H2OCEAN Report Summary

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Final Report Summary - H2OCEAN (Development of a wind-wave power open-sea platform equipped for hydrogen generation with support for multiple users of energy)

Executive Summary:

The sustainable exploitation of ocean resources is seen as a crucial source of renewable energy, and food and water security. In the future, offshore platforms that can combine many functions within the same infrastructure offer significant benefits in terms of economics, optimising spatial planning and minimising the impact on the environment.

H2OCEAN aims to develop an innovative design for an economically and environmentally sustainable multi-use open-sea platform. The challenge is to develop a flexible design which can be varied to address the requirements of the location and local economics. The system will comprise hydrogen generation in open-sea from renewable sources (wave and wind), a facility for fresh water production and multiple uses of the electrical energy produced in open-sea: low power maritime surveillance radar, support for aquaculture, communications, etc. The Consortium brings together 17 partners from 5 European countries, leaders in the fields of renewable energy, offshore engineering, hydrogen generation, energy conversion and process technology, fish farming, maritime transport and other related disciplines.

The basis for the offshore energy harvesting units will be a hybrid (wind + wave) floating modular structure (P80) which is based on the coupling of an existing design of large stable floating wave energy converter with a Vertical Axis Wind Turbine. The energy will be used to directly supply nanomembrane reverse osmosis units at elevated pressures to provide fresh water to electrolytic generators for hydrogen production. The produced hydrogen will be compressed and stored in modular vessels on the service platform for collection by ship. Depending on local economics, options exist to sell the water and hydrogen and transport it to a variety of locations or transmit hydrogen, water or electricity to shore.

The oxygen derived from hydrogen electrolysis can be stored or used directly to boost fish weight gain and prevent algal blooms and BOD contamination caused by high density fish farming. To reduce the risk of handling these sensitive processes in a harsh environment, they have been gathered in a sole service module which will be a stable floating structure, unlike the other energy harvesting units. In addition, the service platform will be equipped with both autonomous remote weather and deep ocean marine monitoring systems including physical, chemical and biological oceanographic measurements. This latter will measure the effect of the platform on the local environment and allow comparison with other nearby ocean stations.

At this stage of investigation the net value of the H2Ocean project is with its three components of the total investment costs (incl. replacement) of 12.2 billion € ,the operational costs of 11.4 billion € and the expected benefits of 2.0 billion € which ends with -21.6 billion € negative. The results depends on the total autonomous production of energy, hydrogen, oxygen, water and last but not least aquaculture products. In a set of alternative scenarios of hydrogen as well as oxygen productions taking place completely not fully offshore may lead to more economic feasible results as currently expected. It is foreseen that with advances in technology efficiency and its associated costs, this could be one day overcome.

Project Context and Objectives:

Seas and oceans constitute two-thirds of our planet and are a source of extensive resources (offshore energy, fisheries and aquaculture, maritime transport, etc.), providing an essential part of our wealth and well-being. In the EU, this blue economy represents 5.4 million jobs and a GVA of just under €500 billion per year. However, in a context of climate change, population growth and increased global trade and competition, human activities are exerting unprecedented huge pressure on the marine environment, threatening marine ecology and sustainable maritime activity.

