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Quasi-Continuous Sliding Mode Speed Control of Tidal Stream Turbine

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Sustainable energy supply for remote island communities is essential towards achieving net-zero carbon emission target by 2050. In this context, tidal stream turbine (TST) has emerged as an interesting solution to harness the power of marine current energy. Recent researches show that many of the adopted TST projects consider fixed-pitch blades for the turbine and choose permanent magnet synchronous machine as the generator [1]. The power output of a TST is proportional to the cubic of the marine current velocity and the turbine power coefficient. In the case of a fixed-pitch turbine, tip-speed ratio determines the turbine power coefficient. Tip-speed ratio is controlled by the rotational speed of the turbine. This highlights the importance of turbine speed control in extracting the maximum power from the marine current by the TST. However, fast and accurate speed control of TST is not a trivial task. Various disturbances such as varying marine current speed, strong swell effect etc. make the speed tracking a challenging task. In the literature, various controllers have already been proposed for speed control of TST such as proportional-integral (PI) control, super-twisting sliding mode control (SMC) [2], model predictive control (MPC) [3] etc. PI controller is easy to tune but performance deteriorates in the presence of disturbances. Moreover, PI controller has limited tracking bandwidth. MPC requires accurate information about system parameters. TSTs are located in the sea and faces harsh marine condition. Environmental effect often change the turbine and generator physical parameters. As such the application of traditional MPC can be limiting in harsh marine conditions. Sliding-mode control is very robust and can work well in the presence of parameter mismatch and/or disturbances. This makes sliding-mode control a very suitable choice for TST. However, traditional sliding-mode control suffers from chattering or high-frequency oscillation. So, steady-state oscillation due to chattering can often be unavoidable. To overcome the limitation of the existing sliding-mode controllers, in this work, our focus is to propose a sliding-mode speed controller based on the principle of quasi-continuous sliding mode [4]. The proposed quasi-continuous SMC (QC-SMC) has similar dynamic performance as ST-SMC, however, with a significantly reduced steady-state oscillation. Matlab/Simulink-based numerical simulation is considered for the validation of proposed QC-SMC controller. The considered parameters of the TST are taken from [5]. Several challenging test scenarios are considered to evaluate the effectiveness of the proposed technique over SMC. Numerical Simulation results show the effectiveness of the proposed technique over SMC. The proposed technique demonstrated significantly smaller steady-state oscillation in the extracted power compared to SMC. In this work, only the development of speed controller is considered. QC-SMC current controller for the generator will be considered in a future work. Figure 1: Rotor speed comparison subject to torque disturbance. Figure 2: Generated power subject to torque disturbance.

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Performance analysis of model-scale tidal stream turbines situated in different array configurations

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Tidal stream technology is a promising source of renewable energy which is expected to contribute to the global energy mix by 2050. The technology is currently still in its infancy and the road to commercialisation relies on extensive research and development that will improve the operability of tidal devices and increase the efficiency of power generation. This report presents the results of an experimental study into the performance of scale model horizontal axis tidal stream turbines placed in different array configurations. Optimising an array configuration can maximise power extraction which is essential in driving reductions in the levelised cost of energy associated with tidal power. In the experimental investigation presented, three scale model turbines were placed in four different configurations. Experimental testing was conducted at the FloWave Ocean Energy Research Facility at the University of Edinburgh. The FloWave facility is a unique, circular testing facility which can generate different combinations of waves and current in any relative direction across the central test volume. The four array layouts were all setup with two upstream devices with a single downstream device. These devices were set in a delta shape with tests repeated with differing lateral separation between upstream devices and longitudinal separation between the front row and the single downstream device. A single array configuration with the downstream device 7.8D downstream of the front row of turbines was tested along with three compact array cases with the downstream device was set at 3.2D downstream of the front row of devices. All three devices were operated at a constant rotational speed for a given test and array configuration. To achieve a range of operating conditions for each array configuration, a range of experiments were undertaken at each layout with the downstream device operating at differing rotational velocities. For each array configuration the flow velocity 1m upstream of each device was measured at hub height. The flow data and turbine performance data (rotational speed and rotor torque) were analysed to determine which array generated the most favourable results. The results agree with some previous findings [1][2] that tightly packing devices can lead to exploitation of the acceleration regions created due to the bypassed flow around upstream devices. This study found that a lateral hub-to-hub separation of 2D negatively effects power output and variability in comparison to cases with 2.7D and 3D lateral separation - all for a longitudinal spacing of 3D. In all cases spectral characteristics reported in literature were found adding to the body of evidence supporting the use of recently developed spectral models.

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The potential for wind farms to affect primary production

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The upcoming renewable energy development in the shelf seas has raised the need for assessing the impacts of new infrastructures in the marine ecosystem. Shelf seas are productive environments that rely upon phytoplankton communities adapted to a range of hydrodynamic regimes as the bases of ecosystems, and supporting local fisheries. The allocation of very large-scale wind farms (fixed and floating) on regions with fishing activity and/or conservation interests requires a complex assessment linking the effects of hydrodynamic changes up through the biological components. The investigation of hydrodynamic changes related to new infrastructures has advanced in recent years, drawing important considerations of the effects of wind extraction on wave induced mixing at the surface and the increasing turbulence downstream of the turbine foundations. The consequential variation of the water column stability (stratification and mixing rates), in space and time, within and around windfarms, opens new questions about the effect of wind turbines on primary production, as the consequences of change have not yet been properly assessed. To investigate the effects of wind energy extraction we focused on the region of Firth of Forth and Tay (FoF, Scotland, UK), which has extensive wildlife and physical surveys, and exemplifies an ecological and economic area frequented by top predators (seabirds, mammals) and the fishing industry due to its heterogeneous bathymetry and spatial patchy productivity. Our initial studies in this area have focused on using in-situ data to characterize and predict (using only physical variables) two attributes of primary production, the abundance, and the vertical distribution in the water column, in relation to physical variables. The vertical distribution and abundance of plankton patches are very ecologically important variables that determine the make-up of the species within phytoplankton community and drive the availability of food to the upper trophic levels. The structures and operations of wind farms can affect the important physical variables: the depth of the pycnocline, tidal flow velocity, bathymetry, and wind speed at sea surface (< 10 m), that drive the important plankton attributes. Therefore, we adopted different methodologies to predict the changes primary productivity in this region, ranging from statistical to fine-scale (< 1 km) hydrodynamic 3D models (FVCOM). We are exploring the potential effects of changes to the timing of the blooms and/or horizontal and vertical patchiness in primary productivity and how they might affect the ability of top predators to find/use productive areas. Our aim is to explore variations of temporal and spatial patterns within and around large wind farm arrays, using FVCOM coupled with ERSEM (European Regional Seas Ecosystem Model) under two different scenarios: with and without wind turbines. This type of assessment is essential to move towards an ecosystem approach that can be used to evaluate the resilience of local food webs in dealing with new spatial patterns of production in the marine environment changed by the introduction of multiple structures and large-scale extraction of energy.

Wave energy assessment and feasibility study for the island of ‘Eua, Kingdom of Tong

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The Pacific Island Countries (PICs) have characteristics that render them vulnerable to climate change impacts, such as remoteness, limited natural resources, and narrow-based economies. Because of that, resilient development is a crucial process for PICs, which also includes low-carbon development through the transition to renewable energy. As a result, several countries have already committed to optimistic renewable energy targets; The Kingdom of Tonga, for instance, declared the goal to achieve 70% renewable energy generation by 2030. To diversify the energy portfolios in the region, there have been studies on wave energy, including resource assessment and preliminary cost analysis. The study has shown that a significant number of islands in Tonga have the potential to harness wave energy. This study chose to focus on conducting a pre-feasibility assessment on a local scale to identify potential challenges and opportunities for wave energy in the Pacific environment; the study case is the island of ‘Eua from the Kingdom of Tonga. The research process was divided into four main stages: 1. Establishment of a framework that identifies potential challenges for wave energy in the Pacific 2.Estimate wave energy resource assessment (kW/m); 3.Estimate the extractable power (kW) and Annual Energy Production (kWh); 4. Cost and risk analysis. The goal was to identify suitable sites for energy harnessing surrounding ‘Eua Island as well as disadvantages and advantages based on the local society and environment. Wave energy flux data were analyzed along with bathymetry data throughout the island surroundings; monthly, seasonal, and annual climatology estimates were conducted for wave energy resource and their variability. Based on the results found, four sites in the South, West, and Northern areas were selected to conduct further analysis. For these four sites, potential challenges were found to be the presence of humpback whales, pelagic sharks, touristic areas, fishing spots, nearshore coral reefs, frequent hurricanes, and the navigation route between ‘Eua and Tongatapu. To estimate the Levelized Cost of Energy (LCOE), Monte Carlo Simulation was applied into the calculation process considering the following variables: costs variation, unplanned maintenance, overhaul, conversion rate, discount rate, climate variability and shipping costs variation. A bottom mounted Wave Energy Converter (WEC) that converts pressure changes into electrical power was selected for annual energy production and cost assessment; the reasoning was its resistance to extreme weather scenarios, proximity to the Pacific Islands, and open-access data. Final results showed that in the South of ‘Eua it is possible to achieve a LCOE in the range of 277-278 USD/MWh, which can compete with diesel generation costs and provide an alternative to fossil fuels.

