated the power (see fig. 3) that is being generated obtain good agreement.

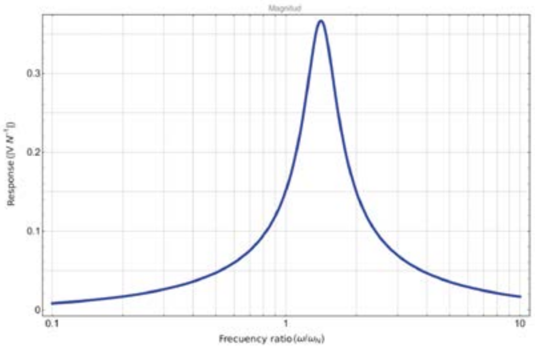

Fig. 2. The result of the transfer function module is the electrical response, in blue line, that is given in volts over Newtons in function of the ratio $\frac{\omega}{\omega_N}$. In this case, the wave energy converter has resonance in the ratio of 1.5 $\frac{\omega}{\omega_N}$, where ω the frequency of the wave input and ω_N is the natural frequency. The amplitude of the peak can be varied by changing the hydrodynamic damping and electrical resistance.

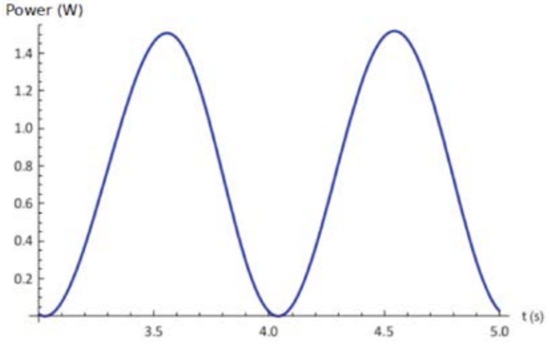

Fig. 3. The result of converting the mechanical power of the waves to electrical power, in blue line, through the transfer function obtained in this work, of a wave energy converter with a degree of freedom in its movement.

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Dynamic analysis of a novel six degrees of freedom device for wave energy extraction

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***Keywords**: Wave Energy, Waver Energy Converter, Stewart-Gough Platform, Planned Trajectory, Wave-Structured Interaction.*

A novel wave energy converter (WEC) design, based on the concept of the Stewart-Gough platform (SGP) is being investigated, see figure 1.

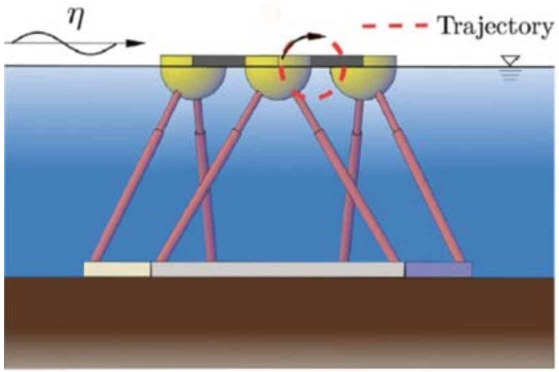

Fig. 1. Sketch of the WEC-SGP concept fixed at the sea floor. The influence of ocean surface waves induce its motion, and the planned trajectory of the upper floating component is depicted (dashed red circle).

The main objectives of this study are to present the proposed WEC based on the SGP (WEC-SGP) and to establish the necessary equations to describe the motion of the SGP to be used as a WEC. A kinematic analysis is developed to evaluate the leg lengths required to track the planned trajectory determined by the elevation of the free surface of the sea. Furthermore, the WEC-SGP dynamical analysis as formulated by the Newton-Euler approach [1,2] is solved to find the required leg forces to support the effect of the hydrodynamic forces and the force moments acting on the upper floating component. The novel idea is to include the forces arising from the wave-structure interaction [3,4] in the general dynamic equations of the SGP. Linear wave theory is used to analyze the WEC-SGP and some of the kinematic aspects of linear waves [5] are used as input information for the kinematic and dynamic analysis. The instantaneous and mean power provided by the WEC-PSG are calculated for regular wave conditions, see figure 2.

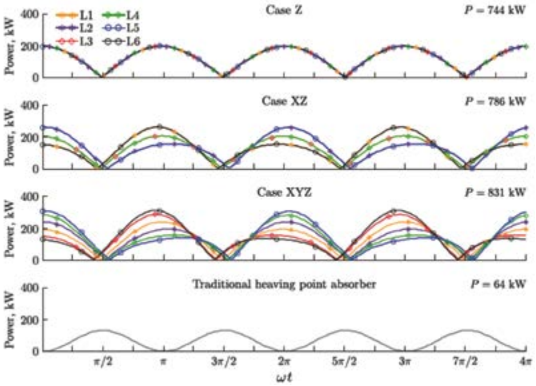

Fig. 2. Instantaneous and mean power extracted by cases Z, XZ and XYZ of the WEC-SGP, and comparison with the THPA WEC.

The results show that the proposed WEC-SGP configuration might increase the conversion of the wave energy, since all degrees of freedom in its motion are being used, as compared with the traditional heaving point absorber (THPA) WEC.

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Tidal energy for hydrogen production through reversible solid oxide cells

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Keywords: *Tidal Energy, rSOC system, Energy Storage, Hydrogen Production, Time-Domain Modelling.*

The high predictability of the tidal resource in combination with its guaranteed short cycles, makes tidal power a very convenient renewable technology to be used in combination with energy storage solutions [1]. In particular the production of hydrogen from renewable sources is of interest due its ability to produce electricity as well as heat for both transport and stationary applications without the high environmental impact [2-4]. The first production of hydrogen from excess of tidal power generated was successfully achieved in August, 2017 at the European Marine Energy Centre (EMEC) tidal energy test site at the Fall of Warness, at the Orkney islands [5-6].

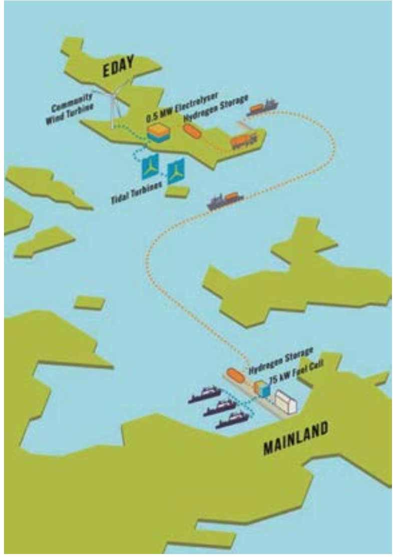

Fig. 1. First hydrogen gas produced from tidal power at test site of EMEC in the Orkney Islands [5]

Reversible Solid Oxide Cell (rSOC) is a promising energy storage technology that turns effectively surplus of tidal power into hydrogen when operated in electrolyser mode (SOEC) and produce power by the reverse process when operated in fuel cell mode (SOFC) in the same device [7].

However, rSOC design and operation is uniquely challenging because of the need to operate in both SOFC and SOEC to enable a baseload dispatchability. In addition, the rSOC should be able to cope with the tidal power fluctuations as a result of turbulence and swell effects on the current velocities.

This paper presents intermediate results on the dynamic behavior of the integration of a horizontal axis tidal turbine with a Reversible Solid Oxide Cell. A numerical model is used to predict the dynamic behavior of both the tidal turbine and the rSOC when operating under different turbulent current speed conditions. The individual models of the horizontal tidal turbine and the rSOC are used from existing literature and coupled in a time-domain model [7-9]. The aim of this work is to define a proper operation strategy for power balancing considering the requirements and restrictions of both systems. The simulation results are shown for the most relevant operating conditions of both the tidal turbine and the rSOC.

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Adoption of Deep Ocean Water Technologies and their Contribution to Sustainable Development in the Caribbean

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Keywords: *Ocean Ecoparks, Ocean Thermal Energy Conversion, Practical Potential, Seawater Air Conditioning, Energy Policy.*

The world has today the urge of mitigating climate change and reducing fossil fuels dependence. This urge has led to an accelerated –yet insufficient– increase in the global renewable energy capacity, with a large deployment of solar and wind energy in recent years. The ocean has the potential to provide energy for the entire planet; still, marine technologies such as tidal, wave, thermal, and osmotic energy have a minor share in the energy mix, given that most of these are in preliminary stages of development. Of particular interest, ocean thermal energy conversion (OTEC) and other deep ocean water (DOW) technologies are arising as a suitable option for tropical islands.

There are gaps that should be filled in order to make DOW technologies competitive with both conventional and other renewable alternatives, such as evaluation of practical potential, identification of main barriers, and design of policy incentives for supporting technology development. While solar and wind energy have the lead on cost, DOW technologies have the potential to compete with the added value that can provide, especially for insular areas and Small Island Developing States. This study contributes to such gaps by evaluating the DOW potential of in the Caribbean, and the benefits that these can provide to achieve sustainable development goals.

Small islands, particularly in the Caribbean, face today many sustainable development challenges. First, they need to guarantee energy supply, improve energy efficiency, and reduce the high dependence on fossil fuels [1]. Additionally, they need to guarantee freshwater and food supply, both threatened by climate change [2], and improve economic development, highly dependent on tourism [3].

DOW is a renewable resource that can provide thermal energy for refrigeration, through a SWAC district, electricity and desalinized water through an OTEC plant, and nutrients for food production through seawater greenhouses and mariculture. In this study, we propose the integration of an ocean technology Ecopark [4] as an alternative to using a renewable resource (DOW) to address several sustainable development issues, as shown in Fig. 1.

Fig. 1. Needs and challenges that can be addressed with DOW technologies

Second, this study contributes to ocean energy gaps by proposing a methodology for estimating the practical potential of DOW, as the maximum water flows that can be extracted from –and returned to– the ocean considering market and socio-economic conditions, technology requirements, and environmental constraints. These last have been identified as one of the main constraints to renewable energy implementation in the Caribbean [5]; thus, we paid particular attention to these in the potential estimation model, considering historical variations in ocean currents, temperature, and salinity.

We estimated the potential in five cities in the Caribbean: Bridgetown (Barbados), Montego Bay (Jamaica), Puerto Plata (The Dominican Republic), San Andres (Colombia), and Willemstad (Curacao). We found that the average DOW potential is around 50 m3/s per city; the found flows are enough to supply more than 100% of the city's air conditioning (AC) demand and 60% of the electricity demand in each island. We also estimated a monthly availability of DOW resource, finding maximum extraction potentials between December to March, and minimum values between August to October, as shown in Fig. 2.

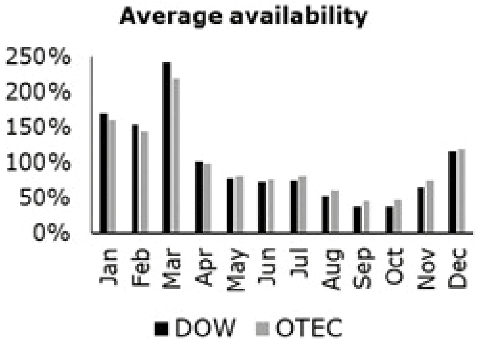

Fig. 2. Average monthly availability of DOW and OTEC in the five cities considered

Finally, this study analysed the market potential for SWAC in the Caribbean, and potential contribution of this technology to the Caribbean sustainable development goals. 90% of the electricity generation in the Caribbean comes from fossil fuels [3]; and about 16% of that electricity is used in air conditioning (AC) [6]. AC demand is expected to increase by 35% in the residential sector and 67% in the commercial sector by 2050, as a result of population growth and climate change [7]. SWAC is one of the most mature DOW technologies; it is a renewable energy that uses cold DOW to provide AC to a set of buildings through a cooling district. By replacing traditional AC with SWAC, a building could increase its efficiency by about 80% and could eliminate the use of fossil fuel for AC generation. Despite the advantages, the adoption of SWAC in the world, and especially in the Caribbean, is limited. The adoption of SWAC is strategic for sustainable development in the Caribbean, given that it could drive the adoption of other less-mature DOW technologies such as OTEC.

We developed a system dynamics simulation model to understand the adoption process of SWAC in the Caribbean, identifying the main barriers, and testing different policy incentives for promoting its adoption. Simulations show that, similar to other renewables, the adoption of SWAC follows an S-shaped path. Despite the high investment costs, the profitability is not a limitation to adopt since SWAC has a lower levelized cost of energy (LCOE) than traditional AC. A SWAC network provides AC to several buildings; thus the construction of the first system needs to guarantee a minimum AC demand (threshold capacity) to be economically feasible. We found that the main limitation to SWAC adoption is the low technology acceptance, necessary to reach such threshold capacity. Thus, policymakers should design incentives to increase acceptance and reach the threshold capacity, instead of providing incentives to decrease costs, such as tax exceptions.

Results suggest that, by 2030, renewable AC use in the Caribbean could reach 36% if the countries adopt individual policies. This percentage could increase up to 60% if they adopt a regional policy, as shown in Fig. 3. We found that the regional policies are the most effective to impulse the adoption of SWAC, which in turn contributes to attaining sustainable energy targets such as reduction in greenhouse gases emissions, refrigerants emissions, energy efficiency, and energy diversification.

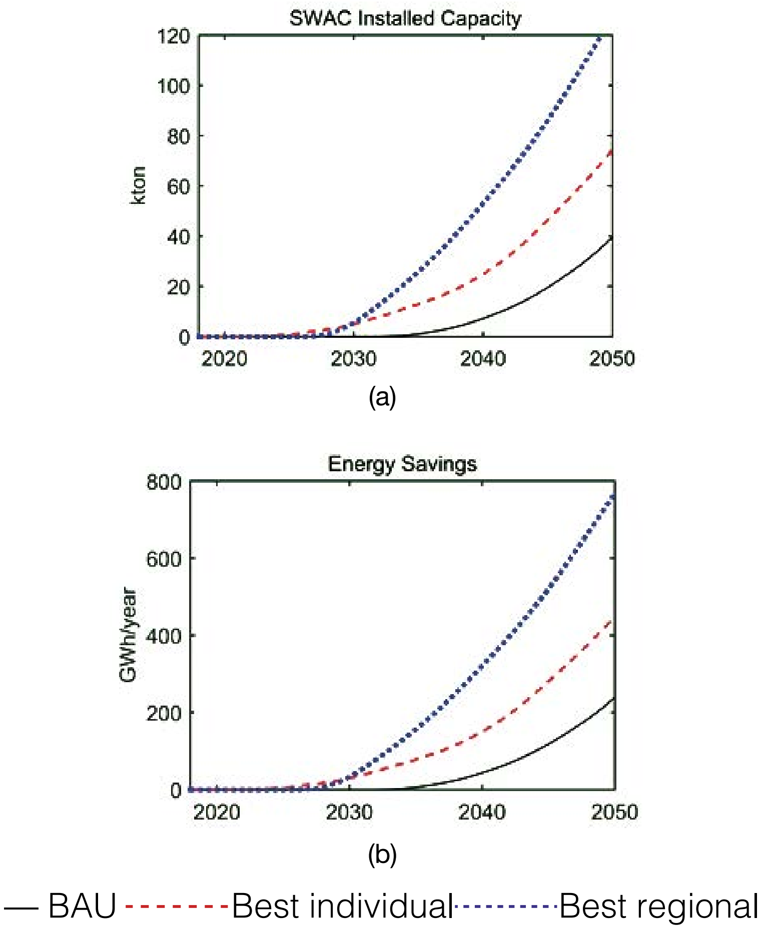

Fig. 3. SWAC installed capacity and potential energy savings under different policy scenarios [8]

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Considerations for Offshore Wind Turbine Design in the North Pacific of Costa Rica

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***Keywords**: Wind turbine, Wind turbine design, site assessment, offshore wind, foundation.*

The wind energy sector is one of the fastest-growing energy industries, as a consequence of the ever-rising energy demand in the global path toward decarbonization. It has long been known that there is great offshore wind energy generation potential, however, due to the complexity of the technology, as wells as the adverse environmental conditions that lead to high installation and operation costs, there are fewer efforts by stakeholders to advance offshore as quickly as onshore wind parks. Nevertheless, the growing market incentivizes developers to seek new projects in areas that might not have been previously considered.