H2OCEAN (“Development of a wind-wave power open-sea platform equipped for hydrogen generation with support for multiple uses of energy”) is a project selected and funded within the “Ocean of Tomorrow” joint call to design novel multi-use platforms that allow the coupling of ocean renewable energy with aquaculture, offshore transport facilities, environmental monitoring and other relevant activities .
The overall objective of the H2OCEAN project is to develop a proof-of-concept design that fully integrates existing technology in a novel manner to a multi-component and multi-purpose platform to make the most of far offshore ocean resources in a sustainable way. The main challenge is to achieve a flexible design which can address, worldwide, the requirements of different locations and local economics and assess the impact at environmental and economic levels.
To this purpose, an existing design of large stable floating wave energy converter (WEC) is used as the basis for the energy harvesting units. An hybrid modular structure with a high flow water power take-off system has been designed, by integrating into the WEC a novel vertical axis wind turbine (VAWT) and modelling the coupling effects (aerodynamic/hydrodynamic loading, dynamic response and structural dynamics). The energy output will be used both in the form of electricity and as hydraulic power. A unique feature of the H2OCEAN concept is the conversion of offshore energy into hydrogen, to be stored and used as a green energy carrier (refuelling at the platform or shipped to shore). For the reverse osmosis units producing fresh water (RO), new low fouling high-pressure membranes have been investigated. A fully integrated multi-trophic aquaculture system has been designed as well, taking into account the constraints of the trophic chain (fish, seaweeds, sea urchins and bivalve molluscs) and the adaptation to various cold and warm water locations; and include a novel type of floating digester to mitigate organic pollution caused by the system (capable to recover energy from the residual marine biomass). Finally, a web-based geographic information tool has been developed, incorporating data for selected locations influencing the establishment and operation of an H2OCEAN platform (potential for energy harvesting, aquaculture farming, logistics and shipping operations, environmental impact, economic assessment, etc.).
The scientific/technical (S/T) objectives of H2OCEAN were defined in accordance to the integration rationale and the sub-concepts for activities in the platform:

1. Develop technical integration of different (wind and wave) renewable power generation systems fulfilling the power demands of on-board applications and producing energy to be sent to shore in various forms.

2. Develop specifications for mechanical designs of VAWT Darrieus wind turbines suitable for deep-sea deployment and study the performance of these units for a range of known wind and sea states whilst mounted on the defined wave platform.

3. Develop use of shock tolerant water based transmission system for the new hybrid converter to feed the other energy demanding activities in the platform

4. Develop a dependable marinised hydrogen generator, capable of producing hydrogen under variable electrical feed in harsh climate conditions (motion insensitive).

5. Optimize conversion of the power harvested into hydrogen, for a more flexible and cheaper transmission of offshore generated power.

6. Develop an automated nanomembrane based reverse osmosis system to provide clean water to the hydrogen generators. The use of electrical power and chemical products will be minimized by using automated prefiltration and membranes with low-fouling properties.

7. To specify and design in conjunction with the designers of the energy platform a self-contained system for the combined culture of finfish seaweeds and sea urchins and bivalve molluscs using the effluent from the fish cages and products and by-products e.g. oxygen from the hydrogen generation systems as the primary inputs to the aquaculture system.

8. To specify and design the necessary infrastructure facilities (e.g. feed storage automatic feeding harvesting packing

processing waste management security) needed for the efficient operation and management of the aquaculture unit.

9. To develop an operational specification for the above combined system integrated with the design.

10. Design of modular storage methodologies for safe platform storage, operations and hydrogen transportation in non specialized ships. Evaluation of large (1000+ tonne) modular ocean towable bladders for low cost fresh water transport.

11. Evaluate the possibility and adaptations needed for using hydrogen as fuel for ships with gas turbines.

12. Develop a software tool to evaluate different scenarios for optimal location of the platform, with a multidisciplinary marine spatial planning method to allow impact evaluation in terms of marine environment, socioeconomics, security, surveillance and other maritime affairs.

13. Assess maritime legal, legislation, safety and socioeconomics relevant to the design of such process and power generation plant offshore and the deployment of large scale wave farms in international waters.

14. Develop multi-sectoral service connection layout structure of modular floating “wind+wave farm” to permit service functions e.g. delivery of fish food harvesting hydrogen loading and security hazards management.

15. Develop/identify designs for deep water ruggedized mooring, cable and flexible pipeline connections for water, electricity and hydrogen transmission suitable for the operating environment.

16. Develop hydrodynamic models of diffusion/distribution to optimize location of oxygen spargers and assess dispersion of platform by-products (fish farming and hydrogen generation). Also to execute a life cycle and alternative use analysis

17. Develop hydrodynamic models to assess effect of energy consumer activities structures on the power generation performance of the platforms and devise power maximization scenarios.