Analysis of higher harmonics in a focused water wave group

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An engineering interest of studying the extreme waves is that these waves would produce significant nonlinear loads which may cause serious damage to offshore structures. Understanding the characteristics of the nonlinear extreme waves improves the prediction of wave loading and has economic benefits of the offshore structures design. However, the extreme waves in a random sea state are transient, which increases the difficulties of capturing the wave elevation raw data. Therefore, a focused wave group which is based on a deterministic wave energy spectrum is used to represent the extreme event in the experiments and numerical simulations. In order to analyse the higher harmonic wave elevations of focused wave groups, a fully nonlinear potential flow model is employed to generate nonlinear wave groups by the NewWave theory. After recording the free surface focused wave elevations, an important task is to extract the higher harmonic components. A phase-manipulation approach is employed that is based on the assumption of a "Stokes-type" nonlinear harmonic structure. In addition, the fast Fourier transform is applied to separate the elevations up to fourth harmonics in the frequency domain. Comparisons with the experimental data and mathematical model show remarkably good agreements for the higher harmonic elevation coefficients. With increased wave steepnesses, the non-dimensional harmonic coefficients are found almost constant against the wave steepness. The "Stokes-type" harmonic structure suggests that the higher harmonics of a focused wave group can be estimated using only the linear component.

Array power curve: investigating a new method for computationally efficient tidal farm modelling

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Simulating large tidal stream turbine arrays is computationally expensive, prohibiting accurate quantification of long term energy yield and array optimisation. This research investigates a new method for quantifying long term array energy yield, through the implementation of an 'array power curve'. First, a coarse ambient model is run for the site of interest (simulation 1), over the period that energy yield is to be estimated. Second, a higher-resolution model is run (simulation 2), in which array drag is included as a sink in the shallow water momentum equations. Simulation 2 is run for a shorter period of time that coincides with the ambient model. Outputs from both simulations are used to establish the relationship between the ambient flow (of simulation 1) and the array power (calculated from simulation 2). The long term energy yield is then estimated by correlating the long term ambient flow time series from simulation 1, with the array power from the array power curve. This research demonstrates the array power curve method using arrays of different sizes/shapes located in the Alderney Race, in the Channel Islands. Hydrodynamic modelling of the English Channel is carried out using the coastal flow solver Thetis, which is implemented using the Firedrake finite element partial differential equation solver framework. The accuracy of the array power curve method is investigated to establish its applicability to different array configurations. This will be carried out by running array simulation over long durations to calculate array power directly, to then compare against the array power curve method. We investigate the impact of the location of the ambient flow time series, and the impact of the duration and timing (e.g. spring vs. neap tide) of the data series used to generate the array power curve, on the accuracy of the method for estimating long term energy production.

A Framework for Resolving Collision Risk as a Barrier to Consenting Tidal Projects

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The risk of marine animals, particularly marine mammals and fish, colliding with moving turbine blades remains the most uncertain risk that developers face in consenting and licensing tidal energy projects, and it remains the most difficult to resolve. While other potential risks, such as effects of underwater sound from operating devices or electromagnetic field (EMF) emissions from power export cables, can be informed by analogous structures or operations, there are no real analogues to collision risk for a tidal turbine. To date, regulators and stakeholders have been very concerned about the risk of collision to endangered and commercially important species, resulting in the need for costly and extensive data collection efforts around new tidal projects that have not yet resolved the perceived risk. Research studies and monitoring data collection around operating tidal and river turbines have provided some limited direct observations of animals around turbines. In addition, numerical models that have been applied so far have provided some sense of how animals might collide with or encounter turbines. As the stakes for tidal developers become greater with early commercial deployments, there is a need to comprehensively examine what is needed to collect the necessary data, parameterize and validate realistic models, and ensure that regulators and stakeholders are confident that marine mammals, fish, and other marine life will be protected. This paper will lay out a framework for assessing current knowledge related to collision risk, determining necessary research needed to fill critical gaps in understanding potential interactions, defining monitoring needs around deployed turbines, and highlighting essential engagement with regulators to ensure that the information collected will satisfy their needs. The 16 nations of the Ocean Energy Systems-Environmental initiative have been pursuing a process known as risk retirement to decrease the need to collect comprehensive baseline and post-installation monitoring data around every new marine energy project. While this process has been able to rely on existing information and understanding from research projects and offshore projects that are analogous to marine energy, collision risk is a more difficult interaction to resolve. This framework will act as the roadmap for reaching the same level of certainty for collision risk that is being achieved for other environmental risks, including underwater sound, EMF, changes in benthic and pelagic habitats, and changes in oceanographic systems.

Optimization of the layout of vertical axis tidal turbine arrays for maximising power generation

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Vertical axis turbines (VATs) are rarely used today as these lift-driven turbines seem to have a low power performance compared to their horizontal axis counterparts. However, they offer key advantages such as faster recovery of the velocity deficit downstream [1] or the possibility to cluster several devices very closely [2] to enhance their power generation density. The applications of VATs to tidal energy production is also motivated by their lower operational tip-speed ratio which reduces noise and adverse impact on the ecosystems [3]. The energy yield of vertical axis tidal turbine (VATT) arrays need to be more precisely studied in order to assess the economic viability of these technology, specifically the quantification of turbine-wake interaction. The recently developed theoretical super-Gaussian model [4] allows to accurately predict the three-dimensional evolution of VAT wakes and thus account for the interaction between devices in close proximity as well as the wake evolution further downstream. The aim of the current research is to use this super-Gaussian model to optimise the layout of VATT arrays to be deployed in a confined region. While these subject has been extensively investigated for horizontal axis turbines [5], there has been no comparable work for VATs despite they have unique characteristics such as their omni-directionality, that make them better suited for river and tidal applications. An adapted optimization method is used to find the turbine arrangement that maximises the power output (objective function) of an array under design constraints such as the deployment area limits, number of turbines or thrust coefficient ... The role of critical dimensioning parameters such as the wake recovery rate is also investigated in comparison to analogous arrays that considered horizontal axis turbines [5] with identical swept area. Our work will contribute to shed new light into the future financial viability of VATT arrays by estimating the global performance of optimised layouts taking into count the wake interactions in an accurate manner.

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Comparisons between a Particle-In-Cell solver and OpenFOAM on the simulation of a TLP floating offshore wind turbine

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The mesh-based Eulerian model and the particle-based Lagrangian model are typical examples for the computational fluid dynamics (CFD) tools. OpenFOAM which is based on the Eulerian model is supposed to be relatively efficient on the computational time than the Lagrangian model due to the use of a fixed grid. With the application of the volume of fluid (VOF) method, OpenFOAM can accurately track the free-surface position for the multiple-phase flow. And the accuracy of OpenFOAM to represent the wave-structure interactions has been proved by many previous studies. The Lagrangian model compared with the Eulerian model is more suitable for handling large free-surface deformations via using particles. To improve the efficiency on the computational time of the particle-based Lagrangian model, a Particle-In-Cell (PIC) solver was developed and utilised for wave-structure interaction issues in [1]. The PIC solver combines the Lagrangian model with the Eulerian model by employing particles to solve the transport terms and track the free-surface position and utilising grid to solve the non-advection terms. This research aims to compare the efficiency and accuracy of the PIC solver and OpenFOAM using the same HPC facility. Figure 1. Dimensions of the tension leg platform. A tension leg platform (TLP) model representing TLP floating offshore wind is used for the validation and the comparison of the two CFD models. Figure 1 shows the dimensions of the TLP model which is mooring-restrained, only the surge motion is considered in this research due to the high axial stiffness of moorings in the initial vertical direction. Figure 2 shows the surge response amplitude operator (RAO) with the comparison between the CFD models and physical experiments in [2]. It indicates that both OpenFOAM results and the PIC solver results have a good agreement with the experimental results. And the execution time is shown in the table in Figure 2. The mesh cell number of this TLP model in the PIC solver is around 9 times of that in OpenFOAM because only uniform mesh can be applied in the current PIC solver. And the execution time for the TLP model simulation by the PIC solver is around three times of the execution time of OpenFOAM. More detailed information and further comparison results will be presented during the conference. Figure 2. Surge RAO with the comparison between CFD and experimental results (left) and execution time with the comparison between OpenFOAM and the PIC solver (right).

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Local environmental impact underpins coastal community attitudes toward wave and tidal energy developments: A photo-elicitation study on the Bristol Channel, UK

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In the decade of action and delivery for the UN Sustainable Development Goals, renewables present a real and, now, competitive delivery mechanism for energy decarbonisation. For the UK Government to meet its net zero carbon emissions by 2050 commitment, it will need to accelerate decarbonisation proposals. Wave and tidal energy can contribute to collective progress toward this target, generating a balanced green energy mix. While investment in technological advances continues to be a priority in wave and tidal energy solutions, with associated cost reductions, qualitative research exploring alternative long-term decarbonisation pathways can, in the meantime, provide policy-makers with 'the people's voice' regarding issues to consider in respect to potential tidal energy developments. Little is known about the human dimensions of wave and tidal energy devices and their public acceptability. This research project explored perceptions of wave and tidal energy developments among residents in three case study sites along the Bristol Channel (Weston-super-Mare, Minehead, and Barnstaple), an area of known wave and tidal energy potential, and attempted to understand these perceptions through a social and cultural impact lens. A mixed-method approach was adopted, integrating photo elicitation and a questionnaire survey involving residents of the study locations. Data from the elicitation interviews were analysed thematically and further explored through extracted survey data, revealing a generally positive perception toward wave and tidal energy development albeit with some clear ideas of acceptable trade-offs and concerns regarding impact on a range of coastal attributes found to be of particular importance to participants. Local environmental impact was found to be a key consideration. Public opinions about renewable energy tend to be technology and location specific. It is therefore important for energy sector and planning decision-makers to understand what sort of benefits potentially impacted communities would want realised in order to gain their support and minimise opposition to proposed tidal and wave energy developments.