Recently in Costa Rica, the possibility of offshore wind energy generation has begun to be explored, which presents the unique opportunity to study the specific environmental conditions of the area. An initial review of the Wind Atlas [1], showed that there is great wind power density toward the Northern Pacific region, as can be seen in Fig.1. By focusing the analysis on this one area, a concrete plan can be developed to define what kind of wind turbines, if feasible, can be employed on a future wind farm.

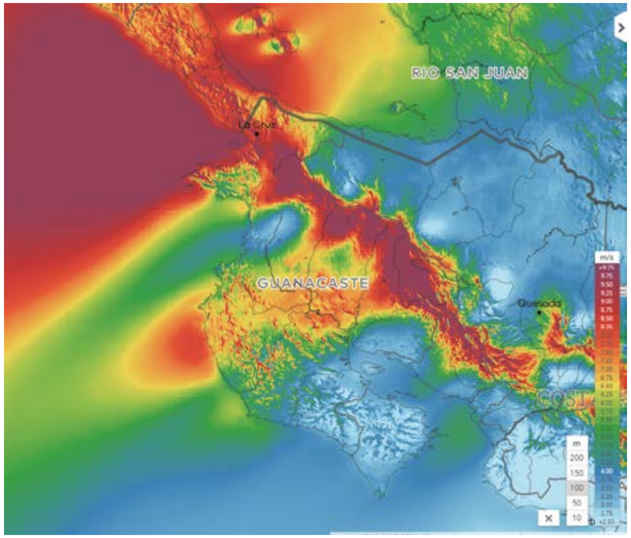

Fig. 1. Wind power density in the northern Pacific region of Costa Rica. [1]

This particular body of work focuses on the planning and design phases of a wind turbine utility cycle. Site assessment as well as rotor, tower, and foundation selection and design are taken into consideration. Other aspects of wind farm planning like legislature, social acceptance, grid connection, and operation are not within the scope of this project and therefore are not considered. Thus, the goal is to distinguish the different parts of the design of an offshore wind turbine and to propose, according to the selected site, a design guideline useful for developers to select and design of a wind turbine.

Following industrial practices, as well as international standards such as the IEC 61400-3 written by the International Electrotechnical Commission of minimal requirements for offshore wind turbines, the main design steps are defined. In four clear parts, the general planning and design practices are:

- External conditions analyses, in which the wind, current, and soil conditions are assessed, so that input conditions are generated for the design of structures.
- Selection, where basic turbine and foundation types are selected given the conditions.
- Load design, in which aerodynamic rotor analysis, tower load analysis, and foundation analysis are performed.
- Reiteration, where the process is reiterated toward a fully integrated design of the entire structure.

Each part is fully considered and solutions are offered to assist developers in the appropriate decision making for the optimal operational success of a possible offshore wind farm in the chosen region.

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Pressure drop in Reverse Electrodialysis: Analysis using CFD

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Keywords: *Salinity Gradient Energy, Reverse Electrodialysis, Pressure Drop, Computational Fluids Dynamics, Electro-membrane Processes.*

Salinity gradient energy–SGE is probably the less studied form of energy available in marine systems. Even though it is known since 1954, SGE started to gain some attention about 13 years ago [1], [2]. When two water bodies of different salinity (i.e. concentration) are mixed, free energy is released in the form of heat, therefore, it is a spontaneous process, which occurs naturally in several systems like estuaries and coastal lagoons. Recent studies conclude that SGE may supply 3% of global energy consumption, being the Mediterranean Sea, the Caribbean Sea, and the Gulf of Mexico the zones with higher potential for its harnessing [3].

The driving force in the mixing process is a chemical potential (associated with concentration) difference. The aim of SG technologies is to change the process path by which the chemical potential gradient between the two waters of different salinity is reduced.

Regarding technologies to convert SGE into electricity, Reverse Electrodialysis – RED is one of the most promising. It is analogous to Electrodialysis, which has been widely studied in desalination [4]. RED is a direct conversion method based in electrochemistry and ion exchange membranes. Theoretical analyses suggest that it is suitable for applications with salinity gradients in nature (e.g. river and seawater) and for small generation systems in coastal communities through modular devices [5]. RED study is at pilot unit stage in Europe, mainly, with plants in the Netherlands and Italy operating since 2014; the first one uses seawater and river water as feed solutions, while the second one harness salinity gradient between brine and brackish water. Both having an installed capacity of about 50 and 1 kW, respectively [2], [6].

The concept of RED is based on the arrangement of two types of ion exchange membranes (IEM): cation exchange membranes (CEM) and anion exchange membranes (AEM); CEM has negative fixed charge, hence ions charged positively (Cations, e.g. Na+) can pass across them while negatively charged ions (Anions, e.g. Cl-) are rejected; conversely, AEM allows the passage of anions rejecting the cations. When IEM are placed in an alternating arrangement, compartments (HCC for high concentration solution i.e. seawater and LCC for low concentration solution i.e. fresh water) are formed, where feed solutions may flow without being brought into contact with each other, following the chemical potential gradient direction, ions will tend to diffuse/migrate from the HCC to the LCC, the latter, coupled to perm selectivity of IEM, generates an ionic current where anions will move in a certain direction, meanwhile the cations do the same in the opposite direction, see Fig 1. If two electrodes are placed at the end of the arrangement of the membranes, the energy of the electric field formed by the movement of the ions can be converted into an electronic current by redox reactions.

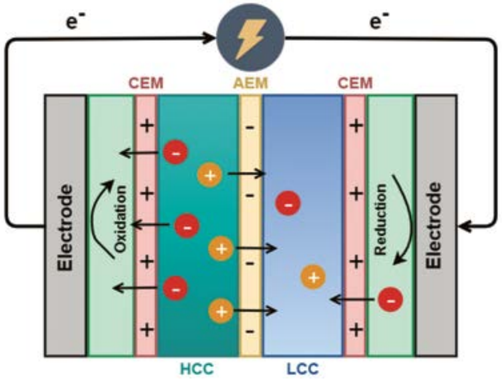

Fig. 1 Schematic representation of RED

Although RED has been studied worldwide, there still some limitations to overcome in terms of net power density and energy efficiency, thus, lowering costs, ensuring long-term stable operation, and increasing its reliability under natural conditions, are necessary for RED to be competitive with other renewable sources of energy, even with the marine ones. For the latter, research in anti-fouling strategies, membranes development, process design, redox couple, and suitable operation conditions are being conducted all over the world [7], [8].

Stack design in reverse electrodialysis has been a major concern in the technology development. Operating conditions, fluid distribution and pressure drop along the channels are some of the most critical aspects in RED since they are directly related to the net power output. For that reason, comprehensive research involving such aspects and their coupled effects has been addressed in the literature []. For the latter, key parameters such as flow velocities, flow configuration, compartment dimensions and geometries, interphase phenomena, ion migration, and ion diffusion must be considered.

A recent approach for RED stack design based on computational fluid dynamics (CFD) has been used to study of channel geometry and spacer effects on the fluid behavior, mass transfer, and pressure drops [9]– [12]. So far, CFD analysis has been mainly focused on stacks with inert turbulence promoters (spacer-filled channels). However, spacers have a major drawback under natural conditions, due to higher pressure drops, scaling, and biofouling, promoted by the spacers. Accordingly, spacer-less stacks should be considered if the technology is to be scaled up.

The aim of this work is to perform CFD simulations of several channel geometries for a RED stack and to consider the pressure drop in empty channels. It is combined with a phenomenological model to obtain adequate stack dimensions and operating conditions, which may lead to a higher net power density output.

So far, two different geometries have been studied, both varying in the inlets and outlets shape. The first comprises sudden expansions and contractions of 90° at the inlets and outlets, respectively, while the other is designed with 45°

expansion and contractions. The 2D laminar flow distribution and for 1 cm/s inlet velocity simulated using ANSYS Fluent® version 19.0 are shown in Fig 2.

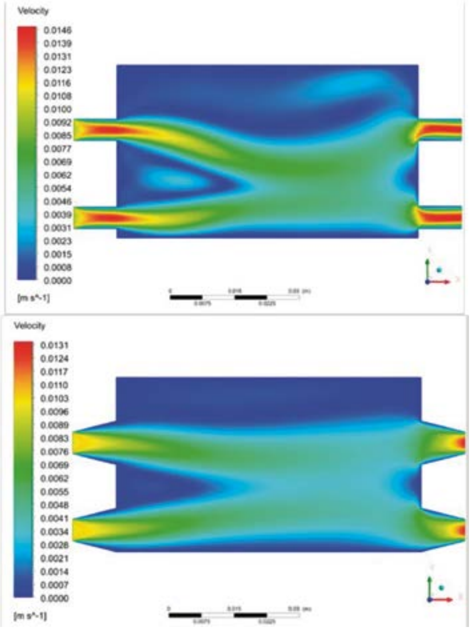

Fig. 2 Flow velocity distribution. 90° Expansion/Contraction (Top). 45° Expansion/Contraction (Bottom).

The flow field shows stagnation zones for both geometries; however, this effect is more visible for the 90° sudden expansion and contraction geometry. On the other hand, dead zones are more evident in the gradual expansion and reduction geometry.

Regarding the velocity profile, higher velocities are achieved in the inlet and outlet of the 90° expansion and reduction geometry. The pressure drop between the inlet and outlet of each geometry is presented in Table 1.

Table 1. Pressure drop for two type of inlet/outlet configuration.

Degree of Expansion and Contraction	ΔP (Outlet–Inlet) [Pa]
90°	0.2087
45°	0.0861

According to the results, the pressure drop in the 90° geometry is around 2.5 times higher than the pressure drop in the 45° geometry, showing that small changes in channel geometries could lead to lower pressure drops and, hence, to higher net power output, providing insights about hydrodynamic losses in this kind of geometries.

ACKNOWLEDGMENTS

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Salinity gradient energy potential in Latin America with emphasis in Colombia and Mexico

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Keywords: *Salinity gradient energy; river mouths; extractable potential.*

When two waters with different salt concentration get in contact, a release of free energy occurs driven by the difference in the chemical potential between both [1, 2]. If the mixing is controlled, the chemical potential can be used to generate electricity [3]. This power source is called salinity gradient energy (SGE). It is completely clean and produces no CO2 or other harmful effluents [4].

The river mouths are manifest location for harnessing SGE as those are globally distributed, in most of the cases are located in the vicinity of cities or industrial zones and provide the sought salinity gradients [5]. In this study an analysis of the extractable SGE resources in the main river mouths of Latin America and the Caribbean islands was carried out (see Fig. 1), with special emphasis on the systems of Colombia and Mexico. For this, a criterion of feasibility, sustainability and reliability of the operation was considered.

The tide is the most restrictive driving force in terms of suitability of SGE exploitation at river mouths. A threshold in the mean tidal range around 1.2 m has been identified as a limit beyond which harnessing this renewable energy may not be suitable [6]. Fig. 1 shows the coastal zones of Latin America where tidal range is smaller than de defined threshold.

Data for estimating the energy potentials were obtained from the following sources: Salinity from Aquarius v3.0 (NASA) and SMOS (University of Hamburg) satellite missions (monthly averages for 2012); temperature from NOAA_OI_SST_V2 monthly mean climatology for the period 1971 – 2000; monthly mean river discharges from Dai et al., 2009. J Clim. Database; and tides from FES2012 model (http://www.aviso.altimetry.fr/).

The results show that 134 TWh/a of SGE are extractable from the mouths of Latin America and the Caribbean islands (Fig. 2). This amount of renewable energy is higher than the electricity consumption of most of the countries in the region, with the exception of Brazil and Mexico. The mouths of the Orinoco, Paraná, Magdalena and Uruguay rivers are in the top 10 of the systems with highest SGE potential in the world, and the Jucai (BR), Usumacinta (MX) and Atrato (CO) rivers are among the top 20, however, river mouth with suitable conditions for SGE generation can be found all along the continent (Fig. 2A). Additionally, the Caribbean Sea and the Gulf of Mexico are (along with the Mediterranean Sea) the ocean basins where more SGE can be generated per cubic meter of fresh water used for generation (Fig. 2B).

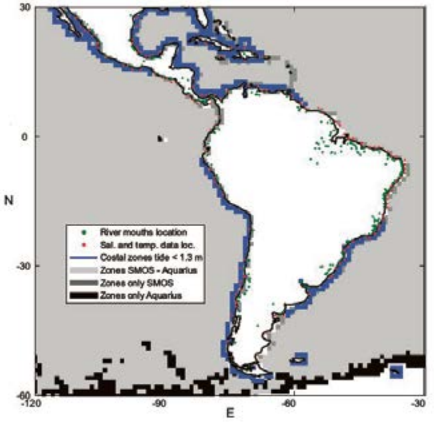
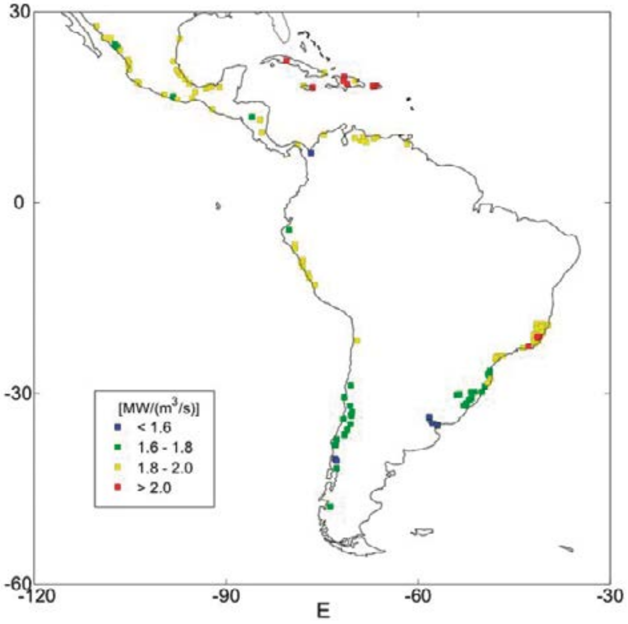


Fig. 1 Coasts with an average tidal range of less than 1.3 m in Latin America; approximate location of the main estuaries; and. location of the points with salinity and temperature information.