Project Results:
During the H2OCEAN project results were achieved for the first period report, some of these results were pursued further during the second report.
Progress and results achieved during M01-M18 are summarised here below:

1. The stakeholder requirements for an H2OCEAN system have been identified and analysed, including design constraints and system boundaries and interfaces. Based on this, three sites have been selected to test and develop the H2OCEAN design :
• A North Atlantic Ocean site, with energetic wave resource,
• A North Sea site, with excellent wind resource and different aquaculture solution,
• A Mediterranean Sea site, with relatively benign wind and wave resource, and different aquaculture combination.
Data (wave, wind, bathymetry, sea temperature, salinity, etc.) have been gathered for each site.

2. An outline design specification for the H2OCEAN concept has been produced in the form of a Technical dimension paper, where key production parameters have been defined (electrical output, wind rose for the sites, fresh water, hydrogen and oxygen, aquaculture farm) and a glossary of terms has been adopted (to fully comprehend the meaning and implications of all distributed documents).
The list in Table 1 sets a starting point for these terms (alphabetical order).
This technical dimension paper gather all the relevant information for each site (see Table2 and Figure3).

3. A pilot version of the software tool for the evaluation of H2OCEAN optimal locations has been presented during the Plenary Meeting held in Barcelona (2013), see Figure 4.
Relevant databases are being identified and data selected and incorporated to the software tool in a continuously open process; and the operating scenarios for the selected sites are being created.

The database is split into a number of fields relating to the type of data and information covered. The fields each have their own database sheet and are separated into the following categories:

• Environmental. This group includes environmental variables such as pollution, protected areas, species distribution, habitats and biotopes.
• Geophysical. This group includes geophysical variables such as sea bed geophysics and bathymetry.
• Ports and Shipping. This group includes ports and shipping related variables such as port information and ship routes
• Metocean. This group includes metocean variables such as wind, wave, current, water temperature and salinity.
• Legal. This group includes legal variables such as legal boundaries and protected zones.
• Other. This group includes miscellaneous information relevant for the addressed project development such as social indicators, sea user information, etc.

The database has been structured as a multi-filter spreadsheet. The first filter level is defined by the Project Sites; allowing the user to search for data relevant to a particular site. Other filters include variables, spatial extent, temporal extent and data format type. A description of the data is also included within the database. In addition, the database provides one or several web links directing the user towards web based databases, in which raw data related to the searched variables is contained.
In order to facilitate the search, filters have been introduced for each entry of the spreadsheet enabling the user to customize their selection accordingly to each data search.

4. An aerodynamic modeling of a floating VAWT, considering unsteady wind profiles and platform motions has been developed (allowing aerodynamic, hydrostatic, hydrodynamic, gyroscopic, inertia and mooring loads). Individual modules have been validated with data where possible. Also, based on the P80 WEC, an integrated WEC+VAWT hydrodynamic model has been build and a number of design sensitivities have been conducted for a range of VAWT parameters (size, shape and number of blades, operational rotational speeds, etc.).
Initially, only the platform position and orientation were considered for the computation of aerodynamic loads as reported at the Roskilde plenary meeting (January 2013). This has been later extended to include platform motions. The VAWT model has been integrated in a Matlab multi-body dynamics code to allow the modelling of aerodynamic, hydrostatic, hydrodynamic, gyroscopic, inertia, mooring loads).The main assumption with the current model is that the configuration is rigid and any aero-elastic or hydro-elastic effects are ignored. Individual modules are validated using existing experimental data where possible, though there is no data available to validate the full dynamics of a floating VAWT.
Figure 5 compares the predicted and measured power produced by a fixed 100KW H-rotor turbine with a steady uniform wind profile indicating good agreement.
Validation of the hydrodynamic model was performed using the GVA 4000 semi-submersible investigated by Clauss et al. (2002) as a case study. Simulations in a random sea state composed of 1000 harmonic wave components and length three hours were carried out and the resulting heave and pitch Response Amplitude Operators (RAOs) is shown Figure 6, again showing good agreement between predicted and measured data.
The P80 has an 80m width, capable of supporting a MW rated VAWT, as illustrated in Figure 7, which shows an initial concept model. A preliminary P80 design was supplied to CRAN on 16/04/13, including the external shape and initial mass distribution estimate. This has allowed CRAN to build a hydrodynamic model of the P80 shown in Figure 8, and a number of design sensitivities have been conducted for a range of VAWT design parameters such as size, shape, number of blades, operating rotational speeds.
Work on this line continued to optimise the VAWT shape and WEC parameters assuming that each WEC-VAWT unit will have a combined rated power of about 6.3MW (i.e. 1.6MW WEC and 5.0MW VAWT). With assumed efficiencies for the PTO system

each unit should contribute about 5MW electrical power when the WEC and VAWT are operating at their respective rated conditions. These designs were completed by the end of September 2013 (Milestone 3).