Analysis of higher harmonics in a focused water wave group

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An engineering interest of studying the extreme waves is that these waves would produce significant nonlinear loads which may cause serious damage to offshore structures. Understanding the characteristics of the nonlinear extreme waves improves the prediction of wave loading and has economic benefits of the offshore structures design. However, the extreme waves in a random sea state are transient, which increases the difficulties of capturing the wave elevation raw data. Therefore, a focused wave group which is based on a deterministic wave energy spectrum is used to represent the extreme event in the experiments and numerical simulations. In order to analyse the higher harmonic wave elevations of focused wave groups, a fully nonlinear potential flow model is employed to generate nonlinear wave groups by the NewWave theory. After recording the free surface focused wave elevations, an important task is to extract the higher harmonic components. A phase-manipulation approach is employed that is based on the assumption of a "Stokes-type" nonlinear harmonic structure. In addition, the fast Fourier transform is applied to separate the elevations up to fourth harmonics in the frequency domain. Comparisons with the experimental data and mathematical model show remarkably good agreements for the higher harmonic elevation coefficients. With increased wave steepnesses, the non-dimensional harmonic coefficients are found almost constant against the wave steepness. The "Stokes-type" harmonic structure suggests that the higher harmonics of a focused wave group can be estimated using only the linear component.

Complementarity in offshore renewable energy sources off the coast of São Paulo, Brazil.

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Renewable energy sources are variable in their natural availability. That is, the system controller cannot simply switch it on or off according to demand. Thus, the study of its temporal variations is of fundamental importance for the sector, mainly to assess how different resources can complement each other over time. This not only brings greater energy security but can also lead to other gains, such as lower investment costs with infrastructure and minimization of environmental impacts. For this reason, this work proposes to investigate the temporal variability of renewable offshore resources (solar, wind, and ocean currents) off the coast of the most populous region in South America as an example. For this purpose, the work uses data from three different sources in the region of São Sebastião, on the coast of the State of São Paulo, Brazil. For the solar, the data comes from the Brazilian Reference Center for Solar and Wind Energy (CRESESB), from which values of monthly average solar irradiation in kWh / m² obtained for the different periods. The wind potential was estimated from an atmospheric simulation of the Weather Research and Forecast (WRF) model used to downscaling the results of the Climate Forecast System reanalysis (CFSR). The wind speeds were validated with data from the Brazilian National Buoy Program (PNBOIA) and the monthly averages of power densities in W / m² were calculated from them. Ocean current data was collected by Argonaut/SonTek Acoustic Doppler Current Profilers (ADCP) installed on the São Sebastião Channel (CSS) from 20/05/2009 to 10/16/2017. After properly treated, the power density in W / m² was calculated from the measured speeds and their monthly averages were calculated. We assume that the generation from each source would be directly proportional to the potentials obtained, thus we were able to calculate the monthly average of each one of them and then normalize by the maximum monthly average. From that, we got dimensionless values from 0 to 1, which are directly proportional to the energy generated by each source each month. To evaluate the seasonal variation we use a monthly mean capacity factor (MMCF) which is the mean monthly average divided by the maximum monthly average. The lower the MMCF value more unequally the energy is distributed along the year, the closer to 1 the MMCF is, the more even the potential over the seasons. For this region, we calculate MMCF for each source obtaining 0.574 for the winds, 0.789 for the solar, and 0.814 for the currents. With the curves, we simulated a scenario with the three sources, and each one's participation was optimized to maximize the MMCF, which reached 0.934. In this case, the composition would be 16.3% wind, 55.0% solar, and 28.7% current. Another benefit was that when analyzing the hourly averages of all sources, we observed that both currents and winds reach their peak at night, opposite from solar, which reinforces the benefits of complementing sources also in short periods (24h).

Flow interaction between multiple tidal power plants (Deep Green) using large eddy simulations and the actuator line method

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Tidal energy can potentially provide a substantial part of the future generation of sustainable electric power. The here studied tidal power plant developed by Minesto, called Deep Green, is a novel technology using a 'flying' kite with an attached turbine. It moves at a speed several times higher than the mean flow, thereby enabling an utilization of sites with typically lower tidal flows than stationary horizontally mounted power plants. It is beneficial since larger areas of tidal flow generation can be used and eventually makes it also suitable for multipurpose platforms. As the technology for tidal power plants is becoming increasingly mature, the use of power plant arrays attracts more interest. Design and operation of arrays require knowledge of how individual devices interacts and how the arrays influence the surrounding environment. Previous studies have shown that individual Deep Green plants can be modelled using eddy simulations (LES) and an actuator line model (ALM), to analyse tidally oscillating turbulent boundary layer flow. For these studies a special case of ALM was developed to be able to model arbitrary paths or trajectories necessary since the Deep Green is not stationary but moves in a lying figure-eight trajectory controlled by its control system. The trajectory width Dy was found to be an appropriate reference length scale in previous studies with velocity deficit of approximately 5% at a distance of 10Dy downstream of Deep Green. At the same distance the turbulence intensity was found to increase substantially (almost by a factor of two compared to undisturbed conditions). In the present study multiple Deep Greens forming an array have been modelled using cyclic boundary conditions in the flow direction. Here preliminary results of velocity and power deficit, and turbulence intensity are presented.

The future of tidal stream in England and France – an analysis of costs, subsidies and expected capacity

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Tidal stream is an exciting technology. Studies estimate that 300GW of tidal stream could be installed globally by 2050, with 100GW in Europe (representing 10% of Europe's electricity demand). The UK and France have very large resources, the former an estimated 50% of Europe's resource, and both have notable test sites and growing supply chains. Recently there have been significant pilot projects from developers like Orbital Marine Power, Sabella, Minesto and Magallenes. SIMEC Atlantis and Nova Innovation operate arrays, Meygen and the Shetland Array respectively, which have been operating reliably for a number of years and exporting consistent power. Despite these successes, progress has been slower than anticipated. Offshore wind's dramatic growth and cost reductions has made it difficult for tidal stream to compete economically. For example, the UK CFD Round 3 in 2019 saw offshore wind projects secure CFDs at about £40/MWh (£48 in 2020 currency), below the £250-350/MWh cost of energy estimated for tidal stream. Tidal stream has proven technical viability, so now needs to reduce costs, secure government support, and show that it can compete. There is limited operational experience in the sector, hampered by the lack of financial incentives and the large investment required to install devices. The small number of devices constructed means that supply chains are in early stages. It will be challenging for the industry to transition towards high volume manufacturing, partly due to the bespoke characteristics of each technology which is largely unstandardised. As the world moves to a low carbon future, there are wider benefits that will help tidal stream. By 2050 both France and the UK have pledged net zero carbon emissions. If the sector can demonstrate meaningful contribution towards these legally binding targets then it can widen the investment case. Tidal stream has a unique advantage over other renewables: it is highly predictable, over hundreds of years, so could assist with grid stabilisation and baseload power production, complimenting more variable renewables like wind and solar. Deploying devices will drive down costs through innovation and "learning by doing", as has been seen to great effect in offshore wind. The €45.4m TIGER project was devised to accelerate innovation by helping to get sites in the UK-France channel region consented and devices in the water. It is the largest ever Interreg funded project. The project is made up of 18 partners, including tidal developers and two PRIMaRE partners: the Universities of Plymouth and Exeter. In this session we will present techno-economic analyses of the six TIGER sites being developed. We will estimate the potential capacity build-out that can be expected under different support mechanisms, and correlate this to a national outlook to understand how the subsidy influences the tidal capacity that could be deployed. We will discuss the leading innovations that we anticipate in the sector, and how it can transition towards volume manufacture. Lastly, we shall present results from a study investigating system-level benefits of tidal stream when providing baseload power (using Imperial College London's IWES model).

The North Sea 3D project – From footage to biomass

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Continued developments in marine infrastructure have given rise to an increasing number of artificial structures in the marine environment. This has become known as 'ocean sprawl'. These structures are quickly colonised, becoming artificial reefs. To understand the role of these structure in marine systems, the colonising organisms need to be quantified, both by species and biomass. To date, this quantification has been limited by the difficulties in performing the studies on the scales needed. In the North Sea 3D (NS3D) project we plan to use existing footage collected by offshore energy operators with remotely operated vehicles (ROVs). This footage already exists in abundance, since structures are routinely surveyed by ROV for maintenance purposes. We will use recent advances in image/video processing - Structure from Motion (SfM) Photogrammetry and semantic segmentation by convolutional neural networks (CNNs) to generate 3D images of marine growth classified by taxa from standard 2D-video ROV footage. These can then be calibrated and used for biomass quantification. In this talk the NS3D project is introduced. The methodology of the associated image analysis is discussed, including the challenges of underwater photogrammetry and species auto identification, particularly when ROV footage is not taken specifically for this task. A call will be put out for suitable ROV footage from potential collaborators.