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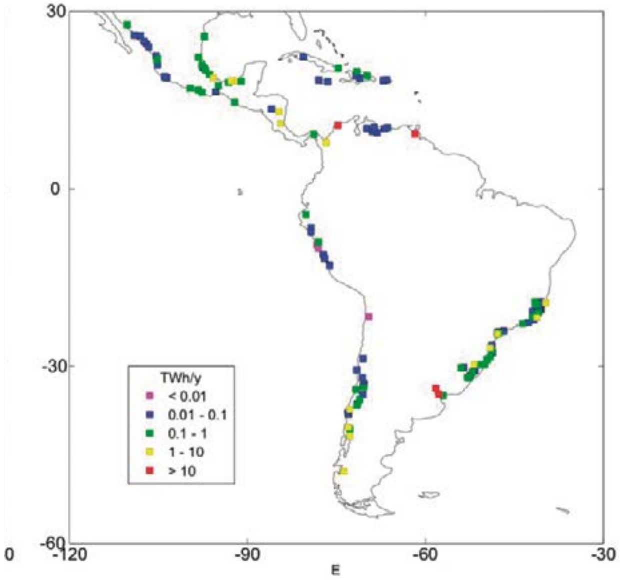

Fig. 2a. Maps of extractive energy potential and 2b. Energy density (lower panel) for the Latin American estuaries with an average tidal range of less than 1.3 m.

In the particular case of Colombia, the SGE resources are concentrated at the rivers of the Caribbean coast (Fig. 3) and the extractable potential is 5.6 TWh/y, equivalent to 11% of the country's electricity consumption on average, although this potential varies depending on the climatic season and the phase of the ENSO phenomenon.

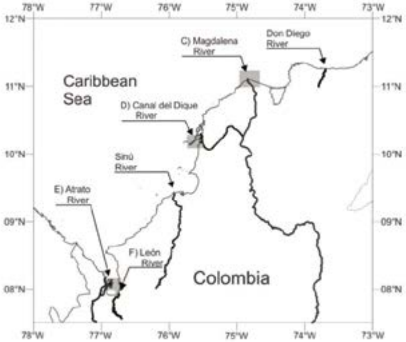

Fig. 3 Main river mouths in the Colombian Caribbean Sea.

Most of the potential for Colombia is concentrated at the Magdalena River mouth, corresponding to 4.4 TWh/a on average, fluctuating between 3.9 TWh/a and 4.6 TWh/a due to the temporal variability of the salinity structure. The systems with more stable potential -i.e. highest capacity factor- is the León River, which is, therefore, an excellent place for stablishing a pilot plant.

Meanwhile, Mexico has numerous rivers discharging to the Pacific Ocean and to the Gulf of Mexico (Fig. 4). Both are micro-tidal basins, so that the mixing due to tides is small, favoring salinity gradient development. From 29 analyzed rivers in the country, 17 discharging to the Pacific Ocean and 12 to the Gulf of Mexico (Fig 4), the total SGE potential obtained was 12.94 TWh/y. 35% of the potential is available at Usumacinta River. 84% of the potential of the country can be exploited in the river mouths of the Gulf of Mexico, even though only the 41% of the studied rivers discharge in this basin.

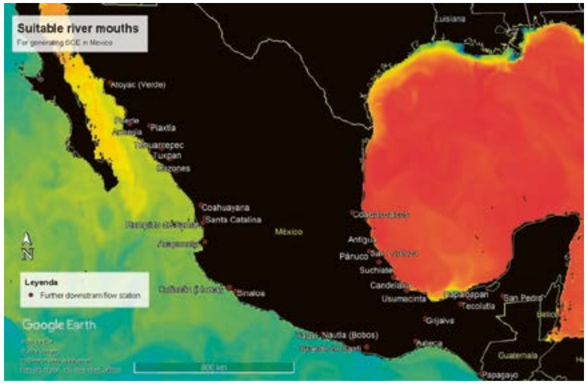

Fig. 4 A sample plot using colors that contrast well both on screen and on a black-and-white hardcopy.

The Gulf of Mexico has higher salinities and temperatures– which increase the energy density-, less tidal range, and bigger rivers than the Pacific -which increase the potential-. Greater rivers also tend to have milder discharge variations due to the buffer effects of the aquifers on the outflow; therefore, the capacity factors of the river mouths discharging into the Gulf of Mexico are also greater on average.

The Latin American continent is a manifest region for the development of SGE research and exploitation. Bringing SGE to a commercially competitive stage will still be technologically and politically challenging, however, its development is feasible and is gaining momentum. Sustaining this trend depends on the joint effort of scientist, engineers, and decision makers.

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Bathymetry and capacity factor study in areas of the Gulf of Baja California and the southwest coast of Mexico

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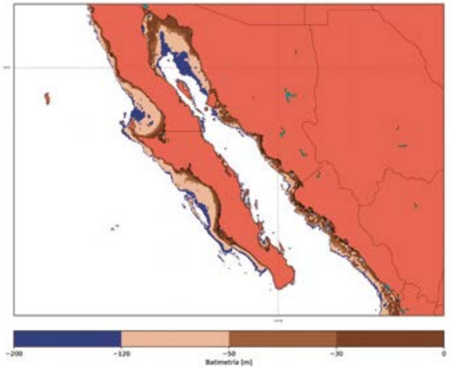
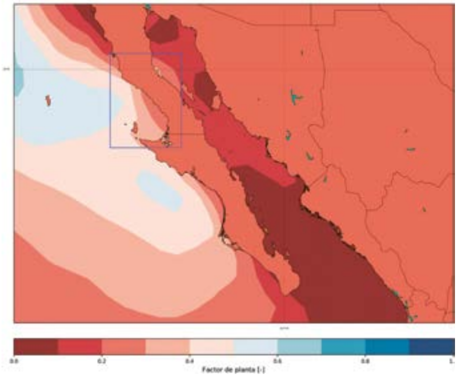
Keywords: *Offshore Wind Energy, Mexico, Pacific Coast, MERA-2, GECBO.*

Bathymetry or water depth plays a fundamental role in offshore wind energy development. Their determination, together with wind speeds and capacity factors, can indicate the main potential sites for harnessing this energy. In addition to the above, the use of reanalysis data (MERRA-2) as well as aquatic depth databases (GEBCO) allows the realization of maps through a programming language such as Python, following a methodology where bathymetry is classified into ranges and type of foundations and the wind speed is evaluated in a power curve. That said, the present bathymetry study, together with the calculation of capacity factors for the Gulf of California and southwest coast of Mexico, led to the determination of two potential sites. One of them is located in a section of Baja California Norte while the other is located in the southern part of Oaxaca. For both sites, four types of foundations were determined viable, which are: monopile, gravity, jacket and tripod. On the other hand, the most pronounced capacity factors occur in spring for the Gulf and in winter for Oaxaca, in ranges of 0-0.6 and 0.5-1 respectively.





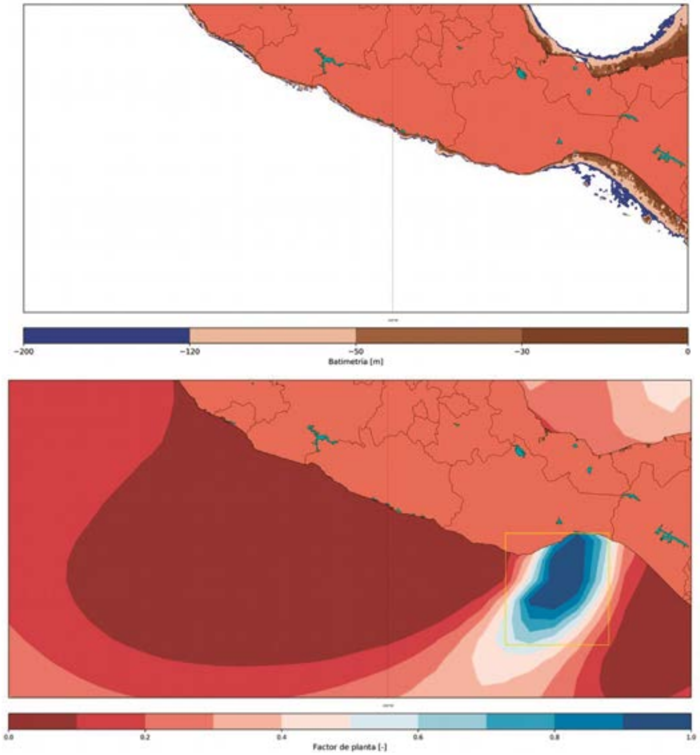


Fig. 1 Bathymetry (white background maps) and capacity factors (red and blue background maps) for two potentials areas in the Golf of California and the southwest coast of Mexico.

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Analysis of the performance and efficiency of a turbine for an Ocean Thermal Energy Conversion (OTEC) plant by simulation using the Ansys Fluent program

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***Keywords**: Curtis Turbine, Computational Fluid Dynamics (CFD), OTEC prototype, Numerical Simulation.*

This document presents the progress of the simulation of the Curtis type turbine for a prototype of a 1 kWe OTEC plant using the Ansys Fluent program, and compares its operating parameters with those calculated in the theoretical design, mainly the power output and its efficiency. For the simulation of the turbine, the operating conditions of the closed thermodynamic cycle of the OTEC plant were used; This will allow optimizing the times and costs of laboratory experimentation, establishing a methodology that will serve as the basis for future analyzes of the design characteristics of turbines and similar devices for ocean energy utilization systems.

For the design of this experimental turbine, two Curtis stages and one impulse stage are proposed, considering the following operating advantages:

- The turbine is low power.
- The average diameter of the impeller is small and this will reduce the tensile stresses on the blades.
- The design allows minimizing energy losses from the flow through the impellers, minimizing the loss of turbine efficiency.
- This design facilitates the construction of the turbine.

METHODOLOGY

The simulation of the flow in the Curtis type turbine in the Ansys Fluent program was carried out considering the refrigerant R152a (difluorethane) in the saturated vapor state as a working fluid and a static mesh in the turbine geometry. The simulation process in the Ansys Fluent program was carried out with the following 4 stages:

1. Construction of the turbine geometry.
2. Discretization of the control volume.
3. Selection of mathematical models and establishment of operating conditions (initial and boundary conditions).
4. Simulation and analysis of results.

In the first stage, the assembly of each of the components of the Curtis turbine was carried out, as can be seen in Figure 1.

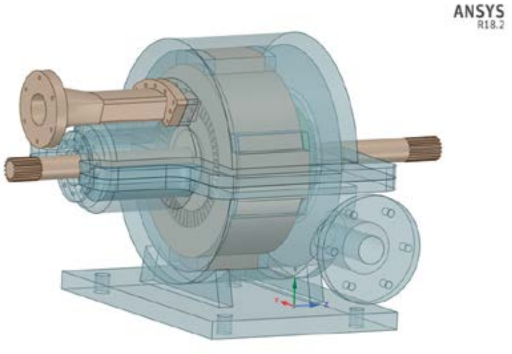

Fig. 1 Assembly of the components of the Curtis Turbine

From the geometry of the turbine, the control volume representing the volume of the working fluid was constructed and its discretization was carried out obtaining 24,391,815 mesh elements as shown in Figure 2. Subsequently, mathematical models were selected for the calculation of steady state flow properties, and the properties of the working fluid in a saturated vapor state were established.

RESULTS

The average values of the speeds at the inlet and the outlet of the turbine can be seen by means of flow stream lines through the turbine in Figure 3. The power at the inlet and outlet of the turbine were determined from the speeds, the density of the working fluid and the corresponding areas, obtaining an efficiency of 99.8%, as shown in Table 1.

Table 1. Power of turbine

	Area $[m^2]$	Velocity $[\frac{m}{s}]$	Power [W]
Inlet	0.00017	15.6581	1805.499
Outlet	0.00008	19.8821	1.934e-3

Fig.2. Discretization of turbine control volume

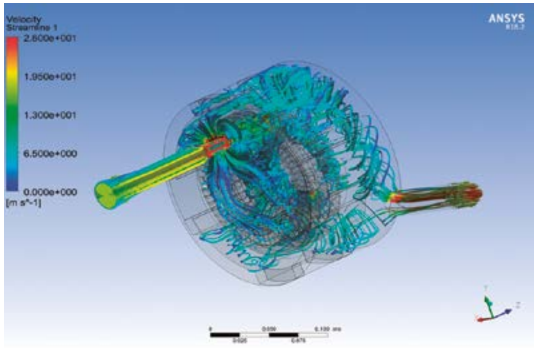

Fig.3. Streamlines of the flow in the turbine

FUTURE WORK

The results obtained during the first stage of the project are planned to be improved by carrying out the following considerations:

- Perform a simulation of the turbine with a dynamic mesh that allows the movement of the rotors to improve the approximation to the real behavior of the flow.
- Consider the phase change of the working fluid.

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Design of a prototype of a 1kWe open-cycle OTEC power plant for the Mexican Caribbean Sea

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***Keyword**: OTEC-OC, Thermal Gradient, Rankine Cycle, Mexican Caribbean.*

INTRODUCTION

Currently, the production of clean energy is one of the most outstanding and necessary for reducing greenhouse gas factors, these have led to growing problems related to climate change and global warming, this is where renewables play a role essential to provide a solution [1].

Ocean water retains approximately 15% of total solar energy as thermal energy. The technology that enables the ocean to generate energy through temperature differences is called Ocean Thermal Energy Conversion (OTEC). This type of energy is concentrated in the superficial part of the seawater and decreases exponentially with increasing depth [5].

The implementation of an OTEC plant can occur in tropical regions because the optimum temperature differences between warm surface seawaters and deep cold seawaters sea are satisfied, and have attracted the attention of many researchers [2].

Mexico has ideal thermal gradient conditions for the installation of OTEC plants [6] specifically; the Mexican Caribbean Sea has a thermal gradient of 20 °C throughout the year. Potential locations in the State of Quintana Roo suitable to build an OTEC plant at distances less than 10 km from the coast are Isla Cozumel, Punta Allen, Tulum, Sian Ka´an, Xcalac, Mahahual and Banco Chinchorro [3].

Currently, the Universidad del Caribe and the Instituto de Ciencias del Mar y Limnología with the support of the Centro Mexicano de Innovación en Energía – Oceano (CEMIE-O), are implementing a prototype of a closed cycle OTEC plant (OTEC-CC-MX-1kWe) in Cancun, Quintana Roo. This prototype uses the difference of temperatures between the warm surface seawaters (27 °C) and the cold deep seawaters (7 °C) of the Mexican Caribbean Sea to generate 1 kW of electrical energy [4].

This article presents the advances made for the design of the open cycle OTEC plant prototype (OTECA-MX-1kWe) and its energy comparison with OTECC-MX-1kWe.

OTEC-OC PLANT PROTOTYPE

The open cycle or Claude cycle is the precursor to several OTEC cycles and refers to the use of seawater as a working fluid. Basic Rankine cycle convert the thermal energy of the hot surface water into electrical energy. Figure 1 shows the diagram with the basic components of the prototype: flash evaporator, turbine connected to an electric generator, steam condenser, and a deaerator.