5. Electrolysis technologies have been evaluated with the requirements of an H2OCEAN design (alkaline, proton exchange membrane, high-temperature ceramic); and a low pressure alkaline electrolyser has been selected. Also, a preliminary design of the offshore desalination system has been performed (See Figure 9).
Several electrolysis technologies (Low-temperature and High-temperature alkaline electrolysis PEM electrolysis and High-temperature ceramic electrolysis) have been evaluated for the expected application to generate hydrogen with a purity of > 99.97% (grade “D” as used in the automotive industry). Evaluation has concentrated on those technologies that are expected to be commercially available for the expected application at the level of power output of the wave/wind farm provided by WP4. These technologies are PEM Low pressure and High pressure alkaline electrolysis. Based on the results of Task 5.2 low pressure alkaline electrolysers have been selected as they are already commercially available at the required size and are suited to variable production. Its integration with the rest of the components is being developed. Experiments are on-going to further clarify the water requirements for electrolysis and reveal the sensitivity to specific ions in the water and not only to the overall conductivity of the water.
Based on the preliminary requirements for the Desalination system from task 5.2 (acceptable limits of concentration of salts, pH, and temperature for the inlet water for the electrolysers, the water quality and flow required for human use and other secondary uses), a preliminary design of the Desalination system has been developed. Based on this design the expected power consumption and the characteristics of the water produced have been obtained for the selected locations in different working conditions.
The surface modification of RO-membranes is being carried out to improve their fouling resistivity. Methods were established to test these fouling properties and are being characterized for both modified and unmodified RO-membranes, including characterisation of material/surface properties of these membranes.
Additionally, work has been carried out as well to improve the performance in terms of energy and operating costs, using Pressure Retarded Osmosis nanomembranes for recovery of osmotic energy from the brines produced by the Desalination systems (see Figure 10). This reuse of brines also reduces the salinity of the effluent which in turn reduces its environmental impact.

6. Specific combination of the species (fish, shellfish and seaweeds) to be cultured at each site have been defined (Table 3); and full production programmes have been developed (stocking levels, feed and growth rates, harvesting schedules, containment requirements, etc.). Transportation requirements for the aquaculture system have been analysed and determined, including a proposal of vessels (relation and characteristics).
The species of fish to be cultured at each site have been decided, based on the literature covering areas such as the temperature tolerance, growth rate, waste production, has been critical in determining various aspects of the production programmes and waste load models for each of the selected species at each site, water temperature optima/limits for the species of greatest market value in the EU, and upon national and EU regulations governing the introduction of non-native species. This first involved finding and collating sea surface temperature for each area, which proved to be rather more difficult than expected as the data that is readily available tends to be rather coarse.
The overall production facilities available to the aquaculture operators have been described, an in-depth analysis on the spices to be farmed (feeding, transportation, max. density, etc.) and on the facilities required for that has also been performed. See Figures 11, 12 and 13.

7. A broad environmental impact scoping study for the three sites has been produced (European statutory directives, baseline conditions/impacts, potential impact factors, broad identification of stakeholders, recommendations for the environmental impact assessment, etc.) following the typical flowchart (Figure 14).
The scoping process encourages mitigation and enhancement measures to be identified at an early stage and allows them to be incorporated into the project design, guaranteeing that the final proposed solution is as environmentally sound as possible.