Are fish in danger? Review of effects of marine energy development on fishes

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Many fish species are threatened worldwide by overfishing, contamination, coastal development, and other anthropogenic activities, as well as the impacts of climate change. Marine energy is under development as a sustainable alternative to carbon-based energy sources. Regulators and stakeholders worry that marine energy devices will add another threat to fish populations under pressure. This paper will review the current knowledge of potential effects of marine energy development on fishes. These may include collision with devices that may lead to injury or death; underwater noise generated by marine energy devices that may affect fish behavior and health; electromagnetic fields from power cables and other electrical infrastructure that may lead sensitive fish species to approach or avoid them; changes in critical fish habitat, including nursery, feeding, and spawning grounds; shoaling of fish around marine energy devices; and displacement of fish populations or communities around arrays of multiple marine energy devices. The state of investigation and knowledge of effects of marine energy devices on fishes is such that focus is largely on developing and testing methods that can accurately observe and characterize key interactions, as well as defining and decreasing the uncertainty of these effects. Although there is a need to move toward tracking key biological metrics over time to detect effects of marine energy devices, few such studies have been undertaken to date. This is due to operational challenges, scarce deployments typically of short duration, and logistically difficult biological study designs and methods. However, field- and laboratory-based studies that have examined fish presence, avoidance, and evasion around marine energy devices suggest that collisions and other negative effects are likely to be rare. Progress is being made on data collection to better understand the behavior and ecology of fishes at sites targeted for marine energy development, and on modeling tools to estimate fish encounter rates with mane energy devices, the consequences of collisions, and population-level ecological risks. Similarly, studies exposing fishes to turbine-generated noise and electromagnetic fields demonstrate little effect on fish behavior. Inquiry into the effects of marine energy devices on fishes is in its infancy, and ongoing research is needed to ensure the health of fish populations while also facilitating the development of sustainable energy sources. Marine and diadromous fish populations are likely to be strongly affected by ocean warming, changes in coastal watershed precipitation patterns, ocean acidification, and other aspects of the changing climate. With the anticipated increase in marine energy deployments around the world, there will be a need to anticipate how fish populations and critical habitats will be affected under climate change scenarios, and how the effects of marine energy deployment and operation will cumulatively interact with other anthropogenic activities in the oceans and coastal regions.

Developing an agenda for biofouling research in Indonesia to support the development of marine renewable energy

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As an archipelago country located between the Indian Ocean and the Pacific Ocean, Indonesia has enormous potential energy resources from the ocean. The total practical resource potential of around 60 GW, including tidal current, wave, and ocean thermal, could be utilised to provide access to clean energy for the wider region within the country, ranging from Aceh in the West to West Papua in the East. A breakthrough policy is however urgently needed to promote the marine renewable energy industry in Indonesia as the industry is still in its infancy; existing research is limited to studies on resource assessment and prototype testing. Reflecting on the experience in temperate waters, biofouling is one of several key challenges faced by the marine renewable energy industry affecting the performance and longevity of the materials. This study aims to identify research gaps on marine renewable energy and biofouling in Indonesia, learning from the knowledge generated in temperate water deployments. It is anticipated that following the literature review, technical recommendations can be developed to promote and accelerate the commercialisation stage of marine renewable energy in Indonesia by focussing attention on the effects of biofouling on the durability of materials. Key topics identified via the literature review of biofouling studies in Indonesia include geographical aspects, bacterial biofilm, ship drag, biological invasion, biocorrosion, mitigation measures, and biosecurity risk management. Types of infrastructure for which effects of biofouling are reported in the literature for Indonesia are vessels, jetties and bridges, with no specific mention of potential impacts on marine renewable energy infrastructure. On the other hand, review from studies performed in the last two decades highlighted that research in marine renewable energy in Indonesia focused mainly on: (i) wave and tidal current resources assessment and (ii) energy conversion tests on the prototypes of marine current and wave energy technologies. None of this previous research addressed biofouling issues and identified their potential impacts on the marine renewable energy devices in the Indonesian tropical waters. In the UK, gradual development of the marine renewable industry has been made since the 1970s. As the industry has approached the commercial stage, attention is being paid more to ensure the devices' longevity and support operational and maintenance issues. This includes the development of biofouling mitigation plans. Based on findings from the review, we conclude that some adoption and adaptation steps could be developed to promote the progress of the marine renewable energy industry in Indonesian tropical waters by embedding biofouling topics into the national research and development plan.

Can citizen science and local knowledge provide robust evidence in consenting marine developments?

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Detailed surveys of species and habitats are the first step in understanding the interraction any marine renewable energy development may have with a site. Observations acquired through citizen science and expert local knowledge on marine biota represent a significant, growing and underutilised source of species and ecosystem knowledge. Such data have the potential to augment data from traditional surveys and enhance the evidence base used for consenting of marine renewable energy developments. However, understanding how to use and combine these data for consenting purposes is unclear owing to uncertainty in sampling distribution and data quality as well as comparability of different data and information sources. This poster will describe the citizen science mobile phone app (Sea Watcher), present some initial results and describe the challenges in the application of citizen science and local expert knowledge to reduce uncertainty in the consenting evidence base using Bardsey Island and marine mammals as a cse study. SEACAMS2 is a collaborative research programme, part-funded from the European Regional Development Fund through the Welsh Government, designed to drive blue growth in the Welsh Ocean Renewable Energy (ORE) sector. Under SEACAMS2 Bangor University in collaboration with Nova Innovation and the Sea Watch Foundation are exploring the value of citizen science data and local knowledge alongside traditional sources of data for consenting purposes. Firstly the knowledge held by local experts such as boat handlers, fishers and residents about marine mammal distribution and use of habitats in and around Bardsey Sound is being gathered and analysed to explore and map their knowledge of marine mammal movements. Secondly the Sea Watcher mobile phone app has been developed for the public to report marine mammal sightings data, resulting in a larger data set than would be possible from standard survey methods alone. Standard land based marine mammal surveys are being undertaken to better understand fine-scale distribution and occupancy patterns of marine mammals in Bardsey Sound. The use of these diverse data and information sources for assessment of the potential effects of a proposed tidal stream energy project in Bardsey Sound on marine mammals will be determined. Their potential for bolstering the evidence base for consenting purposes will also be evaluated. This will inform an evaluation of this novel approach for wider application elsewhere in Wales, UK and internationally, or for other receptors such as seabirds.

Study on short design waves in the prediction of extreme loads for a generic hinged-raft wave energy converter

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Studying extreme responses corresponding to a long return period (e.g., 25 years or even 50 years) is of fundamental importance during the design stage of a wave energy converter (WEC) system. The conventional method requires long-duration (3 hours) simulations on a large numbers of sea states. This long-term analysis is easy to achieve with linear transfer function of the system response, but will be considerably time-consuming when using time-domain nonlinear model and impractical for the use of computational fluid dynamic (CFD) method or physical tank testing. In that case, we try to evaluate the feasibility of using some short design waves (e.g., several minutes) to replace long-duration waves for generating extremes. Two different methods are compared. One is the New Wave method which takes into account the frequency content of the sea states used in the long-term analysis; another is the most likely extreme response (MLER) method, considering the frequency content of the response spectrum to back-calculate the short wave profile. The two different methods are applied to a 1/25th scale generic hinged-raft WEC and evaluated based on the physical tank tests in the Ocean Basin of University of Plymouth. Results show that MLER performs better in predicting extreme responses for this floating WEC structure to some extent, compared with the New Wave.

Multi-use platforms at sea in the Irish Sea: a numerical study

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Offshore management is a future challenge for the development of offshore renewable energy (ORE) industries and aquaculture. The synergetic development of marine renewable energy infrastructure with mariculture has been hypothesized as a way to share services and reduce costs. Reducing barriers to the development of Multi-use platforms at sea (MUPS) would provide a pathway for a high-tech low carbon energy industry that aligns with UN sustainability goals. In the Irish Sea, blue mussels (Mytilus edulis L.) represent 40% to 50 % of the total gross turnover of Welsh shellfish industries and the industry has been operating sustainably for over 50 years in North Wales. Also, the strong tidal currents (> 2m/s) occurring in North Wales, make this area an attractive place for the development of tidal renewable energy projects (Holyhead deep tidal stream project, tidal lagoon project in Rhyl). In this context, it is a scientific and economical interest to study the potential impact of ORE on larvae recruitment. A numerical approach has been developed using 2D hydrodynamic model (TELEMAC) coupled with particle tracking model (Matlab), which allowed to simulate tidal currents, wind-driven currents and larval dispersal. Results show: 1) the density distribution of larvae and 2) the connectivity between commercial shellfish beds and ORE sites. These results were studied for different depth (surface vs mid-water depth), different year (2014 vs 2018) and different pelagic larvae duration (PLD, from 1 week to 6 weeks). This study show the importance to choose adequately were to install ORE in order to: 1) reduce biofouling on ORE infastructures and/or 2) develop MUPS to combine needs for ORE and for mariculture.