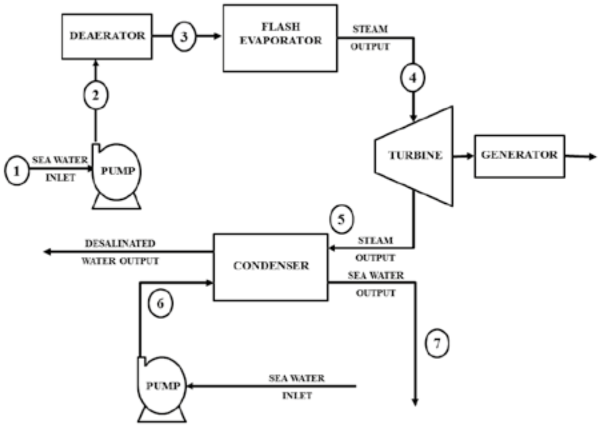

Figure 1. Open cycle OTEC plant diagram (OTECA-MX-1kWe)

In the open cycle, hot seawater is de-aerated and then passed to a flash evaporation chamber, where a fraction of the seawater turns to low pressure steam. Steam passes through a turbine, which draws energy from it, and then exits into a condenser. This cycle gets the name “open” from the fact that the condensed fluid does not return to the evaporator as in the “closed” cycle. Instead, the condensed fluid can be used as desalinated water, or it is mixed with the cooling water and it is discharged back into the ocean.

The mass and energy balances were evaluated with the following equations:

The heat transferred in the evaporator in kJ/s (qe) is:

$$q_e = \dot{m}_{\omega\omega}(h_2 - h_1)$$

where $\dot{m}_{\omega\omega}$ is the mass flow and h is the enthalpy.

Steam generation rate (kg/s):

$$\dot{m}_s = \frac{q_\omega}{hfg}$$

hfg is the water vaporization heat.

Turbine work in J/s (W_T) is:

$$W_T = \dot{m}_s(h_2 - h_4)$$

The rejected heat in J/s (q_c) is:

$$q_c = \dot{m}_{c\omega}(h_5 - h_4)$$

Thermal efficiency is:

$$n_{th} = \left(1 - \frac{q_c}{q_\epsilon}\right)$$

The monthly thermal efficiency of the OTECA-MX-1kWe prototype will be compared with the monthly efficiency of OTECC-MX-1kWe with the aim of contributing to decision making for the selection of the optimal OTEC plant for the Mexican Caribbean. It is the first step to design a prototype of an open-cycle 1MWe OTEC plant that will serve as the basis for future research on the life cycle, environmental and social impacts of this type of OTEC plants.

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Criteria for optimal sites selection for the installation of Ocean Thermal Energy Conversion (OTEC) plants in the Mexican Pacific (MP)

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Keywords: *OTEC, Optimal sites, Operability, Mexican Pacific, LCOE.*

Among the diverse Renewable Energy (RE) generation options include Ocean Thermal Energy Conversion (OTEC), which takes advantage of Temperature Differences (TD) between upper ocean layers and colder seawater, generally below 1000 m, to generate electricity. In order to ensure greater thermodynamic efficiency of the plant, it is preferable to work in areas where the TD´s of the water columns are ≥ 20 °C, with slight exceptions such as in South Korea where it works with 18 °C [1], [3-5]. Tropical regions are areas with enormous thermal potential. Mexico has seawater with optimal characteristics to develop OTEC, mainly in its tropical seas of the Mexican Pacific (MP) and Caribbean Sea (CS) supported by [5-9].

To know the reliability of any renewable plant is needed to estimate the operability, generally defined as the availability time of the system compared to the amount of time it is unavailable. By means of a comprehensive Sea Surface Temperature (SST) data, Daily Operability (DO) of OTEC plant could be estimated in the MP.

SST database used was the Satellite Oceanic Monitoring System (SATMO, from its name in Spanish) [2], which is part of the Marine Ecosystem Information and Analysis System of Mexico (SIMAR, from its name in Spanish) developed by the National Commission for the Knowledge and Use of Biodiversity (CONABIO, from its name in Spanish). The SST geoproducts have a spatial resolution of 0.01 x 0.01 grades and a daily temporal resolution of 16 years (1 Jun 2002–24 Aug 2018).

SST data results are daily averages in the time series. Where T_{sd} are SST data of every day of year, d, are days of the year and T_{Sdi} are SST data of every day of the year for every year in the time series between 2002 and 2018 (1 ≤ □ ≤ 16). Hence, T_{sd} equal to 365 for each of the points in the database. Data were grouped by season.

$$T_{s_d} = \sum_{i=1}^{16} \frac{T_{s_{di}}}{16}$$

According with data of seawater temperature to 1000 m (T-1000) from World Ocean Atlas (WOA, 2013) from 1955 to 2013, the average value T-1000 are 5 ºC with a variability of 0.2 ºC, leaving its value at 5 ºC for the entire study area.

Taking into consideration optimal TD and using de SST daily database, we estimate the DO, based on the percentage of days that exceed SST > 24 ° C in time series.

The purpose of this paper was to evaluate the time availability of the OTEC operation through DO based on SST database and to select optimal sites to OTEC deployment around MP by way of a Decision Matrix (DM) fed by different parameters, such as physical, economic, social and environmental aspects. The methodology involves a combination of Geographic Information Systems (GIS) and statistical models to identify the regions with the greatest potential for the development of OTEC.

The parameters evaluated were the following:

- Accessibility to cold and deep seawater pumping (< 10 km) [3]
- DO based on SST > 24˚C (% days) by season
- SST means by season
- Natural hazards (high, medium, low) [4]
- Distances to the connection of nodes or power plants (km) [5]
- Residential Electricity Consumption MWh (own estimate) [6]
- Homes without electricity [7]
- Peace Index (level of violence on site) [8]
- Risk of damage Protected Natural Areas (high, medium, low) [4].

Through parameters evaluated in DM, optimal OTEC deployment sites are *Puerto Ángel, Oaxaca and Cabo Corrientes, Jalisco*. However, sites selection depends on the sponsor and investor point of view.

Economics literature about OTEC [9,10,11,12,13] suggest investing in plants above 50 MW to have the lowest Levelized Cost of Energy (LCOE). OTEC plants has a high-level capacity factor, making attractive to markets that require high availability to supply base-load power; however, OTEC's LCOE is higher compared with other conventional energy technologies, including wave and current. Although these last ones, cost reduction depend on the construction of early matrices, and not on the big scale projects immediate progression. Other seawater secondary products generated by OTEC could trigger the social and economic development in the chosen areas.

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Salinity gradient determination on the Mexican Caribbean Coastal zone and the technical viability to generate blue energy

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Keywords: *Mexican Caribbean, fresh water discharging, saline gradient, monitoring, energy potential.*

This research is focused around freshwater discharges to the sea that according to measurements, indicate, at least salinity gradients up to 35 ups with temperatures of approximately 26`C. these discharges (volumetric flow rate) coming from the basin, vary in time: inter-annual, seasonal; it is even different from day to day, mainly because of different forcing that impact the sea level variability due to wind, tides, air pressure or even sea temperature, among other reasons. These freshwater discharges are usually clear in appearance; however, they contain carbonates, pollutants coming from the basin and generally, they have a lower temperature than the sea. It is essential to mention that through Quintana Roo coasts, several discharges with volumetric flow rates can be found, the vast majority of them have not been neither measured nor kept a record, there are not even systematic measurements of physical, chemical or biological criteria, for instance. In this regional context the energy potential evaluation of salinity gradient is a matter that could lead to provide more information t other research areas as well as environmental, social, hydrological areas, etc. measured discharges in this research are in the range of 250 liters per second -Punta Esmeralda en Playa del Carmen-, up to 5000 cubic meters per second, Cenote Manatí close to Tulum- however, other locations with the same or larger scale have been observed. These potential locations were monitored with CTD-Castaway equipment and current meter, both belonging to Universidad del Caribe, data obtained by the CTD profiler were processed in the software Castaway, having graphics related to depth, salinity, and temperature of every and each of the measured spots. The volumetric flow rate was obtained by substituting provided data by the current meter in equations, equation 1 and 2, determined by FAO (2009). Potential values of 191.3kW and 2503.46kW were obtained.

INTRODUCTION

The energy extracted from the ocean is considered as a renewable energy source, with a major potential due to the earth is covered by 70% of the ocean (Siddiqui et al., 2015). Among the types of ocean energy, the generation of energy from saline gradient can be found (Vallejo, 2013).

Mexico has got a wide potential for this resource harvesting due to it is rich in rains that discharge in a large number of rivers that lead to the Pacific Ocean as well as in the Gulf of Mexico (Enríquez et al., 2018).

Although, there is not an existing technology so far, that allows generation of energy from saline gradients at an affordable cost, being familiar with this resource potential in places like Mexico, could call the technological development's world attention in order to make the process of producing blue energy more efficient (Enríquez et al., 2015).

The aim of this study is to focus on a non-performed diagnosis in the state of Quintana Roo, with the aim of taking part in the energy transition performed in the country, due to the performed studies have no generation of energy aims but rather they focus on knowing the quality of water, having an overview about the technical and social viability to generating and implementing equipment that provides blue energy as a result.

This diagnosis will be supported by the determination of the saline gradient in several water discharges, located on the Coastal zone of Quintana Roo, using measurement equipment

and other countries research estimates replica in order to know the technical viability to generate blue energy.

METHODOLOGY

The methodology of this study is divided into three stages, the first one consisting in defining the potential locations of the Mexican Caribbean north zone, creating a database provided by NOAA, Argo, Oceanographic monitoring service, and water quality studies performed on the Coastal zone of Quintana Roo.

On the second stage, saline gradients were measured, as well as temperature and mass flow on the potential locations by replicating the provided methodologies by FAO, (2009), applying the following equations:

$$Q = Ai \cdot V$$

$$\text{Total Area} = \sum (A_1 + A_2 + \ldots + A_9 + A_{10})$$

in monitoring campaigns by means of CastAway-CTD Sontek and WH-50 current meter, both belonging to Universidad del Caribe.

Lastly an energy potential evaluation was made in the monitored locations based on the Van't Hoff's equation:

$$P_{e(v)} = 2n \cdot \dot{m} \cdot c \cdot R \cdot T$$

RESULTS

Cenote Manatí, Tulum and Punta Esmeralda, Playa del Carmen, were the two potential locations monitored during june – october, 2019. Having the following results:

LOCATION	FLOE RATE	CAUDAL	SALINITY GRADIENT	TEMPERATURE	ENERGY POTENTIAL
Cenote Manatí	0.112 m/s	3.654 m^3/s	22 PSU	25.6 °C	2502.46 kW
Punta Esmeralda	0.1305 m/s	0.2142 m^3/s	31.1 PSU	28.1 °C	191.3 kW

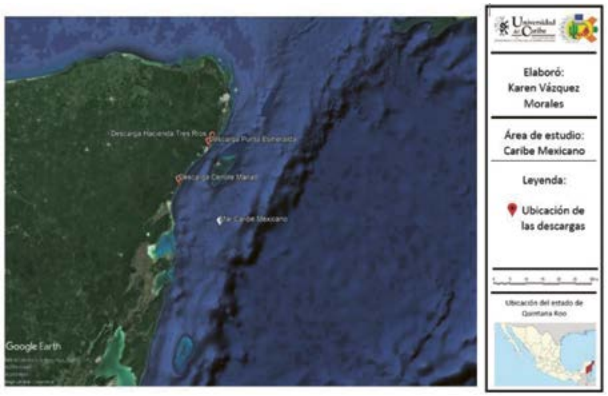

Figure 1. Location of the potential sites

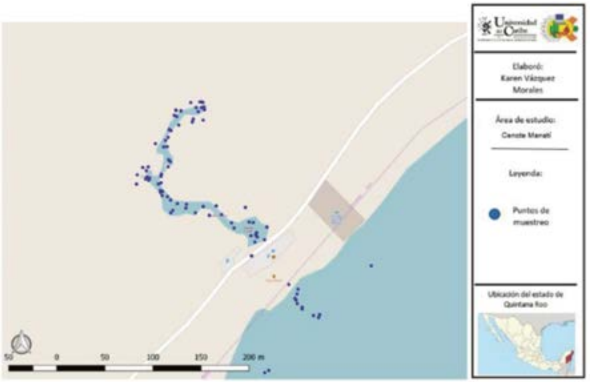

Figure 3. Sampling sites, Cenote Manatí

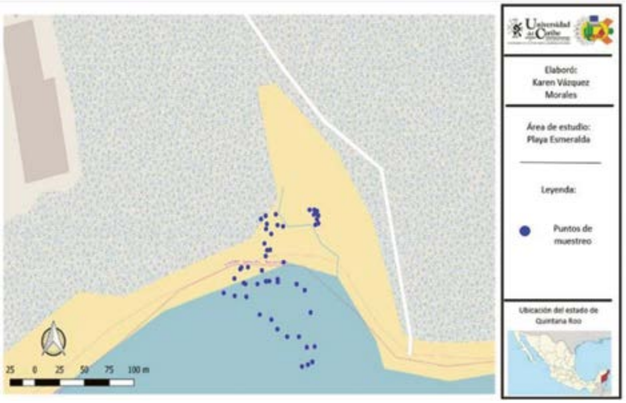

Figure 2. Sampling Sites, Punta Esmeralda.

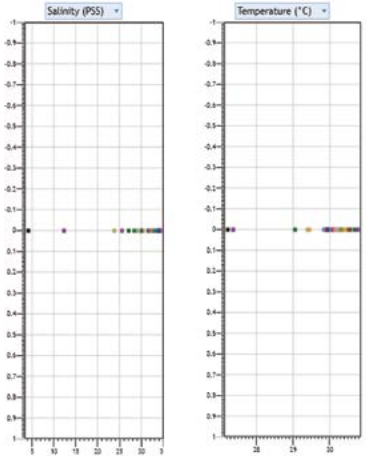

Figure 4. Salinity and temperature profiles, Punta Esmeralda.

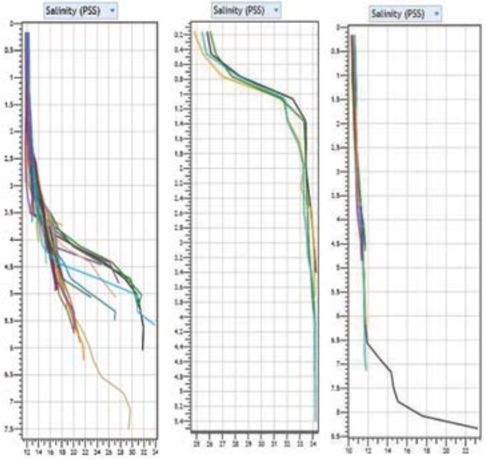

Figure 5. Salinity profiles, Cenote Manatí

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Hydrodynamic analysis of a reverse electrodialysis device spacer

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***Keywords**: Hydrodynamic, PIV, Simulation, Reverse electrodialyis.*

The hydrodynamics of within a serpentine type separator with obstacles, of a reverse electrodialysis (RED) prototype were analysed. The fluid dynamics, where the fresh and salt water circulate, were measured with particle imagen velocimetry (PIV). The results were validated with a numerical solution using COMSOL Multiphysics software.

It was found that the modifications made inside the spacer, improved the ion exchange significantly due to the change in the velocities and directions of the fluid during its passage through the separator.