8. A transport mesoscale and a CFD microscale models to assess dispersion effects (wind, tide, salinity diffusion) have been elaborated, and calculations have been performed for one site.
This model describes the path that an elevated saline plume will spread from a fixed point and the dispersal of the saline plume in the ocean with the action of wind and tide. This model was originally designed to model salinity dispersal from a desalination plant. The model is general purpose and is designed to model any similar salinity dispersal from a single point source.
The application (Salinity.jar) is written in JAVA version 1.7 utilising minimal resources in terms of CPU time and operating system capability. It is designed to work across platforms and to interface with other programs using input and control data read from a xml file format data file or an interface API It provides two output files one a .csv file designed to interface with EXCEL or ParaView and an xml plot file designed to operate with an appropriate 3D package.
Transport mesoscale modelling for one site has been elaborated using stochastic differential equations that enable to consider the randomised effects of wind and tide in oceanic mixing. Two approaches have been taken:
• A Lagrangian random walk for the movement of salinity away from the outflow,
• A Wiener process for the dissolution of the outflow into the ocean through tide and wind mixing.

A Mesoscale mathematical analysis model for 1 location and a Macroscale CFD model for 1 location have been developed. Calculations have been performed considering:
• Maple software used for Lagrangian analysis of the flowfield,
• Lyapunov Exponents are computing, to enable the system to be characterised.

For the Mesoscale model (stochastic differential equations are used to enable the randomised effects of wind and tide in oceanic mixing to be considered) a model of salinity diffusion at the outflow has been developed. The tracking of the behaviour of the salinity with distance from the outflow is demonstrable with sporadic rises and falls in salinity. The format of the data (in csv or xml) is such that it can be plotted on a Virtual GEOmap (i.e. virtual Ocean).

To perform the final calculations, it‘s necessary to define more exactly:
• Provisional data (as environmental data: wind/wave, current, tides, salinities and others),
• Number of desalination units, fish cages, wind/waves devices.

Estimates of fish wastes need refining for the three proposed sites.

Through this approach a model of salinity diffusion at the outflow has been developed:
• Model at mesoscale of 1 site: MS20
• CFD model at microscale of 1 site: MS21

The study produced two models to estimate the dispersion of the brine in the sea. It was shown that the plume disperses extremely fast, within few meters from the brine outlet, for all cases analysed. It can be concluded that as long as the outlet is at least 4 meters from the fish farm, then the fish won’t be affected.
Different scenarios where studied. A scenario is shown in Figure X. On the surface blue colour represents the background salinity of 36 ppt and red all salinity values greater than 40 ppt. Under the seawater surface the isovolumes represent the salinity values of 37, 38, 39 and 40 ppt, from the larger to smaller volume respectively. It can be seen that the salinity level drops to 40 ppt in a distance of less than 4m from the release location. From Figure 15 is evident that the wind has a greater effect on the direction of the plum than the sea current.

9. The cost structure for equipment and functional units has been completed, and an adaptable tool to collect data on every cost (investment, maintenance, insurance) has been prepared.

10. The approach “from cradle to grave”, the operative framework and the collaborative tool, to be the basis of the LCA

analysis, have been defined.

11. Requirements specification from technology developers has been collected and a functional analysis of the H2OCEAN design has been completed. A preliminary design of platform units (process modules), Process Flow Diagrams, and a Block Flow Diagram have been developed. A Work Center Summary and a Functional Layout Diagram have been produced; and an initial proposal of layout and sea deployment of an H2OCEAN platform has been prepared (Figure 16).

12. The H2OCEAN concept and progress have been presented to different audiences at national and international events; and information is available at website (www.h2ocean-project.eu). Close collaboration has been established with MERMAID and TROPOS. A joint workshop has been organized (Brussels 23/04/13) and coordination has been agreed in environmental impact socio-economic analysis and life cycle assessment.

Progress and results achieved during M18-M36 are detailed bellow:

1. The societal and ethical issues of exploitation have been documented in a report, which stresses that the ethical dimensions of sustainable development of a multi-use platform should be made under the principles and criteria of the sustainable use of natural renewable resources and on their contribution to human and ecosystem well-being, and always with the involvement of the local communities; even though there is no explicit framework for dealing with ethical concerns of this kind.

2. A Technical Dimension Paper – a collation of all technical information for the project - not included in the DoW, has been reviewed according to the new advances and information of the last moths, to ensure that every partner was using the same terminology, parameters and inputs.