Marine renewable energy resource mapping for observation and communication systems

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A fundamental challenge in earth system observations is powering instrumentation for long term deployments in challenging locations, here we investigate the potential application of marine renewable energy. With decreasing power consumption through technological innovations such as the Self-Contained Ocean Observation Payload (SCOOP) systems collecting real time oceanic and meteorological data on buoys, lower power demands may open the way to using renewable micro energy resources. Wind driven surface currents are one renewable energy source with the potential to power these buoys, and we hypothesis the persistence of these ocean surface currents provides the firmest renewable energy resource to power oceanographic instrumentation. For example, during winter months the solar-PV resource is too low at high latitudes and deployment timescales may be greatly extended with micro-hydrokinetic energy devices. The simulated results show the availability of this micro resource. Modelling components of U and V wind data along with mean wave data from the European Centre for Medium Weather Forecasting (ECMWF) latest reanalysis ERA5 data set. The ERA5 data is used to model the momentum transfer from the wind into the upper few meters of the water column, through the wind shear as surface drag and wave energy from stokes drift. Included within the model an average roughness length value is used to cover all wave range types, from ocean swell to steep young. Combining all three elements to provide the surface shear stress current. This modelled data provides correlation between surface stress coefficient and a neutral wind velocity at a height above the ocean's surface. These results show availability of the hydrokinetic energy available from these wind driven surface currents.

A three-dimensional regional scale model for tidal stream turbine implementation and impact assessment

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This research aims to introduce a 3D regional scale numerical model for a part of the Irish Sea (between 52.808˚N and 53.842˚N) that is suitable for turbine implementation and impact assessment. This research is based on a 3D wave-current-sediment fully coupled oceanographic model — the Unstructured Grid Finite Volume Community Ocean Model (FVCOM), and modifications made by the authors to the current, turbulence, waves modules to simulate the potential impact of tidal turbines1,2. In the modified FVCOM model, to simulate energy extraction which leads to reduced flow rate, an additional body force is added to the momentum equations. To reflect the varying turbine configuration and operation along the water depth, the coefficient related to the additional body force is depth dependent. Three turbulence perturbation terms are added to the MY-2.5 turbulence closure to simulate the turbine-induced turbulence generation, dissipation and interference for turbulence length-scale. Wave energy flux across the device is reduced to simulate the impacts of turbine operation on surface waves. The baseline Irish Sea model, i.e. without turbine implementation, is set up using bathymetry data extracted from a model covers the West Coast of the UK3. The largest mesh size is 1600 m at the two open boundaries and the smallest mesh size is 15 m at the turbine farm location (the Sound between the Skerries and Carmel Head on mainland Anglesey, North Wales, UK) to allow turbines within the farm to be presented individually. The model is driven by tidal elevations obtained through harmonic analysis of 15 tidal constituents extracted from the High Resolution UK Continental Shelf Model (CS20-15HC3) and wave conditions provided by the ECMWF 'ERA-Interim' dataset. A time varying uniform wind field created based on data measured at the Hilbre Island weather station is used to drive the wave climate. The model is validated extensively against water level measurements at two tide gauges, tidal current at the sea surface, mid-depth and bottom layers measured at four locations, wave climate collected by a WaveNet by, and suspended sediment concentration at one location. The validation results suggest that the model can accurately simulate the hydrodynamics and suspended sediment transport in the configured domain. The case study in which 18 turbines (diameter is 15 m) are modelled individually in the waterway between Anglesey and the Skerries reveals the large scale impacts of the turbine farm on free surface elevation, flow field, turbulence kinetic energy (TKE), surface waves, bottom shear stress and suspended sediment transport. The wake is observable up to 4.5 km downstream of the device farm. Flow near the bed in the wake is accelerated, leading to enhanced bottom shear stress. The device farm has a strong influence on TKE and hence the vertical mixing of suspended sediment in the wake. Further, the eastwards directed residual sediment transport along the north coast of Anglesey is found to be weakened by the turbine farm.

1Li et al. (2017) Renewable Energy, 114, 297-307
2Li et al. (2019) Renewable Energy, 130, 725-734.
3Burrows et al. (2009) Applied Ocean Research, 31(4), 229-238.

A machine learning model for wave prediction based on support vector machine

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Accurate prediction of wave propagation is always a challenging task for offshore structures. There are a variety of mathematical and physical models that can predict the irregular ocean waves with a certain accuracy. The rapid development of artificial intelligence technology has attracted the attention of the marine offshore industry. The application of machine learning (ML) for wave prediction has been an alternative in recent years. Compared with the traditional calculation models, machine learning methods are more efficient. Support vector machine (SVM), as a typical ML model, could be effectively applied for wave prediction with its strong learning ability. Different from existing prediction methods, this abstract proposed a SVM regression model, incorporating the combination of a frequency analysis algorithms and the wave elevation time signals. In this study, the wave elevation measured from a tank test using a JONSWAP spectrum was used for validation. A new SVM method considering the wave spectrum was proposed. In this method the time series of wave elevation was transformed into the frequency domain which is then divided into equal frequency subdomains. For components of each frequency subdomain, predictions by the SVM model are carried out separately in the time domain. By linear superposition, the prediction of the elevations can be obtained. After fully optimizing the parameters such as training time and sampling frequency, a short-term wave prediction model making use of the ML package is established. The model is shown to be accuracy and efficient in predicting the waves in the time domain and is promising for real-time wave prediction for offshore structures.

Single and multi-objective optimisation of benchmark wind farm optimisation problems

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It is expected that in the UK alone, by the year 2030 around 30% of the energy will be extracted from the wind. Initially wind farms were built on land, but due to limited space, environmental issues, and low wind velocities, increased number of wind farms are placed in the ocean. Installation of the offshore wind turbines poses a significant difficulty. It is generally accepted that the fixed wind turbines can be built in waters of up to 60 meters deep. Beyond that, fixed foundations are not technically or economically feasible. To get the most of high wind velocities found in deeper waters, floating offshore wind turbines need to be installed. To minimise wake interference from wind turbines, those turbines are placed afield from each other. But the amount of space for wind farms is also limited and therefore we desire a way of placing as many wind turbines as possible in the smallest area with minimal impact on power output. In 1994 Mosetti et al. showed that genetic algorithms can be used to solve the wind farm optimisation problem. Others followed and demonstrated that similar or better results can be obtained using modified genetic algorithms, particle swarm optimisation algorithms and mathematical programming, to name a few. All these approaches have been applied to the single objective optimisation problem variant where cost to power ratio was minimised. We have shown in our paper that the identical or even better results can be produced by using a remarkably simple deterministic algorithm and by multi-objective optimisation algorithms. The problem characterised by Mosetti et al. involves one type of wind turbine, a fixed size of wind farm, pre-defined potential locations for wind turbines, Jensen's wake model and three different wind scenarios: one wind direction with constant speed, thirty-six wind directions with constant speed and thirty-six wind directions with various speeds. Interestingly, even though such formulated problems do not look too complex, and it has been investigated over twenty years, no optimal solution was found for the second and third wind scenarios. Apart from the deterministic algorithm above, we have used three multi-objective algorithms: Non-dominated Sorting Genetic Algorithm II (NSGA II), Pareto Envelope-Based Selection Algorithm II and Strength Pareto Evolutionary Algorithm II. In terms of single objective optimisation there exists only one optimal solution, whereas in a multi-objective approach an infinite number of solutions can be found where the trade-off between power and the cost functions exists. Decision makers can then decide which of the available solutions is the best. But, having said that, we have also demonstrated that for such an easily defined problem there is no need to employ such sophisticated methods; we were able to find optimal solutions using a simple single objective algorithm. This paper presents a framework for optimising static offshore wind farm layouts that will be extended to optimise floating offshore wind farm layouts in our ongoing work.

IMARDIS - An end-user driven cloud-based data infrastructure supporting the Welsh maritime sector

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SEACAMS2 is collaborative research programme, part-funded from the European Regional Development Fund through the Welsh Government, designed to drive blue growth in the Welsh Ocean Renewable Energy (ORE) sector. SEACAM2 and an earlier programme SEACAMS1 generated extensive multidisciplinary data sets through the application of modern data intensive science techniques in Welsh coastal waters. To meet industry requirements for a single point of access to trusted data and researcher requirements to secure large data sets a new data infrastructure IMARDIS (Integrated Marine Data and Information System) has been developed. The poster will give an overview of the development and current status of IMARDIS, demonstrate how it is meeting core user requirements and is already delivering societal benefit beyond its initial brief. The primary aim of this work was to provide industry, researchers and other users with a fit-for-purpose data management and information system that allows storage and re-use of trusted marine data. A stakeholder workshop (https://tinyurl.com/279zaxx2) confirmed the ORE sectors requirement for a single point of access to data and informed the design of the IMARDIS portal (portal.imardis.org) and underlying systems architecture. The IMARDIS architecture is based on series of micro-services, each capable of operating semi-independently accessible through a RESTful JSON based Application Programming Interface layer (API). The services are implemented in Java and deployed within the Amazon Web Services cloud environment. IMARDIS is scalable in terms of storage capacity and throughput. The API allows a range of services to be delivered as required by end-users that include a data discovery and download service for the ORE sector and web publishing of real-time data that can support operational decision making by d-users. The IMARDIS data discovery and download portal now has about 100 registered users. It currently provides access to SEACAMS seabed bathymetry, ADCP (Acoustic Doppler Current Profiler), CTD (Conductivity, Temperature and Pressure) data alongside sub-bottom geotechnical data. Two case studies illustrate wider user uptake. Cemex UK Ops Ltd. operated a pier near Colwyn Bay instrumented with sensors. IMARDIS ingested and published real-time data on tidal height, wind speed and direction at the pier. This enables the operators of a bulk carrier to make better informed decisions for berthing on the pier. Natural Resources Wales uses IMARDIS to ingest, store and publish to the web Met Station data from a coastal location on Anglesey. Met data informs measures to manage dynamic sand dune environments in Wales as part of their statutory responsibilities. In keeping with their wider public service duties they are keen to promote uptake of real-time Met data by the public for general use e.g. kayaking, kite surfing and their coastal activities. In both case studies impact has been achieved through provision of timely access to data and actionable information that reduces risk for the commercial sector and improves the NRW evidence base for decisions on improving environmental status and for both partners accelerates the time to insight. Commercial and wider user uptake suggests IMARDIS is achieving its goal to support organisations driving Blue Growth in Wales.