INTRODUCTION

Renewable energy sources such as solar, biofuels, ocean and thermal, are helping to meet the world's growing demand for energy. According to the International Energy Agency [1], 13.2% of world energy consumption in 2012 was supplied by renewable energy sources, while in 2013 this figure rose to approximately 22%.

There is therefore a need to identify more renewable energy sources as well as to improve the methods used to obtain it. Salinity gradient energy (SGE) is one of the least investigated yet most promising sources of renewable energy. In areas where rivers or lakes flow in the sea, there is a natural difference of salinity and a great potential to implement SGE technology.

To take advantage of SGE, or blue energy, Pressure Retarded Osmosis (PRO) or Reverse Electrodialysis (RED) are the techniques usually used. In the latter electrical energy is extracted directly from the chemical potential of the salinity gradients [2]. In a RED device a battery of cation and anion exchange membranes are placed, alternating with each other. The compartments between the membranes are fed two saline solutions, one concentrated and the other diluted, for example, seawater and river water [3].

The efficiency of this type of device is low and there are very few studies on the behaviour of the fluid inside the cell. The present work analyses the hydrodynamics inside a RED cell developed recently by the Mexican Centre for Innovation in Ocean Energy (CEMIE-Oceáno) [4]. The objective of the work is to optimize the RED process in order to produce more energy using the same effective area of membrane.

Flow analysis was performed through experiments using particle image velocimetry (PIV). This quantitative non-invasive measurement technique, luminous tracer particles are added to the fluid. A laser sheet was used to illuminate the water and photographs were taken by the high-speed camera. This provides information on the velocity and displacement of the particles in linear and/or rotary motion, by comparing images captured at different moments in time [5]. A linear displacement vector field produced by the pair of images, where each vector is obtained by examining the motion of the tracer particles [6].

EXPERIMENTAL SET UP

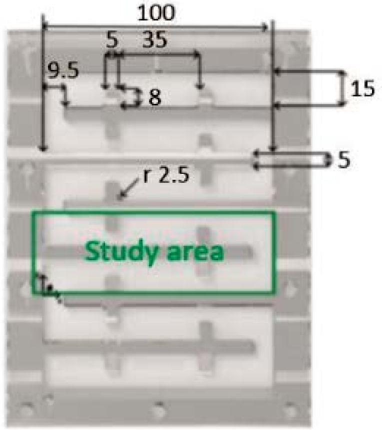


Fig. 1 Spacer front view. Dimensions in mm.

The analysis focuses on the middle part of the separator, where freshwater circulates [7]. The effective membrane area was of 100 cm^2. The separator features a serpentine of seven connected channels and rectangular obstacles, Figure 1.

The study area is the third and fourth channels from the bottom. The origin of the coordinate system is marked, where the third channel begins. The x axis is positive rightwards while the y axis is positive upwards. The spacer is made of acrylic with a thickness of 5 mm.

Figure 2 shows a schematic view of the experimental setup. The spacer was fed with water at constant velocity. A laser beam is passed through a lens to create a light sheet behind the study area. The camera captures images of the tracer particles, which are later processed in a PIV analysis.

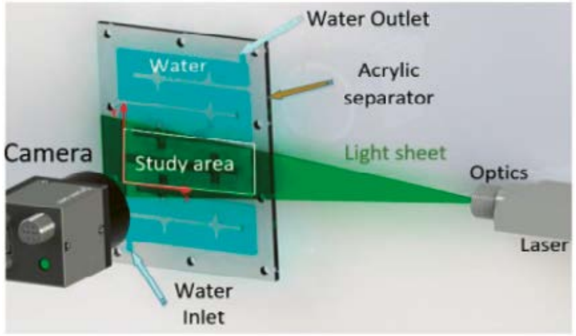
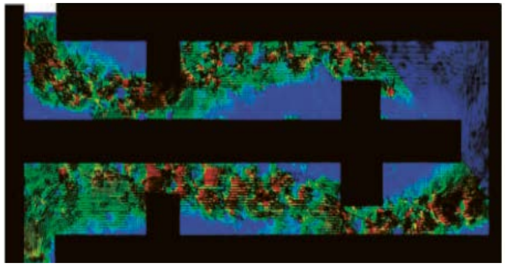


Fig. 2 Experimental setup for the PIV measurements.

a)



b)

Fig. 3 a) Tracer particles captured by the camera at t=4 s and b) PIV analysis.

RESULTS

Three tests were performed with a constant flow rate of 1.3 cm^3/s. For each test 1000 images were captured at 50 hz per frame. Figure 3a) shows the reflection of the tracer particles captured by the camera at time t=4 s. Following image filtering and masking, a PIV analysis was carried out using Dynamic Studio v3.16 software. The resulting vectors are shown in figure 3b).

The validation of the experiment, a numerical simulation was made using the RANS equations [8] with Comsol Multiphysics 5.3 software. Two plane cuts were taken to compare the velocity profiles of the physical and numerical model; figure 4.a-4.b shows the control sections between points A-B and C-D, respectively, the coordinates of the points are as follows: A(0,0), B(0,9.5), C(30,28) y D(30,36). According to the experimental and numerical results, it can be seen that its have a very similar behavior.

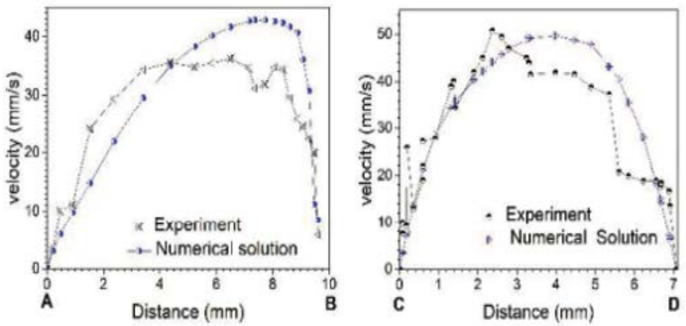


Fig. 5 Comparison of the measured (PIV) and numerical (CFD) velocity profiles between points a) A-B and b) C-D.

CONCLUSIONS

In this work part of the internal hydrodynamics of a reverse electrosialysis cell spacer are analysed. The geometry of the spacer produces significantly different behaviour in the velocity and direction of the fluid, associated with contractions and expansions that exist. This configuration improves the ion exchanges, which increases the efficiency of the device.

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Optimization of a reverse electrodialysis device

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Keywords: *Energy device, Salt Gradient, Reverse Electrodialysis, Ion Exchange*

In reverse electrodialysis (RED) the chemical energy of the salinity gradient of two solutions is converted into electrical energy through the use of ion-exchange membranes. This work presents an RED device in which the internal part of the cell is modified to include a serpentine with obstacles in the path of the solution fluxes. The net power delivered by the cell in different tests with various salt concentrations, was compared for the conventional RED device and the optimized configuration.

INTRODUCTION

One of the challenges facing humanity today is to ensure sufficient energy in the face of a growing world population. Innovative solutions to exploit new forms of energy are needed that will allow present and future generations guaranteed energy availability [1].

As the use of fossil fuels is unsustainable, developing alternative routes for energy production has become a priority [2]. Energy security in the coming years could come through the generation of solar, wind, biomass and ocean energy. Of those sources, ocean energy is the least exploited and one of the most promising [3], since the ocean is a virtually inexhaustible source of energy.

Salinity gradient energy (SGE) makes use of the difference in salinity between seawater and freshwater [4]. SGE, also called blue energy, has most potential at river mouths, where a large body of freshwater flows into the sea. The theoretical global potential for salt gradient energy has been estimated at about 2.6 TW [5].

EXPERIMENTAL SET UP

RED is a membrane-based technology in which the controlled mixing of saline solutions is used to generate electricity. A RED cell is composed of a matrix of cationic and anionic exchange membranes, arranged alternately (CEM and AEM) and stacked between two electrodes [6]. The conventional RED design [7], separates the membranes with spacers to keep the distance between the membranes constant. The compartments thus formed are fed alternately with concentrated and diluted salt solutions, (Fig. 1).

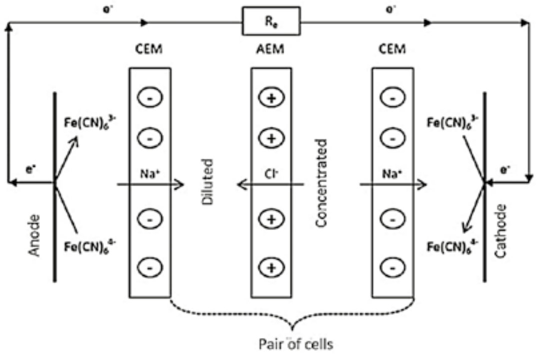
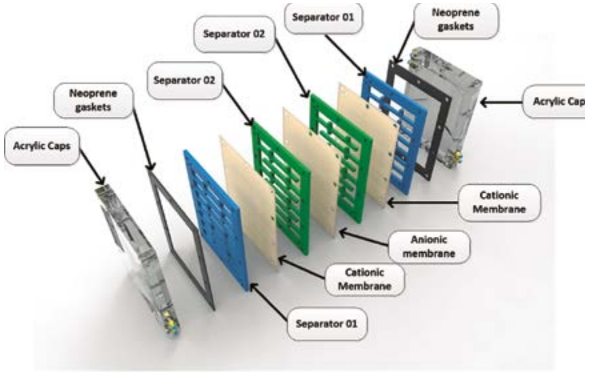


Fig. 1 Schematic representation of the RED principle.

Two different types of cells were analysed. The conventional cell, with a hollow compartment, is described in detail in [8]. The proposed cell (Fig. 2), has obstacles and a serpentine between the separators, to improve its efficiency. Both cells were equipped with the same type of membrane and redox pair. The effective area of each of the membranes was 100 cm^2.



(Hernandez_fig2.png)
Fig. 2 View of the RED cell with the proposed new separators.

The configuration of the cells is shown in Fig. 3. In the conventional cell the internal part of the spacer is hollow and the path of the saline solution is perpendicular to the direction of the inlet flow. In the proposed cell, the effective area was not altered, but spacers with obstacles were added to slow down the mixing of the solutions, thus improving the ion exchange through the membranes.

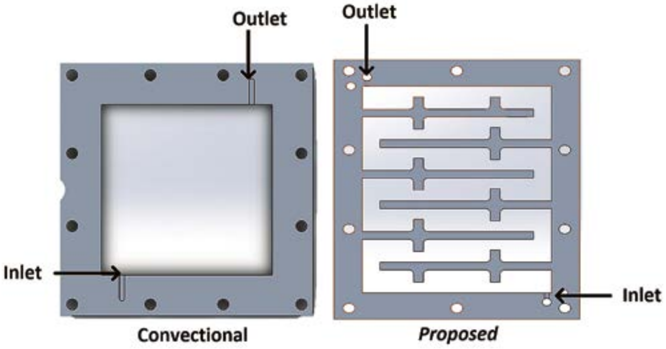


Fig. 3 Spacers employed in the tests.

The scheme of the device operation is shown in Fig. 4. Three gear pumps were used to provide freshwater, saltwater, titanium electrodes and potassium ferro-ferricyanide electrolyte solution to the model. The input flow to the cell was regulated by the pumps and the data acquisition system recorded the electrical power produced. The data was sent to a computer, stored and then processed.

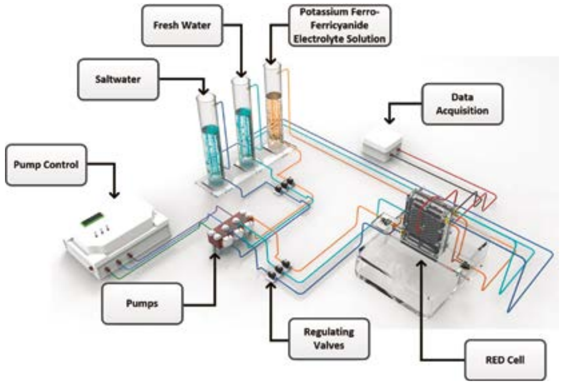
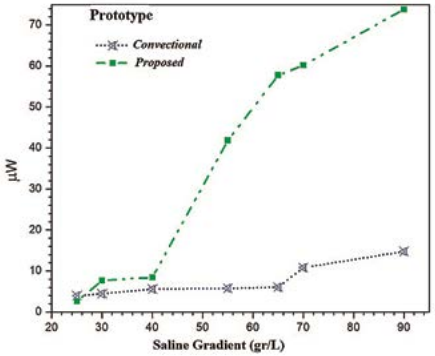


Fig. 4 View of the cell operation.



(Hernandez_fig5.png)
Fig. 5 Comparison of power recorded for the two cells.

RESULTS

Seven tests were performed with 3 repeatability validations each for both cell configurations. The relationships between the salinity gradients and the power produced. (Fig. 5) shows that the higher the salinity gradient, the higher the electrical power obtained. The salinity gradients used in the tests ranged from 25 to 90 (g/l). The duration of each test was 5 minutes. The value of the electrical power presented in Fig 5 corresponds to the measure when the stationary condition was reached.

CONCLUSIONS

A modified RED cell was developed, with separators to improve the electrical power delivered. By creating disturbances to the flow path, it is possible to improve the mixing inside the cell and, at the same time, achieve a greater ion exchange, so that the ions released increase the amount of electrical power obtained. It was observed that the higher the salinity gradient, the higher the electrical power ratio compared to the classic cell, meaning that this device will perform better with high salinity gradients.

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Possible oceanographic and biological effects due to the operation of an OTEC (Ocean Thermal Energy Conversion) plant in the area of Puerto Angel, Oaxaca, Mexico

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***Keywords**: OTEC cycle, harmful algal blooms, bio feather, thermal gradient, Gulf of Tehuantepec.*

An OTEC plant uses the thermal gradient (oceanic thermal difference, which should preferably not be less than 20ºC) to transform heat into electrical energy and the best regions to implement it are those found in the inter-tropical and tropical areas of the planet. Among the countries currently experimenting with this cycle are France (experimental plant without generation in the Reunion Island Overseas Department), South Korea (20 kW in Goseong), Japan (100 kW in Okinawa and an experimental plant in the Saga University that generates 35 kW) and the United States (105 kW in Hawaii). Recently, Mexico began to be interested in this type of alternative energy technologies, since it presents the ideal geographic and oceanographic conditions for its use, and before the establishment of the Mexican Center for Ocean Energy Innovation (CeMIE-O), both theoretical and laboratory research is being carried out. to know if it is possible to use this technology in the country and one of the lines to work on is the part of the environmental assessment. For this reason, the objective was to analyze at a theoretical level the possible environmental effect that the operation of a high-power generation plant (100 MWe) could cause in the area of Puerto Angel, Oaxaca, Mexico due to the bio-feather that would discharge the installation.

Firstly, surface and bottom temperature data (up to 1000 m) were used from databases of the National Oceanographic Data Center (NODC) and the World Ocean Atlas Database (WOA) 2018 with the purpose of calculating the annual and seasonal thermal gradient of the Gulf of Tehuantepec area. Subsequently vertical profiles of temperature, salinity and nutrients were made in order to analyze their behavior at different depths depending on seasonality. With this information, the velocity of the plant discharge water and its density were calculated to establish the maximum depth at which it would stabilize in the water column, as well as possible changes in the vertical profile of the parameters. Because the operation of the plant is very similar to that of an ocean upwelling (due to the pumping of cold bottom water and warm surface water), the bio feather data was compared with the upwelling data generated in the Gulf of Tehuantepec to review the type of possible environmental impact that could exist in Puerto Angel once the plant operates.

With the biofeather in the ocean and when establishing its maximum depth, the possible biological effect was analyzed by means of a numerical simulation to describe the progress of the biofeather, the dilution rate of the nutrients, the initial and final concentrations of the same from of the operation of the plant and with this analyze the effect on marine phytoplankton to define those organisms that could benefit from their biological parameters, especially emphasizing those that can cause FAN (harmful algal blooms) or red tides.

The results describe that the plant's feather would stabilize at 64 m depth, so it is within the photic zone of the area, which could generate positive or negative environmental effects. Regarding the parameters of temperature, salinity and density, it is observed that there would be no thermal and hyaline contamination, which is why the plant is beneficial to the marine environment. Lastly, since the discharge water presents nutrient concentrations that are important for the development of phytoplankton, it is observed that due to the dilution rates and the path of the bio-feather there will be no risk regarding the generation of a “bloom” algal, whether they are FAN generating organisms or not.

From the results, it is concluded that the discharge water can be used for different secondary by-products that the OTEC plant can offer, such as drinking water, air conditioning, aquaculture of macroalgae and fish in the area, cold water agriculture, among others with In order that there are no possible environmental effects in the area, as well as frequently monitoring what can happen with the bioplume in the water column in order to have security, prevention and mitigation measures with which the implementation of this technology in the country.

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STORAGE AND INTEGRATION

Island and Remote Grid Considerations for Marine Energy Development

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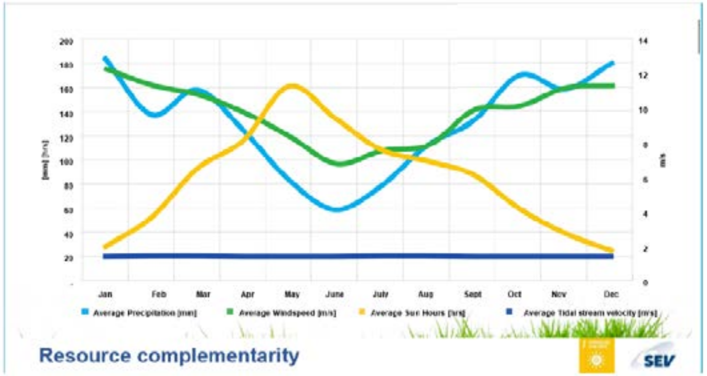
Keywords: *Marine Energy, Islands, Remote Communities, Faroe, Hawaii.*

Fossil fuels are the main source of energy for many of the world's islands and remote communities. However, their use presents several challenges and is not environmentally sustainable. Accordingly, islands and remote communities have been exploring renewable energy resources to provide clean, reliable and resilient electricity generation. Marine renewable energy resources are likely to be part of the solution. These resources include wave, tidal, ocean current, ocean thermal and offshore wind energy, amongst others, and can serve to provide energy within a portfolio of resources, as standalone energy generators, or as components of microgrids [1, 2]. This work explores the technology, financial and policy considerations associated with the development of marine energy resources on islands and in remote communities. It answers the question of what are potential ways that marine energy can come to life in these communities.

Island and coastal communities are at the forefront of climate impacts and have a strong driver to move to cleaner energy sources [3]. Indeed, the development of renewable resources in remote communities has had realized benefits in job creation, economic development and emissions reductions [4]. However, the integration of renewables presents challenges in dealing with variability and intermittency and a lack of predictability of the typically utilized resources, namely wind and solar. A further issue arises where land is limited and resources cannot be developed. These issues are particularly salient in islands and remote communities [5].

The utility in the Faroe Islands, Electrical Power Company SEV, has evaluated the use of tidal energy as part of their exploration of how they achieve a 100% renewable energy generating portfolio. They found that tidal energy can provide a consistent and predictable output, complementing their other seasonally variable resources, namely wind, hydroelectric generation and PV. See Figure 1 below. The utility is presently working on a pilot project to showcase the use of tidal energy, and if successful, intends to expand this effort with larger tidal turbine units.



(Bhatnagar_fig1.png)
Fig. 1 Resource complementarity of tidal, hydro, wind and solar

The Hawaiian Islands have a mandate to meet 100% renewable energy generation by 2040. To achieve this goal, Hawaiian Electric Company has published plans to use a portfolio of resources. Although the plans do not explicitly identify marine energy resources, the University of Hawaii's Natural Energy Institute is home to the United States' first grid connected wave energy test site, which helps evaluate device performance and supports device development. Its grid connection was enabled by Hawaiian Electric. In the long term, future utility plans to meet system requirements might reasonably be expected to include marine energy resources.

Marine energy resources, and their inherent predictability, have the potential to play a significant role as part of the energy resource portfolio for islands and remote communities, avoiding the impacts of fossil fuel use and serving to address some of the challenges associated with renewable integration. The energy provided by marine energy resources is reliable, predictable, does not generate carbon emissions and can be developed in an environmentally friendly manner. Tidal resources, for example, are predictable with a high degree of certainty and although still variable resources, this predictability creates the possibility of a baseload power resource.

Research suggests that marine energy resources can avoid transmission investments to remote, coastal locations [6, 7]; that as a predictable resource, marine energy would require a fraction of associated integration costs and support the integration of other resources; and that to achieve high physical penetration levels of renewable energy, winter peaking resources with seasonal variation such as marine energy could be valuable. The use of marine energy in a portfolio increases resource diversity, reducing vulnerability to grid and fuel supply disruptions and exposure to fuel price volatility. Further, the use of marine energy resources can provide energy in locations where there is limited land area or limited natural resources available for energy development. For example, in the 2017 Integrated Resource Plan for the Caribbean Utilities Company, the public electric utility for Grand Cayman, a contractor evaluated land use associated with different generation technologies and found a significant advantage to using marine energy, in this case, ocean thermal energy conversion [5].

This work explores the technology, financial and policy considerations associated with the development of marine energy resources on islands and in remote communities. It uses the Faroe Islands and the Hawaiian Islands as case studies, and their experience with marine energy, as well as other renewable energy development, to identify and characterize these considerations. The work evaluates how each of these communities have considered marine energy technologies from an integration and system operations perspective, from a financing perspective and from a policy perspective. It identifies the challenges and successes of this effort in both islands and from this, extrapolates learnings for other island environments and remote communities. With this effort, the authors hope to share learnings with technology developers, utilities, governments and other stakeholders to help them understand marine energy and consider approaches to enable its development.

Limited technical expertise and funding amongst many island and remote communities leads to limited technical capabilities and poor system reliability [1, 3]. The technical considerations explored in this work include marine energy integration into small systems and the associated performance and operational requirements. The work considers marine energy resource complementarity to other renewable technologies and the associated operational implications and balancing needs. Small grids cannot rely on either a large portfolio of resources nor interconnections and thus small variances in generation and load can cause significant reliability impacts.

Despite being relatively large from an island or remote grid sense, the islands of Hawaii are susceptible to significant system impacts from a high penetration of renewable energy resources. For example, the island grids have seen significant distribution system voltage fluctuations as a result of a high penetration of photovoltaics. These impacts have become more and more pronounced as penetration of photovoltaics has increased and have led to the state initially limiting solar development and later requiring mandatory controls [8, 9]. If the state wants to continue to meet its ambitious renewables targets while maintaining a stable and reliable electric grid, it will need to address voltage issues. This work evaluates the state's experience and considers the impact to marine energy resource development. Marine energy resources, due to their reduced intermittency relative to other renewables may help to mitigate these voltage impacts, but they may also exacerbate them.

From a financial perspective, island and remote communities have difficulty in financing renewable development. They are often unable to support earlier stage technologies and some island nations in particular are highly dependent on foreign aid [3]. State-owned electricity utilities in these communities are not able to fund significant new capital investment, and private sector investment in the energy sector is limited [1, 3]. Marine energy has its own challenges in this respect, being a developing technology with limited deployment, it faces a greater challenge for financing: it has a high technology and installation costs and its value streams, though plentiful, are difficult to quantify. This work considers energy development financing in islands and remote communities and presents considerations for technology developers and financiers to support marine energy deployment.

Finally, from a policy perspective, island and remote community power sectors vary greatly in structure and operation. Privatization, regulatory oversight and government involvement vary widely across different communities even for those within geographic proximity. As a result, economies and economic conditions vary greatly. This makes energy development a challenge [3, 4]. This work will consider existing structures and identify what market and regulatory structure and policy changes may reduce project development barriers. Considerations include policies around 100% green electricity mandates, workforce requirements, ocean use infrastructure, permitting and environmental siting, and capitalization.

Informed by experience of the Faroe Islands and the Hawaiian Islands, this work engages stakeholders, surveys literature and examples of successful marine energy development, and utilizes technology expertise to characterize the technology limitations, financial experiences and policy challenges that present barriers to marine energy development. It develops technology, financial and policy considerations that will be informative for technology developers, local utilities, and regulatory and government agencies in island and remote communities to spur marine energy development. These stakeholders have limited bandwidth and ability to explore these considerations on their own. This effort seeks to provide them a resource to do so.

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NOMAD: Freedom and autonomy by converging marine life and humankind

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NOMAD

NOMAD: the precursor of floating cities and global network communities, where the main activity is the intensive production of marine crops through a technique known as “Integrated Multi-Trophic Aquaculture” (IMTA), which allows great productivity and very low environmental impacts. Other economic activities focus on environmental monitoring, advanced education in marine sciences, ecotourism and entrepreneurial support. The result is a high functioning, multi-purposed community station with several potential sources of income, which assure its financial success.

IMTA could very well replace unsustainable and obsolete fishing practices, as marine wildlife renewal cannot keep up with the current demand, which has led to troubling overexploitation. Furthermore, trawling activities generate great negative impacts, not least because of the magnitude of each catch, but also because of its non-selective nature, thereby extinguishing entire ecosystems at once. Estimates show instances where trawling may catch close to 50% of its intended target species, while destroying the rest without even any commercial gain.

Fishing however is not an activity that can simply disappear on behalf of the environment. Social and economic factors must be considered as well. Entire communities depend on it, and so does the world’s food supply. Solutions like IMTA must be set in place to farm enough aquaculture crops to satisfy the growing demand, while providing fishing communities with good, decent and lucrative work opportunities, while also helping to mend broken and failing marine ecosystems.

IMTA is not perfect by itself though. Feeding and harvesting tasks require continuous logistical costs, and it is constantly at risk of theft or damage by passing vessels. To solve this, enter the NOMAD Module: a self-sufficient habitable floating station that can be run by a crew of four and can sustain up to 12 people almost indefinitely. Up to six modules can be interconnected together to form a NOMAD Cluster, which can house up to 72 residents and service up to 300 visitors daily. To name a few, the standard version of the Module includes the following features:

- Living quarters.
- Research laboratories.
- Office spaces.
- IMTA growing and harvesting stations.
- Satellite telecommunications.
- Off grid solar PV systems.
- Wave energy A/C and water pumping.
- Photothermic desalination.
- Rain harvesting.
- Overboard water storage

- Hydroponic gardens.
- Tertiary water treatment facilities.
- Anaerobic biogas generators.
- Multipurpose decks.

Other versions incorporate classrooms, infirmaries, restaurants, lounges, bars, theatres, etc. A small land-based operations facility will provide support for several Clusters at once.

It is important to note that the current design supports offshore living, but is still restricted to bays and lakes, safe from strong currents and big waves. Generally, clusters should be located no further than 5 miles within viewing range from shore and require around 40 ft. of water depth.

NOMAD incorporates proven technologies and its modules mostly require easily found materials, as the goal is to replicate them all over the world, thereby creating an online NOMAD Community for a shift in the paradigms of human life, where the focus is to rescue our harmony with the sea.

The Influence of Hybrid Renewable Energy Systems on Energy Storage

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***Keywords**: Hybrid renewable energy system, Marine current power, Energy Storage system, Batteries, Hydrogen.*

INTRODUCTION

The development of hybrid renewable energy systems (HRES) with energy storage systems (ESS) for off-grid or microgrid systems is necessary to have flexible energy availability and a greater degree of autonomy. Hybridization of renewable energy is an important way to increase use and improve efficiency, therefore, it ensures energy supply and reduces capital and equipment operating costs [1]. Likewise, HRES reduce energy storage in relation to generation-consumption times and increase their ESS cycle life by reducing charge and discharge cycles [2].

In this work, the dimensioning of a hybrid current-marine solar system in the Cozumel region, Quintana Roo, Mexico is presented, in which the degree of hybridization varies, being 0 when the energy of marine currents is not considered and 1 when Photovoltaic solar energy is not considered. Two battery banks are included in the system as battery energy storage (BES 1 and BES 2) and a hydrogen energy storage system (HES) with the objective of analysing the variation of the minimum necessary storage according to the degree hybridization.

METHODOLOGY

Consumption profile is the main factor for the dimensioning, which depends on the application of the HSMCS. For this case study, the consumption profile house is 6.32 kWh / day, figure 1.

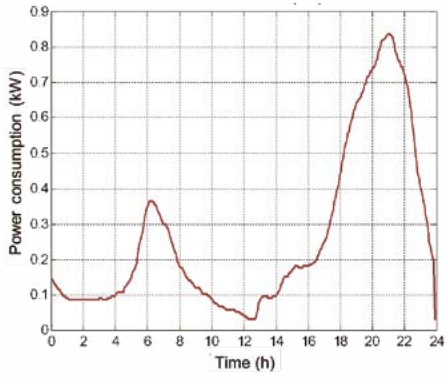

Fig. 1 Household energy consumption profile 6.32kWh / day

Energy profile data for solar energy and marine current energy are essential for its correct sizing. The dimensioning of the hybrid solar-marine current system (HSMCS) is based on the study of solar and marine currents potential. Solar-photovoltaic system (PS) and marine currents system (MCS), figure 2 shows the profiles for dimensioning the SF and the SCM. The degree of data resolution is very important due to higher resolution, allows a proper ESS dimensioning.

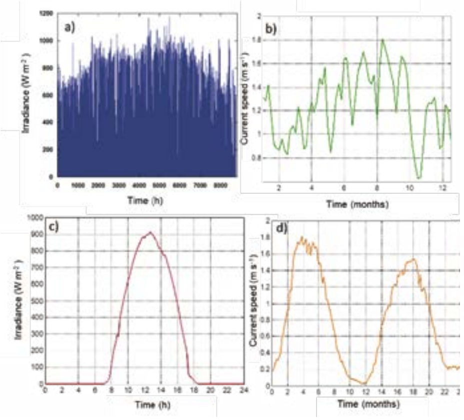

Fig. 2 a) Annual solar generation profile, b) Annual marine current generation profile, c) Solar generation profile per day, d) Marine current generation profile per day [3]

PS sizing is performed according to annual generation minimums, equation 1 [4]. In the case of MCS, equation 2 is considered [5].

$$P_{mp_{|min}} = \frac{E_D G_{CEM}}{G_{dm}(\alpha, \beta) PR} \qquad (1)$$

Where P_{mp} is PS minimum power, E_D is the energy consumption per day, G_{CEM} is the solar irradiance, $G_{dm\ (\alpha,\beta)}$ is the incident radiation in the panel and PR is the global efficiency.

$$P = \frac{1}{2}\rho C_p A V^3 \qquad (2)$$

Where P is the power of the marine current turbine (MCT), ρ is the seawater density and A is the cross-area turbine, these 2 components are considered constant. Cp is the power coefficient, it is a function of the speed ratio of the tip and the angle of inclination, for a typical MCT, the value of Cp is considered in a range of 0.35-0.5 [5].