A new strategic tool to structure Cumulative Impact Assessment (CIA)

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In order to alleviate climate change consequences, UK governments are pioneering offshore energy developments at an ever-increasing pace. The North Sea is a dynamic ecosystem with strong bottom-up/top-down natural and anthropogenic (e.g. fisheries) activities facing rapid climate change impacts. Therefore, to ensure the compatibility of such large-scale developments with nature conservation obligations and fisheries activities, cumulative effects need to be evaluated through cumulative impact assessments (CIA). CIA is currently under the authority of both the Strategic Environmental Assessment (SEA) (Directive 2001/42/EC) and the amended Environmental Impact Assessment (EIA) (Directive 2014/52/EU). By excluding climate change impacts, CIAs lack spatio-temporal appropriate baselines linking ecosystem components (e.g. physical indicators) to population dynamics. This leads to uncertain predictions at populations levels. Although fisheries are part of consultation stages, EIA processes lack a standardised methodology assessing significant levels of fisheries displacement. Fishers have also designated the lack of data and consultations as significant barriers towards a sustainable multi-use of the North Sea. Quantifying socio-economic and ecosystem risks due to potential fisheries displacements, using characteristics such as the type of gears used (e.g. mobile vs fixed), landing values (quantity and quality) and fishing effort, would contribute to enhancing CIAs. Assessing such changes and risks with a user-friendly decision-support tool would contribute to identify and integrate potential mitigation options earlier during licensing processes rather than examining solutions post-consent, as it is the most generally the case today. This study presents an overview of a framework for CIAs using a holistic and pragmatic ecosystem approach, including fisheries activities based on a habitat risk Bayesian network in order to identify pressure pathways, keystone components, ecosystem resilience, population-level changes as well as fisheries socio-economic risks. Finally, we will discuss the usefulness of the two components that make up this framework: a database including potential fisheries data sources and an application of standardised shared tools that will pave the way to more transparent and multi-disciplinary collaborations. This framework will provide a multi-dimensional decision-making toolkit that will also lead towards more strategic SEAs as well as providing the ability to embed the CIAs of projects into regional and multinational schemes.

Non-Destructive Examination of Dynamic Subsea Power Cables

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Subsea power cables are a critical infrastructure sub-system in the generation and distribution of renewable energy. Subsea power cable failures are reported to account for 75-80% of the total cost of offshore wind insurance claims – in comparison, cabling makes up only around 9% of the overall cost of an offshore wind farm [1]. Such failures are costly to repair and may result in a significant loss of revenue due to disruption in power supply; for example, the cost for locating and replacing a section of damaged subsea cable can vary from £0.66 million to £1.71 million [2]. There is a need to develop a method for non-destructive examination (NDE) of dynamic subsea cables to determine the location, cause and type of fault to facilitate repairs and minimise both the associated insurance claims and operation and maintenance costs. The aim of this work, is to test and assess currently available NDE methods, used in other disciplines, for suitability in determining failure modes, mechanisms and locations on a dynamic subsea power cable under test. During this work, three NDE methods were trialled, that had initially been identified as promising, on a cable under test at DMaC. The three techniques were: i) thermography, ii) eddy current testing (ECT), iii) spread spectrum time domain reflectometry (SSTDR). The methods are assessed with regards to what information could be obtained from both a static and oscillating cable, how the results from one technique could potentially inform another technique, and ultimately if any of these techniques had the potential to be combined in the future to create a method NDE for dynamic subsea power cables. The results of the testing are promising, with cable motions and interlayer movements being detected by the three techniques.

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Standardisation of Marine Renewable Energy Technology Testing

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Research Infrastructures including wave tanks, open sea sites, electrical rigs and structural test cells play a key role in supporting innovation in the offshore renewable energy (ORE) industry. Access to and standardisation of testing in these research infrastructures are key to unlocking the energy potential of our oceans. The H2020 MaRINET 2 project, led by the MaREI Centre, UCC, is addressing these issues through network of 57 test infrastructures and 39 partner organisations across Europe. The project combines the provision of free access to technology developers and researchers with a programme of standardisation of testing methodologies for wind, wave, and tidal, electrical and crosscutting technologies. The access programme involves 5 open calls which has a total value of €5million. MaREI has proven a focal point for this success with 5 institutes involved directly in either successful applications or infrastructure provision. Alongside the access provision the research infrastructures have undertaken a benchmarking programme through a series of standardisation tests. The programme utilises generic scale models of floating offshore wind, tidal, wave devices as well as assessing grid integration and moorings analysis standardisation. These coordinated tests, known as round robin testing, will improve the quality and robustness of practises between facilities across Europe. The culmination of this work is the publication of a set of standardised testing procedure for all research infrastructure facilities involved in ORE research and the creation of an E-infrastructure virtually hosting the datasets from all the round robin tests.

Turbulence characterization and comparison from AD2CP measurements from two prospective tidal energy sites in Australia

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Turbulence is known for representing a significant challenge to tidal turbine integrity, increasing fluctuations on mechanical loadings and power coefficients. These fluctuations are proven to be potentially detrimental to the devices and increase maintenance costs substantially. This characteristic of the flow is an important aspect to consider when designing tidal energy converters. The AUSTEn project has put effort into identifying promising tidal energy sites off the coast of Australia. The first candidate site, Banks Strait, is located in Northeast Tasmania with maximum current speeds reaching 2.3m/s observed between March and July 2018. The second site is Clarence Strait, located north of Darwin, Northern Territory, showing current speeds reaching over 2.7m/s and 1.9m/s measured in various locations between May and August 2019. Both sites present strong tidal currents and great potential for energy production. In Banks Strait a Nortek Signature 1000 kHz and a Signature 500kHz sampling at 8Hz with four beams and 4Hz with one beam respectively were deployed. In Clarence Strait both instruments were deployed sampling at 4Hz with 5 beams. The Signature 500kHz was also set to measure wave parameters in Banks Strait, whilst in Clarence Strait wave samples were collected with the Signature 1000kHz. This instrument series includes four 25° slanted beams and a vertical beam, making it possible to measure true vertical velocities and hence provide more accurate estimates of parameters such as total turbulent kinetic energy (TKE) and dissipation rates. These datasets allow for the estimation of current speed, wave height, direction and period and turbulence parameters such as turbulence intensities, TKE, integral scales and dissipation rates. The fact that wave and turbulence measurements were taken simultaneously allows for otherwise scarce detailed observation of wave-turbulence interaction. Turbulence parameters were calculated for both sites with varying instrument configurations and the results were compared. Generally, Banks Strait revealed to have stronger currents and significantly higher turbulent kinetic energy when compared to Clarence Strait. Whilst in Banks Strait total TKE estimates often reached over 0.020m^2/s^2 at mid-depth, in Clarence Strait these values remained below 0.015m^2/s^2 during most of the deployment period. Even though the Howard Channel showed higher current speeds, total TKE still remained below 0.020m^2/s^2 during most of the measurement period. Some level of asymmetry of turbulence parameters between flood and ebb was present in both sites. The sites also differ in terms of wave-current interaction and the need of applying wave-turbulence decomposition techniques prior to the estimation of turbulence parameters. For instance, in Banks Strait a significant energy peak related to the presence of long surface gravity waves was present in the velocity spectra during nearly the full deployment period and represented a consistent characteristic of the site whilst in the Clarence Strait wave peaks were considerably smaller and only observed during isolated events. Our study provides turbine developers with crucial information to allow for the design and deployment of tidal energy devices in Australian sites as well as highlights the importance of establishing guidelines for the characterization of turbulence in tidal energy candidate sites.

Developing E-Learning courses for Offshore Renewable Energy sector

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As the sector is growing, there is an increasing demand to educate and train young professionals pursueing a carreer in the ORE sector. As part of the INTERREG 2SEAS funded ENCORE project, Deftiq and MET-support are developing a series of eight E-learning courses covering topics from testing, financing, policy to certification and environmental impacts. An Educational Advisory Board comprising reputable trainers and international academics ensure high quality of the courses.