The minimum capacity of BES 1 and BES 2 is determined through the energy balance, equation 3.

$$E_{BB} = E_G - E_{Cest} \qquad (3)$$

Where E_{BES} is the minimum necessary energy stored, E_G is the energy generated and E_{Cest} is the estimated energy consumption. The HES system is proposed as a backup system, so its minimum dimensioning is carried out according to the excess energy not stored, equation 4.

$$E_{HES} = E_{Cest} - E_{Creal} \qquad (4)$$

Where E_{HES} is the excess energy not stored by batteries or the minimum energy to be stored by hydrogen and E_{Creal} is the actual consumed energy.

The minimum dimensioning system allows to estimate the minimum hydrogen power generator, HES system can be much larger and it is an important advantage for hydrogen regarding batteries. The variation of the minimum stored energy is analysed in a linear manner through the degree of HSMCS hybridization and the energy balances previously described.

RESULTS

Hybridization allows greater flexibility due it could offer more energy available during the time. However, knowing the optimum degree of hybridization can be difficult, when there is more than one maximization or minimization variable, for example, it is required to minimize energy storage or maximize energy availability. Table 1 presents information of PS and MCS power, as well as the influence that the degree of hybridization has on the BES.

Table 1. HSMCS hybridization

	Hybrdization	**PS (kW)**	**PS (kWh/ day)**	**MCT (kW)**	**MCT (kWh/ day)**	**BES 1 (kWh)**	**BES 2 (kWh)**	**HES (kWh)**
1	0	1.2	6.46	0	0	5.2	0	0.15
2	0.2	0.96	5.168	0.24	1.292	4.16	0.72	0.18
3	0.5	0.6	3.23	0.6	3.23	2.6	1.8	0.225
4	0.8	0.24	1.292	0.96	5.168	1.04	2.88	0.27
5	1	0	0	1.2	6.46	0	3.6	0.3
6	N/A	1.2	6.46	1.2	6.46	5.2	3.6	0.45

Due to consumption profile has a distributed behaviour throughout the day, like the MCS, the HSMCS with a degree of hybridization 1 allows to reduce the BES by 30.76%. Therefore, the MCS allows smaller BES 1 and BES 2 than SF. However, due to fluctuations during monthly MCS periods, Figure 1b, a lower degree of hybridization is much more appropriate.

Considering increasing HSMCS power may be another option to ensure power availability. However, in this case, the BES system is not optimally reduced. This implies a larger BES system, case 6 of table 1, where it ends up generating twice as much energy required and the efficacy falls to 50% due to not stored energy.

In figure 3, the consumption-generation profile of the SHSCM is shown, where according to the sizing methodology there is a PS of 1.2 kW and MCS of 1.2 kW. The region marked with blue represents energy to be storage or lost and in red energy that cannot be supplied by the renewable energies at that time and it must be taken from BES.

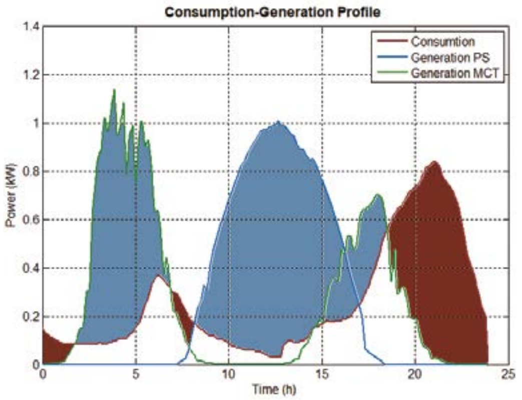

Fig. 3 Perfil de consumo-generación caso 6

It was determined that 8 solar panels of 150 W are required to cover a consumption of 6.32 kWh / day, figure 4. The

MCS consists of a 2.2 m diameter MCT that is coupled to a 3-phase synchronous generator (SG).

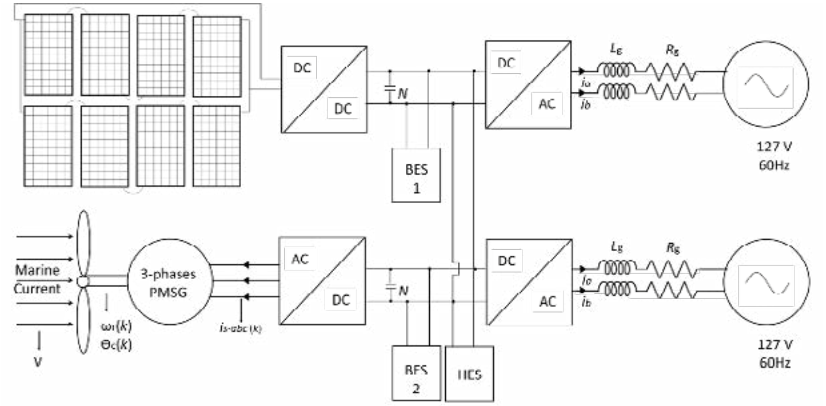

Fig. 4 HSMCS Diagram

CONCLUSIONS

1. Studying renewable energy systems hybridization is very important due to it allows improving their performance.
2. Energy consumption profile and optimization variables like energy storage capacity are factors that determine the hybridization degree.
3. As consumption profile is more similar as generation, less energy will be required to be stored.

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Synthesis and characterization of IrRuOx/TiO2 as electrocatalyst for the oxygen evolution reaction

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Keywords: *Renewable energy, Hydrogen production, PEM electrolysis; Oxygen evolution reaction, Ruthenium oxide.*

There is an immediate need to develop alternative energy sources renewable and with a minimal pollution. A viable alternative is hydrogen, since it has a great advantage over fossil fuels, due to its greater energy density (33 kWh kg-1) and its combustion process has as chemical by-products water vapour and a small amount of nitrogen oxides, which do not significantly influence the environment because of their low concentrations. [1-3]

Electrochemical processes for the generation of hydrogen are viable for industrial and domestic applications using renewable energy sources. Currently, there are three mainly types of electrolysers: alkaline, proton exchange membrane (PEM) and solid oxide. The PEM electrolysers (PEME) are more compact than alkaline and solid oxide electrolysers since these can work with a current density five times higher (~2A cm-2), its solid electrolyte (polymeric membrane) gives a response time of less than one second and it can produce high purity hydrogen (~99.99% w) [4-6].

The commercial catalysts for this type of electrolyzer are made of compounds based on noble metals such as IrO2-RuO2 for the oxygen evolution reaction (OER) for the anode and Pt/C for the hydrogen evolution reaction (REH) for the cathode side since these noble metals have the best catalytic activity and electrochemical stability in the acidic medium in which the reaction took place as a consequence of the proton exchange membrane is generally composed of sulphonated polymers, which gives it an acid character. [7-10]

Consequently, of the noble metals used in PEME, the economic price of PEME is higher than alkaline electrolysers therefore, the need arises to develop new electrocatalytic materials not based on noble metals or, failing that, considerably reduce the amount of them. For OER, several alternative catalytic materials have been synthesized, for example: IrRuCoOx [11] and IrSnO2 [12] to reduce the amount of noble metals by adding a transition metal or, on the other hand, IrO2/ATO [13] and IrO2/SnO2 [14] catalysts have also been developed, in which the metallic phase was dispersed on a support with a specific high area to increase the active area with respect to the metallic load. The catalyst exposed in this work belongs to the second type. The performance of $IrRuO_x/TiO_2$ obtained by impregnation is presented in this work. [15] A catalyst was synthesized with 40%w Ru and 10%w Ir in relation to TiO_2, a mechanical mixture of commercial catalysts 75%w Ru and 25%w Ir was evaluated for comparative purposes. The precursors $IrCl_3$, $RuCl_3$ were dispersed by ultrasound during 5 minutes in 200 ml of deionized water; this solution was transferred to a rotavapor flask where vacuum impregnation took place, the temperature was controlled at 70 ° C for 3 hours. After impregnation, the resulting material was subjected to an oxidative heat treatment in an air atmosphere at 450°C for 4 hours in order to obtain the $IrRuO_x$ spices. The electrochemical tests were performed on a potentiostat/galvanostat Autolab Differentia Electrometer Amplifier PGSTAT12/30/302, linear scanning voltammetry were performed in a double-walled glass cell using a three-electrode arrangement, an ultra-thin layer was deposited on a glassy carbon electrode (work electrode), a sulphates electrode was used like reference (Hg/Hg_2SO_4, E= +0.68 V/NHE) and as counter electrode, a Pt mesh was used. The electrolyte was a 0.5M H_2SO_4 solution previously saturated with Ar. Linear scanning voltammetry was performed in a potential range of 1.0 to 1.68 V/NHE. A membrane-electrode assembly (MEA) with an active area of 4 cm_2 was manufactured. This synthetized catalyst was the anodic coating of the assembly where the REO is carried out, the proton exchange membrane used as a solid electrolyte made of NafionR 115 127 μm thickness, for the cathodic part a commercial carbon cloth electrode was used containing a Pt 40% w coating supported on Vulcan Carbon$_R$, the mechanical mixture of commercial catalysts was used as well as anodic coating in another MEA for comparison proposes. The MEA's performance were tested in a current density sweep from 0 to 0.5 A/cm_2 Figure 1 belongs to the linear voltammetry of the synthetized catalyst, the potential at which the oxygen generation starts is 1.48 V/ENH, coinciding with the potential of the commercial mixture of catalysts, at 1.6 V/ENH reaches a current density of 20 mA cm_{-2} being 20% lower than the commercial electrocatalyst obtained by mechanical mixing, the synthesized catalyst presented a good electrochemical stability since it does not show a significant reduction of its catalytic activity after 5 cycles.

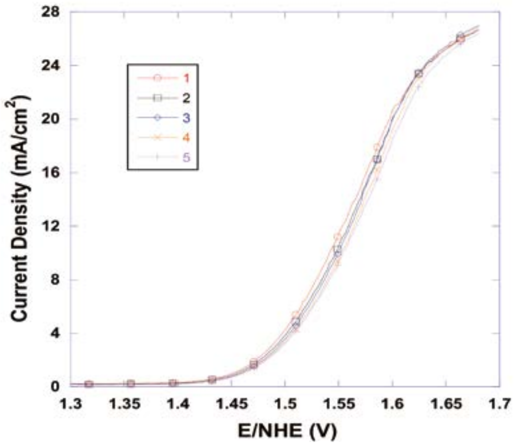

Fig. 1 Linear sweep voltammetry of synthetized catalyst

Figure 2 shows the catalytic activity normalized like electrode mass activity (mA/$mg_{Ru,Ir}$) in the potential interval from 1 to 1.68 V/ENH, at 1.6 V/ENH the synthetized catalyst (red line) reaches a current density of 89 mA/$mg_{Ru,Ir}$ which is 50% higher than the mechanical mixture of commercial catalysts at the same potential (black line), this is an indicator of high active area and dispersion of Ir and Ru species over TiO_2 support.

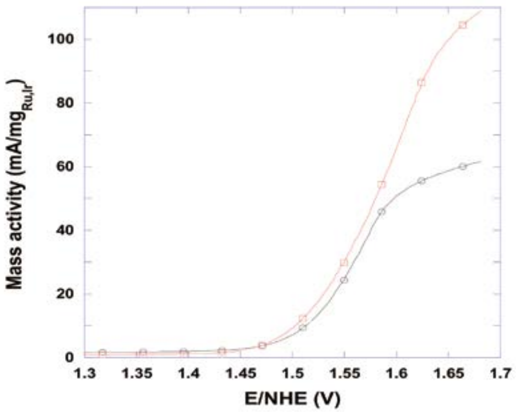

Fig. 2 Mass electrochemical activity

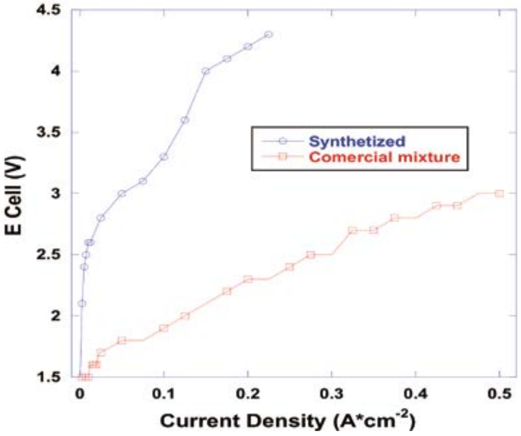

Fig. 3 Test electrolyzer performance

At the test electrolyzer, the synthetized catalyst had a lower performance, namely 66% compared to the commercial mixture, since at a current density of 0.25 A/cm_2 there was a cell potential of 5V for the membrane with the synthetized catalyst coating, while for the membrane with the commercial mixture coating the cell potential was 3V. The lower performance is attributed to the generation of considerable resistance due to the fact that the pores of TiO_2 particles which do not contain IrO_2 or RuO_2 species are in contact with other empty TiO_2 pores increase the transfer of electrons resistance since TiO_2 is a semiconductor with high electronic resistance which affects the performance of the electrolyzer since several layers of catalyst are deposited on the surface of the membrane of the anodic side.

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BUILDING SOCIAL AND POLICY SUPPORT

Governance of Marine Renewable Energy Development In Nova Scotia, Canada

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Keywords: *Marine Renewable Energy, Tidal Development, Regulatory Plan, Accountability, Transparency, Innovation, Ocean Technology, Nova Scotia, Canada.*

Worldwide, governments are increasingly transitioning to renewable energy sources. The most natural place for Nova Scotians to look is the place that has always provided a livelihood and an economic mainstay—the ocean. Surrounded by the ocean, Nova Scotia has a natural advantage in this innovative, emerging renewable energy resource.

In the winter of 2018, the Province of Nova Scotia proclaimed the Marine Renewable-Energy Act [1] to provide a clear, predictable and efficient process to support the sustainable growth of this sector. The legislation will implement the Province's Marine Renewable Energy Strategy [2], released in May 2012, which maps out a high-level plan to continue researching, developing, and regulating how we will harness this resource.

The Act will effectively govern the development of marine renewable energy resources—including waves, tidal range, in-stream tidal, ocean currents, and offshore wind–in designated areas within Nova Scotia's offshore. It will do this in such a way that will protect the environment, respect community and local interests, and ensure that Nova Scotians benefit.

Within these priority areas, the Province will designate smaller areas for project development known as 'Marine Renewable Electricity Areas' or MREAs. The purpose of an MREA is to identify optimal locations to develop marine renewable energy projects and to provide clarity on the use of this marine space.

The regulatory plan established for MRE development includes a robust and effective regulatory and environmental protection system and a public and stakeholder engagement plan founded on accountability and transparency.

A key piece to the legislation is the creation of a licensing and permitting system that will oversee opportunities to test and demonstrate prototype technologies and the development of marine renewable energy projects.