INSITE 2: Connectivity of Hard Substrate Assemblages in the North Sea

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A major programme of decommissioning of North Sea energy installations is planned over the next 20 years and beyond. At the same time, more offshore wind developments are expected. This means that there is an urgent need for a robust scientific rationale and a strong evidence base to support environmental management strategies to make the most of potential ecological benefits of decommissioning and minimise the risks. The INSITE 2 programme is addressing this need by tackling critical gaps in scientific understanding of the role these man-made structures play in North Sea ecosystem structure and function. The CHASANS project team includes academic partners from Hull University, National Oceanographic Centre, Natural History Museum and Aberdeen University. Industry, Government and NGO partners include European Marine Energy Centre, Aquatera Ltd, Marine Scotland Science, Joint Nature Conservation Committee and the International Maritime Organisation. The aim of the CHASANS project is to enhance our understanding of the connectivity of populations of marine fauna colonising artificial substrates across the North Sea. Team expertise in biofouling monitoring, oceanographic modelling, and population genetics will be used to generate a multidisciplinary dataset to validate biologically realistic models of larval connectivity between sites in the North Sea. These models will be used to predict how networks of hard substrate in the North Sea function in the dispersal and metapopulation structure of marine epifauna. One of the outputs of the research is a tool which will predict how the distribution of epifauna is affected when specific artificial platforms are removed or added into the network. Such information will help to provide environmental evidence to decision makers regarding which artificial platforms should be maintained and which ones should be removed. It is also important to consider the ecological consequences on the infrastructure network of new types of energy production installations. Early dialogue with industry developers to work together on opportunities for generating the ecological evidence base is welcomed.

PRIMaRE

Application of Quantitative Route Modelling of Navigation Safety Impacts of Offshore Wind Farms

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Offshore Wind Farms (OWFs) have the potential to impose a significant negative impact to the environment and other marine users if not properly managed. One key aspect is the impact on navigational safety and shipping routes; for example, contacting a turbine increasing the risk of collision by altering existing shipping routes. In addition, OWFs can impact radar coverage, change wind and tidal patterns or increase transit time on shipping routes. These impacts all need to be considered in detail as part of a Navigation Risk Assessment (NRAs) before an OWF is constructed, and where necessary, identify mitigation measures to reduce the impacts to acceptable levels. However, predicting these impacts is challenging as navigational accidents are rare-events and caused by numerous interacting factors and therefore there may be significant uncertainty in both the risk level and requirement for mitigation. The Maritime and Coastguard Agency (MCA) are the statutory consultee in the UK as relates to navigational safety, and in conjunction with other organisations, have produced guidance documents for developers in preparation of their NRAs, principally [1]. In order to assess these risks, alongside consultation and risk assessment, the use of quantitative methods to determine hazard likelihood or consequence are encouraged. However, as yet most applications are site specific and utilise proprietary software, hence the need for greater research and transparency into the effectiveness of these methods. Within this paper, the suitability of the IALA's IWRAP Risk Modelling Toolkit for use in offshore renewable NRAs is evaluated. This toolbox allows the analyst to develop vessel traffic routes, input bathymetry and structures, before using mathematical functions to calculate the probability of collisions, allisions and groundings [2]. Through analysis of historical vessel traffic data, several case studies are developed, principally within the Crown Estate's English Channel "South-East" Round 4 bidding region, to simulate how applications could impact hazard likelihoods. Figure 1: Top: Vessel traffic data in English Channel (2017). Bottom: IWRAP Risk Modelling for Area. The results of this analysis demonstrate that IWRAP has numerous advantageous features for modelling of OWFs. Most significantly, it enables a standardised method of "What-If" scenario risk modelling to facilitate discussions with stakeholders and provide quantitative inputs for risk assessments, thereby reducing uncertainty. However, several key challenges are highlighted; firstly, the outputs of this method are difficult to validate without appropriate benchmarks. Secondly, the method is static and may not be suitable for non-linear systems such as with significant day-night variations. Secondly, the methods are sensitive to input variables that are difficult to estimate. Thirdly, methodological assumptions have been challenged by some authors. As such, further research is needed to address these limitations.

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Self-sensory carbon fibre textile-reinforced concrete for offshore floating foundations

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The Carbon Trust [1] has identified that floating offshore wind turbines have great potential, both as a source of renewable energy for the UK and as an export market. However, the floating substructure has been highlighted as the most critical challenge, of which the construction and installation count for over 30% of the total investment costs. Out of the two market-approved materials for floating substructures: concrete and steel, a reinforced concrete floating structure [2,3] have demonstrated potential of up to 20% reduction in CAPEX (capital expenditure) than a fabricated steel equivalent, and modular construction could yield even greater savings because of the volume advantages. In addition, use of a concrete floating foundation allows the majority of supply and logistical activities to be local. Compared with steel, reinforced concrete demonstrates significantly better carbon footprint and cost stability [4]. This project targets the use of carbon-fibre textile reinforced concrete (CTRC) for floating platforms. Existing research [5] has demonstrated that textile reinforced concrete can be used for creating lightweight slender structures, however no research has been published in the context of offshore floating structures. With regard to the self-sensory capabilities of carbon-fibre textile reinforced concrete, although pilot studies [6] have been carried out utilising piezoresistive changes to the electrical resistance of carbon fibre tows, this technology is not able to detect failure locations. We have proposed a novel self-sensing technique that utilises the contact resistance at the connections of the carbon fibre tows in the mesh. By applying different coatings to the dry carbon fibre tows, we can manipulate the contact resistance of the carbon fibre tows and thus optimise their self-sensory capabilities. There are two objectives: 1) to demonstrate experimentally the feasibility of the proposed sensing technology; and 2) to produce initial input data for numerical modelling and validation, which will serve as a basis for future research. Piezoresistive properties of the textile reinforced concrete will be assessed through four point bending test of beam samples. The load-displacement behaviour and the electro-mechanical response will be investigated. The tests will contribute to the development of guidance on the testing method of self-sensory concrete.

Challenges and opportunities for the integration of tidal energy within the electricity system

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Tidal turbines are interfaced to the electrical grid by means of power converters, in a similar way to other renewable energy sources, such as wind turbines and solar panels. In contrast, synchronous generators (driven by fossil fuels, hydro and nuclear) are connected directly to the power grid. Power converters are used because the turbines used for tidal generation do not rotate at constant speed, while the electrical grid frequency needs to be maintained close to 50 Hz. Power converters ensure that the frequency of the currents generated by the tidal turbine is locked to the system frequency under all operating conditions. The power electronic interface effectively 'decouples' the tidal turbines from the electrical grid, and results in profound consequences on power system operation. As we move to more sources of renewable energy, the impact on electricity system resilience and performance must be understood so to avoid costly solutions, such as large amounts of storage, installed capacity and grid reinforcement. At the same time, power converters offer opportunities to contribute to enhancing power system operation: since these devices respond quickly to external control signals, they can provide of various functionalities that allow improvement and optimisation of power system operation. This presentation will be divided in two parts. Initially, the impact of renewable energy sources on power system operation will be described in terms of dispatchability, inertia and power quality. Dispatchability refers to the availability of energy resources to meet electrical demand: with this regards, tidal energy differs from other renewable energy sources because generation levels can be forecasted decades in advance. A growing concern, in particular in the UK, is the decrease in both system inertia and short circuit levels following the retirement of large synchronous plants. Both these parameters quantify the 'stiffness' of the system to disturbances and are critical to guarantee system stability following outages, trips or other transient conditions. While standard renewable energy sources do not provide sufficient inertia and short-circuit currents under fault conditions, at the moment various control strategies are under development to mitigate this concern. Power quality is a term used to describe the characteristic of current and voltage waveforms during steady-state operation. In an ideal power system, voltage and currents are sinusoid at 50 Hz with no visible distortion. Renewable generation introduce additional frequency components in the voltage and current waveforms due to the non-linear behaviour of the power converters. The second part of the talk will describe ongoing research activities aimed at mitigating the concerns highlighted above, and how tidal energy can contribute positively to enhance power system operation and stability through the provision of additional grid services. Measurements taken on an operational tidal turbine suggest that the cyclic and persistence regular periodicity of the tide may have a lower impact on power quality compared to other non-thermal renewable energy sources. Additionally, a case study based on one of the National Grid future energy scenarios will illustrate how tidal energy can contribute positively to proving a reliable and stable energy supply.

The offshore renewable energy (ORE) sector is increasingly relying on the Internet-of-Things (IoT) and artificial intelligence (AI)

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The offshore renewable energy (ORE) sector is increasingly relying on the Internet-of-Things (IoT) and artificial intelligence (AI) to expand capacity, deliver cost savings, and enable the green future that is the goal of governments worldwide. With this comes the requirement to make sure that the systems used to enable these innovations are secure, transparent and trustworthy. This talk looks at areas within ORE that can benefit from secure, transparent and trustworthy AI and IoT devices, and identifies challenges that must be solved so that these approaches can be adopted by industry. Machine learning and optimisation are two aspects of AI that have been widely employed within the ORE sector. Examples include the design and management of offshore wind farms, maximising the output of wave energy devices and the predictive maintenance of ORE installations. Studies have shown that, in addition to complying with increasingly prevalent legislation around the use of AI, maximising transparency of AI tools can increase their usefulness. This can be achieved via explainability, a process by which an AI tool’s construction, design or decision making process is presented to the end user in an intuitive way. This represents a significant current area of AI research, given that many machine learning and optimisation tools are “black boxes”. Illustrating how a decision or prediction has been arrived at by an AI not only provides reassuring insight into how they are working, which it’s known can increase their uptake, but is also important for providing an audit log that can be inspected at a later date. Explainable AI can take various forms – including visualisation-based approaches that illustrate the behaviour of an AI as well as statistical approaches. While there are studies that apply explainable AI within ORE on specific areas, we argue that an holistic approach is needed to realise the full potential of AI within the sector. One of the important drivers behind using AI, and increasing automation, is that ORE installations are by their nature often in remote locations – consider individual wind turbines many miles out to sea. Securing this critical national infrastructure is therefore highly important, and a range of approaches can be taken drawing on cyber-physical security research. Mitigating vulnerabilities through threat analysis of network and devices can protect both the physical infrastructure and the services they will provide. This will be similar but have different challenges to legacy power grids and new smart grids due to the environment and the ORE technology. The ORE sector’s reliance on AI and IoT is set to increase as nations seek to fulfil their commitments to move toward renewable energy sources. To achieve this, trustworthy AI and cyber security principles must be embedded throughout the industry, to ensure they are used in a way that is both safe and transparent.

Tank testing of hinged-raft wave energy converter with representative sea states

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Wave tank testing is widely used to assess the performance of Wave Energy Converters (WECs). Environmental data collected for testing can be obtained by different instruments, such as buoys, ADCP, HF radar etc. The commonly accepted way to re-create the wave condition is to simplify the data collected to obtain the parametric wave spectrum, such as JONSWAP spectrum or Pierson-Moskowitz spectrum and reproduce it in the wave tank for model testing. However, this kind of parametric spectrum is a simplified numerical model which omits much useful information, such as the details of the wave spectrum shape, which includes the directional information of the waves. Using HF radar technology, 8 months' site-specific hourly directional wave spectra are obtained remotely from a demonstration test site WaveHub in Cornwall, UK. A certain data regrouping technique, the K-means clustering method, has been used to assess the sea states measured and to obtain a series of K representative sea states. A 1:25 hinged-raft WEC model has been tested using the representative sea states of different K values in the COAST lab in University of Plymouth. As expected, the representative sea states produce a stable total energy output prediction with different K values. It confirms the possibility of prediction for the accurate total energy output of a certain WEC from only a few representative sea states tested in the wave tank.

The expansion of offshore windfarms: implications for ecosystem services

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Globally, the deployment of offshore wind is expanding rapidly, with offshore wind capacity in UK waters expected to grow four-fold by 2030 (and potentially ten-fold by 2050). An improved understanding of the social and environmental impacts of this sector, and how they compare with those of other energy systems, is therefore necessary to support energy policy and planning decisions. This presentation will outline the ongoing work of the UKERC energy, environment & landscapes project (2020-2023) which will apply ecosystem service and natural capital approaches to understand the environmental implications of changes in the UK offshore wind energy system. The impacts of offshore wind development on ecosystem services will be assessed through a qualitative process of mapping ecological and cultural parameters informed and tested using existing case study data from UK offshore wind farms, particularly those collected as part of statutory monitoring. By reporting outcomes in societal terms, the approach will help facilitate communication with decision makers and will aid in the evaluation of trade-offs such as environmental net gain and the potential for co-location with other economic activities.

Spatio-temporal analysis of offshore wind field characteristics and energy potential in Southern China

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Offshore wind energy resources assessment is the basis of safe, efficient, and reasonable development and utilization. However, the available resources are subject to change in long-term due to changing climate. Hence, it is important to consider a long-term assessment to take into account the changes. For this purpose, a 55-year wind dataset is employed to assess the wind characteristics and energy potential in the South China Sea. The spatial distributions of monthly, seasonal, and annual mean wind speed and wind power density are presented. To perform a meaningful assessment of the energy output from offshore wind resources, a 6MW wind turbine is considered for wind energy extraction. The capacity factor and percentage of zero output of the wind turbine over the total number of hours considered are calculated. The results show that the highest annual wind power can be found in the eastern region of the study area with amplitudes exceeding 1200 W/m^2, and the capacity factor of the wind turbine exceeds 60% in most nearshore areas. The Taiwan Strait could make an important contribution to the regional demand for electricity in coastal China, while Qiongzhou Strait and Beibu Gulf show low energy output.

Offshore Wind Farms & Marine Protected Areas: Scientific Evidence Needs for the successful use of Compensatory Measures

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The UK Government has committed to deploy 40 GW of offshore wind farms by 2030. Similar targets are mirrored in countries in Europe and beyond. At the same time the UK has pledged to protect 30% of its marine environment, again by 2030 as part of the global 30by30 target. In theory these policies should complement each other. Offshore wind farms, along with other renewable energy technologies are being rolled out to help elevate the effects of climate change. Marine Protected Areas are being set up to protect the vital biodiversity that our oceans supply. Both in essence are seeking to protect the essential ecosystem goods and services that we need to maintain our wellbeing. However, the scale and pace of development means these policies risk coming into conflict with each other. Developers are required to avoid and minimise impacts on protected habitats and species as much as possible, following the mitigation hierarchy. However, not all impacts can be reduced to an acceptable level. In these cases, it may be possible to put in place measures to compensate for the damage done to the protected features. The use of compensatory measures in the offshore environment raises many challenging scientific questions. There is a need to define suitable compensatory measures that could work in the marine environment. For example, many habitats are present because of specific hydrological and environmental conditions and cannot easily be recreated elsewhere. We need to be able to assess impacts at a systems level, well beyond the current cause/effect relationships currently considered. Doing so will require considerable development of cumulative effects assessments. If compensatory measures are to be used, then they will need to be monitored to confirm that they are working. Doing so presents many challenges given the multiple variables and pressures many protected features experience. Many of these features occupy vast areas and are present in a network of sites. Understanding the relationships of these features and the network coherence is still developing. Increasingly we must balance competing demands on marine space between co-existence, co-location, or trade-offs. Such decisions cannot be made simply on finances. Informed decision making will increasingly require new methods of valuing both activities and natural environments. Development in fields such as natural capital and wellbeing assessment is critical. With the urgency to deploy renewable energy it is easy to get lost in a fixation on carbon reduction or on financial development. To successfully tackle the climate emergency, it is essential that we remain focused on the greater goal of preserving a functioning environment to ensure our continued wellbeing.

Offshore Wind Farms & Marine Protected Areas: Scientific Evidence Needs for the successful use of Compensatory Measures

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Fixed wind turbines are becoming limited both by available space and by water depth. Floating wind turbines are being developed and deployed to allow access to wind resources in deeper waters. These turbines create new considerations for environmental impact assessors. We examine the potential for environmental effects based on existing literature. There are three main types of floating platform: tensioned-leg platforms, spar buoy and semi-submersible. The platforms are held in place with either tensioned or catenary moorings and secured to the seabed using anchors. The anchoring methods show the use of noisy pilling may continue, but also the possibility of much quieter anchors depending on seabed conditions. Once operational, floating turbines raise considerations with can be grouped into location, the floating platform, and the moorings. The ability to deploy in deeper waters does not necessarily mean issues with seascape and sensitive species are avoided. The platform reopens questions on electromagnetic fields, operational noise and habitat change. The much larger footprint of many floating turbines means spatial planning could be a bigger issue than currently seen in fixed turbines. The potential for seabed scour, and entanglement of marine animals are also considered. Finally, a prioritization of research needs is offered. The use of chemicals is highlighted as a key knowledge gap. Interactions with the fishing industry are a growing issue for offshore wind farms; the larger footprint of floating turbines may increase these tensions. Underwater noise remains a key environmental consideration with underwater piling requiring further investigation.

‘One-fluid’ formulation of fluid-structure interaction with mooring system

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This work presents a new mooring line modelling capability within the ‘one-fluid’ framework [1]. The linear/nonlinear spring forces are implemented and validated, with the application for offshore floating platform.One-fluid [1] uses the Level Set Method (LSM) to model the kinematics of the interface between the phases. Different fields are represented by Heaviside functions. All the simulations are performed on a fixed Eulerian Cartesian grid and are numerically discretized using a grid-based immersed method. Only fully Eulerian equations will be solved for this in-house code, with additional Lagrange multipliers to ensure rigidity and motion constraint. Three validation cases are carried out: 1. Classical spring-mass system in Simple Harmonic Motion (SHM) immersed in water; 2. Vortex-induced vibrations (VIV) introduced by current. 3. Non-linear catenary line modelling with floating platform. Compared with the none spring cases [1], more iterations will required due to the geometric nonlinearity for strong coupling within each timestep.

[1] L. Yang, “One-fluid formulation for fluid–structure interaction with free surface,” Comput. Methods Appl. Mech. Eng., vol. 332, pp. 102–135, Apr. 2018.

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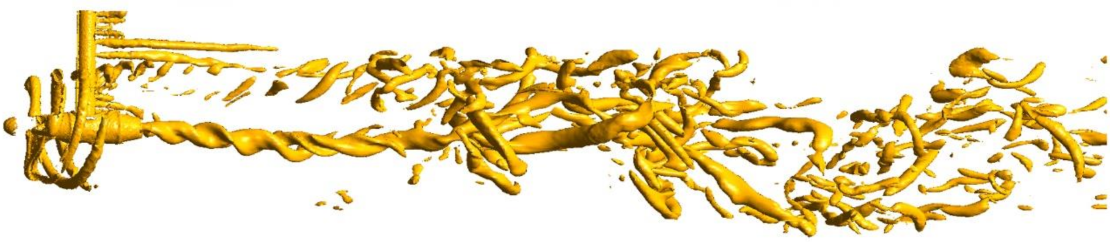

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