The licensing system will ensure projects proceed only after undergoing a thorough review by government and subject to effective government oversight and monitoring. This system and the program requirements are an important instrument in encouraging innovation and technology development and in building industrial capacity and intellectual property in Nova Scotia.

Research, collaboration, and testing have positioned Nova Scotia to move to the next level of MRE development.

The first generation of installed projects will help to establish and validate the actual effects (both positive and negative) of

MRE development. This knowledge will in turn better inform communities, economic considerations, legal frameworks and future decisions respecting tidal development.

A strong integrated regulatory system provides a sound basis for public assurance that their interests are being protected.

This presentation outlines the process the Province of Nova Scotia has established for marine renewable energy development. Particular emphasis is given to the importance of economic, social, legal and political aspects of ocean energy in establishing the Marine Renewable-Energy Act to ensure responsible development of our marine resources.

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Lessons learned for Marine renewable energy development in Chile, Peru and Colombia

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Keywords: *Marine Renewable Energy, Chile, Peru, Colombia, NCRE.*

Aquatera's efforts in South America for the last 10 years, have mainly focused on the marine renewable energy development in Chile, Peru and Colombia. Aquatera has developed a comprehensive analysis on the current regulatory framework, R&D, supply chain, infrastructure and niche market futures for marine renewables on this region. A deeper assessment has been taken to deliver strategic marine energy roadmaps for the Chilean and Peruvian governments. The two years-long study for both countries sets out a region by region roadmap of how to take advantage of the opportunities presented by Aquatic technologies in Chile and Peru. It also provides scenarios of development regarding recommendations around resource characterization, regulatory framework, R&D, market niches, supply chain and infrastructure requirements. The reports outline different steps that government, industry and the R&D community may wish to consider to enable and support the development of aquatic renewable energy projects.

The assessments, consultations and stakeholder's engagement carried out on these countries around wave, tidal, floating wind, floating solar and river hydrokinetic technologies may provide some insights on the aquatic renewable energy development for this area of Latin America.

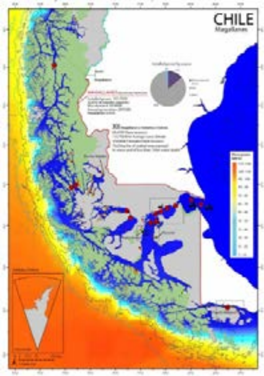
In terms of wave-energy resource, Chile is one of the richest countries in the world, if not the most one. Its coastline receives more wave energy than any other country worldwide (Fig.1). The total available wave resource in Chile is estimated to be 240 gigawatts which accounts for 10 times more electricity offers than the current demand.

Chile's energy short term markets for marine renewable energy are local rather than large scale projects connected to the main national electricity grids. Each one of the natural environments and administrative regions presents different opportunities for the Marine renewable energy industry and different markets for energy supply which have been identified in the roadmap study developed for the country.

Higher up the Pacific Coast, the research done for Peru considered scenarios of development for floating solar, offshore wind, wave and river hydrokinetic technologies (Fig. 2). It included the assessment of the resource potential, technical conditions, enabling infrastructure and market availability/value for each administrative region in Peru.

The results show that the greatest resource areas are to be found at sea in the Pacific North and Central regions and in inland lakes and reservoirs in the basin facing Atlantic North and Titicaca. The exploitable resource areas identified in the

Pacific South and basins facing Atlantic Central and Atlantic South are still significant but noticeably lower.



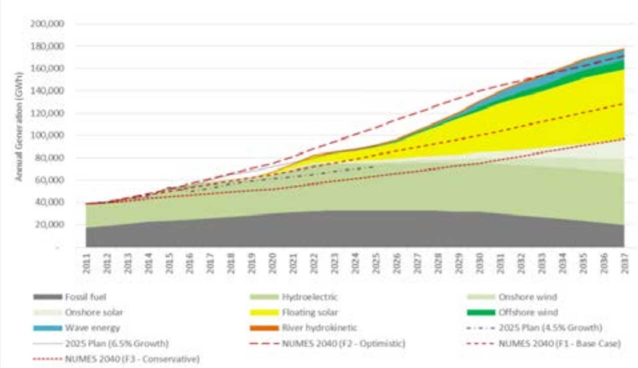
(Davies_fig1.png)
Fig. 1 Marine renewable potential in Magallanes region, Chile

In Colombia current studies are being developed by Aquatera in partnership with the *Universidad Cooperativa de Colombia* (UCC) and the Corporation of Science and Technology for the Development of the Maritime and Fluvial Naval Industry (COTECMAR) to asses local aquatic renewable energy opportunities of development and to promote knowledge transfer for design and adaptation of marine renewable technologies to Colombian conditions.

The current project is the third one of the progressive information building and knowledge transfer projects supported by the Royal Engineering Academy in London to build marine renewable energy capacity in Colombia.

An analysis of the local environmental conditions in Colombia for marine renewables development has been done together with guidelines for adapting these technologies to the country.

PAMEC 2020 offers an opportunity to share a presentation about the main outcomes of the research developed in Chile, Peru and Colombia to date.



(Davies_fig2.png)
Fig. 2 Optimistic (HIGH) growth scenario for aquatic renewable generation in Peru

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MERIC: supporting the development of MRE in Chile

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Keywords: *Chile, marine energy, interdisciplinarity, collaborative research, innovation*

MERIC (Marine Energy Research and Innovation Center), was established in Chile thanks to the support of Ministry of Energy together with CORFO agency, after the call for funding "R&D International Centres of Excellence Attraction". Was funded in Chile by Naval Energies together with Enel Green Power, and currently has three implementation partners: Pontificia Universidad Católica de Chile, Universidad Austral de Chile and Enel Green Power Chile (Figure 1).

Figure 1: MERIC team and collaborates, Annual Coordination Meeting, March 2019

MERIC is an initiative that seeks to diversify the country's energy matrix and to join the international efforts to advance on Marine Renewable Energy (MRE) development, from Chile. MERIC's vision is to drive the sustainable development of MRE industry in Chile, supporting solutions for technology survivability under local conditions.

The Center started its operations on October 2015. During this first four year, MERIC developed R&D on ten areas, each one executed by an implementation partner. This project includes the areas of: resource assessment, biofouling, marine corrosion, social perceptions, marine mammals habitat use, technology adaptation, levelized cost of energy, measurements at sea and creating tools to facilitate the insertion of MRE in the country (Figure 2) (see [1] for more information).

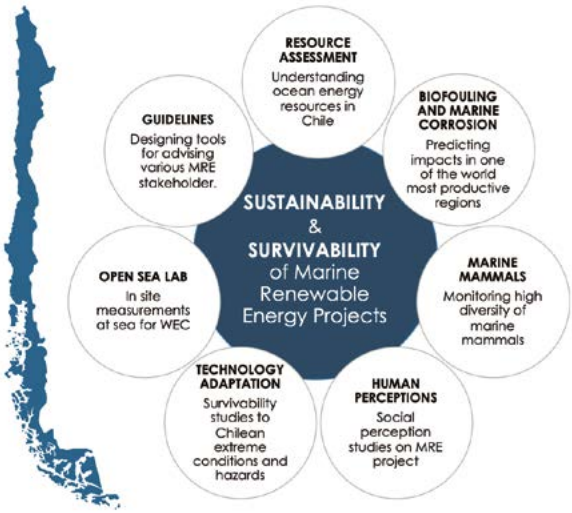

Figure 2: MERIC R&D topics and presence along the country.

During its first four years, more than 130 professionals supported by MERIC, including participation of postdocs, PhD, MSc and undergraduate students. The operational and testing capacities built include fieldwork on energetic and extreme locations, together with technology experiments in Test Tanks and numerical and laboratory work (Figure 3). Networking efforts were intense, collaborating actively with twelve countries and three continents. MERIC's approach is technologically neutral and open to new partnerships.

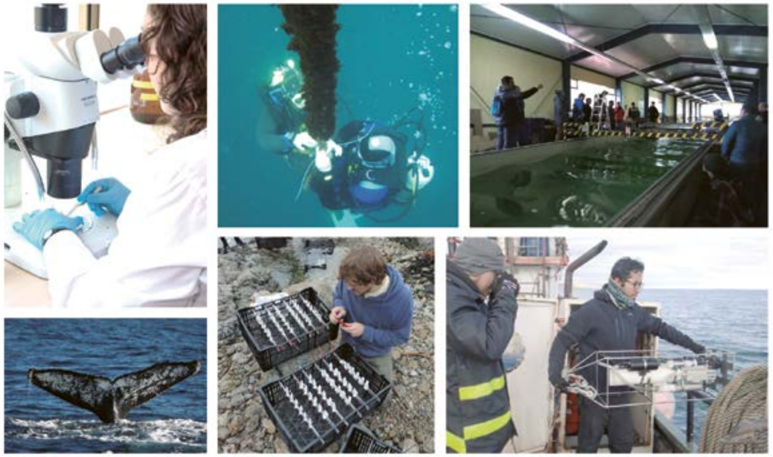

Figure 3: images of MERIC's team R&D work in laboratory and the field.

During the period 2019-2023, MERIC reoriented its R&D strategic goals, focusing on two main lines of work:

- MRE technologies and environmental interactions: includes the input of biofouling, marine corrosion and resource assessment R&D teams, les by the Pontificia Universidad Católica de Chile.
- Technologies at Sea: with projects covering the topics of Adaptation of Technologies and Offshore Technology Integration, led by Universidad Austral de Chile.
- Open Sea Lab: deployment of an offshore data hub connected to a wave energy converter (OPT PB3). This line of work will be closely engaged with the R&D teams previously mentioned, looking for the reinforcement of the multidisciplinary approach of the Centre.

The Centre reorganized itself to work with three strategic pillars (Figure 4), being R&D one of them, to be complemented also by collaboration opportunities that the team strongly support.

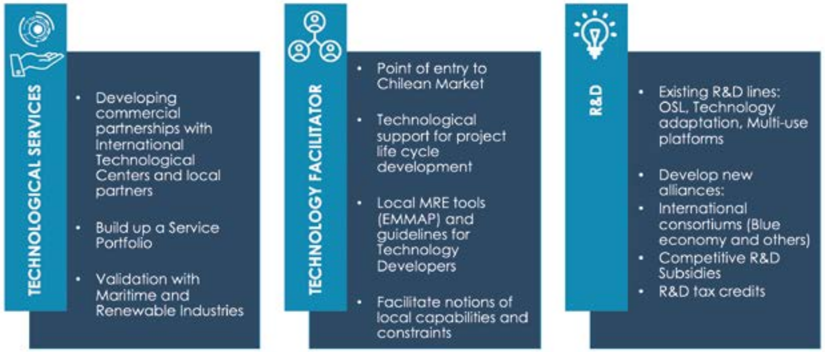

Figure 4: MERIC's three strategic pillars.

One of the main challenges that MERIC faces the next years is to achieve its self-sustainability by 2023, and that is why another strategic pillar is related to Technological Services. Considering that MRE industry is at an early stage internationally, and currently non-existent in Chile, the Centre decided to broaden its industrial scope towards maritime and renewable industries. This, looking for the reinforcement of know-how and generation of internal capacities to be support successfully the MRE industry when machines start to be deployed. With this in mind, the Centre is looking towards the development of alliances and a portfolio of high-level technological services, to be offered in the maritime renewable industry.

The third area of work is to continue to accompany national and international developers willing to deploy their machines in Chilean waters. With this goal, we published Legal Guidelines in environmental, health and safety and community engagement topics, and also co-constructed with them our interactive mapping tool Emmap (www.emmap.cl).

MERIC will continue to be oriented towards supporting the developing of a Blue Economy industry in Chile, offering know how and open to collaborations and strategic alliances. The Center looks for articulating public, private and academic sectors to develop sustainable marine energy in the country, preparing the tools and filling the gaps necessary for a successful insertion of MRE in Chile.

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Keyword Indexing

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WWIII

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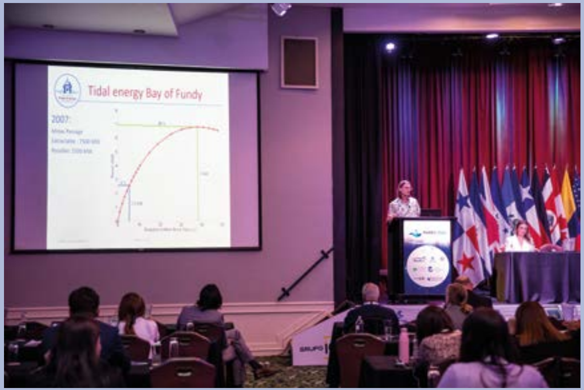
PAMEC 2020
Pan American Marine Energy Conference
Costa Rica

CONFERENCE PHOTOS



PAMEC 2020
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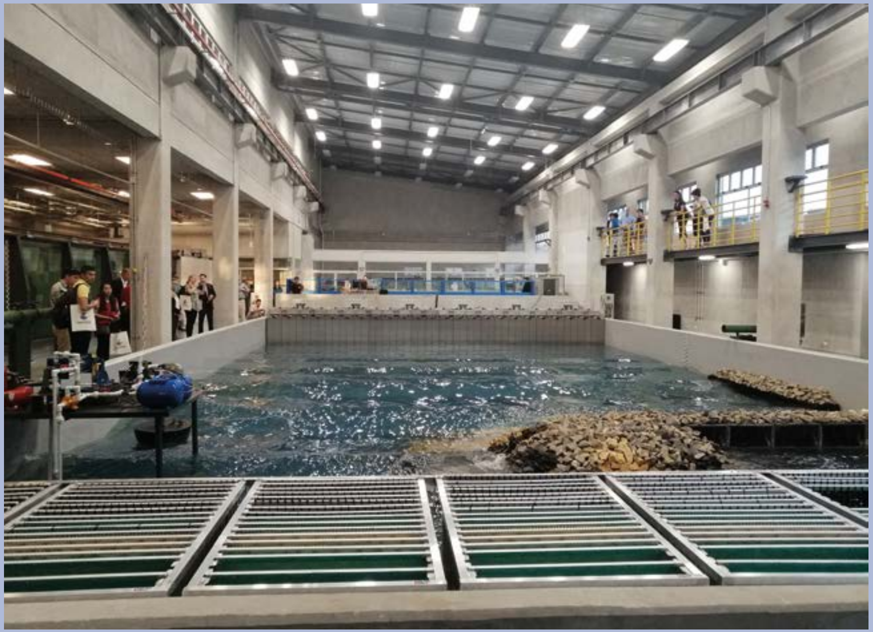

The Pan American Marine Energy Conference, PAMEC 2020, was held in San Jose Costa Rica, from January 26 to 28, 2020. The conference is aimed to foster the development of marine renewable energy through investigation and cooperation among researchers, developers, and suppliers from America and other continents. Before and after the main event, were organized technical workshops in the University of Costa Rica. These workshops were supported by IMARES, UNED, Marine Renewables Canada, ITCR, UNA, ICE, Dutch Marine Energy Centre, Pacific Northwest National Laboratory, Ocean Energy Systems, MERIC, Acadia University, Sandia National Labs, NREL, FORCE and INORE.

Thanks to all

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