3. A Software tool for assessment of location has been uploaded to the Intranet. The software main output it the optimal location selection of multi-use offshore platforms, based on Geographic Information System (GIS) that integrates requisite data for optimal location selection, such as tides, currents, water temperature, salinity, bathymetry, wind resource, etc. (see Figure 17 and Figure 18). The software has been developed in an iterative approach to allow the progress in other activities in the project.

4. A reliable validated prediction methodology for assessing potential VAWT rotor designs has been reported, describing the assessment of different wind turbine configurations, and detailing the optimisation of the turbine characteristics.
Through initial scoping discussions it was agreed that the target maximum electrical power delivered to the central platform i.e. at optimum operating conditions for the WEC and VAWT units would be 500MW. A number of units comprising a WEC with one or more VAWTs mounted on top of the WEC support platform would be required to deliver this target power. The Atlantic site was selected as the primary design location and it was suggested that 100 5MW integrated WEC-VAWT units would be required as a baseline. It was also assumed that losses associated with the PTO system are 20% (i.e. in converting mechanical to electrical power) which will be refined when more details of the PTO design become available.
The WEC for the Atlantic site is based on the FPP's existing P80 design with a rated mechanical power of 1.6MW. For the two other sites considered the relative sizes of the WEC and VAWT might change and/or the number of units in order to meet the power target considering the local wind and wave resources.
Geometry and mass data for the P80 platform was supplied to Cranfield and used to generate a hydrodynamics model for analysis using a numerical multi-body dynamics model developed for the H2OCEAN project. In order to derive a better understanding of the influence of different VAWT sizes, geometry and operating conditions on platform motions, a sensitivity analysis was performed using a baseline 2-bladed VAWT rotor shape with a rated power of ~5MW (Figure 19). Once the sensitivity study was concluded, the motion response of the baseline hybrid device was also investigated for the three sites for 'extreme' operating conditions that represented adverse environmental conditions, but not ultimate limit states. Overall, the addition of the VAWT on the P80 platform had very little effect on the heave and roll motion, with a more moderate effect in pitch, under this extreme condition. Furthermore, the sensitivity study indicated that VAWT shape and operational

parameters had a very limited influence on platform motion, effectively allowing the design of the VAWT to be considered in isolation of the platform. Consequently, this report describes the optimisation of the VAWT shape on a stationary platform located at the Atlantic site. Subsequently, scale factors were determined to re-size the Atlantic VAWT for the North Sea and Mediterranean sites such that the AEY was similar for each site. This gave a North Sea turbine that was 21% smaller (in terms of swept area) than the Atlantic turbine and a Mediterranean turbine that was 7% larger. However, due to poorer wind and wave resources in the Mediterranean a greater number of hybrid WEC-VAWT units are required to achieve the generation target in the Mediterranean.

5. Within D4.2 "Mechanical design of VAWT and Power take off System", the proposed elastomeric power take off system (EPTO) has been analysed and developed, resulting in the VAWT mechanical torque power output. In the same document the estimated masses and relative approximated costs of the main elements of the VAWT rotor, the braking system and the bearing system are presented

The design of the P80 WEC by FPP needs to be modified in order to accommodate the 5 MWe VAWT and the relative PTO.

In the present concept, it is proposed to integrate the PTO box, where the PTO system will be housed, in the upper deck of the P80, and to have a transition piece connecting the tower of the VAWT to the PTO box. Adopting this approach, all the forces and moments (unless for the torque) acting on the VAWT will be transmitted to the transition piece, the PTO box and eventually to the structure of the P80. The torque generated by the VAWT will be transmitted through a shaft to the PTO system, and will eventually be counteracted by the WEC platform.

The forces and moments coming from the VAWT and transmitted to the WEC and the PTO are of two types: inertial and aerodynamics.

The aerodynamic forces and moments generated for the ultimate limit state loads have been estimated and presented, together with the inertial forces. The main observation is that while the heave forces, and the pitch and roll moments, are well counteracted by the hydrostatic stiffness of the WEC P80 platform and do not substantially impact on the operability performance of the wave energy device (as demonstrated in), the surge and sway forces, as well as the yaw moment will be counteracted by the mooring system. The current WEC P80 mooring system is a turret mooring system, allowing the platform to freely rotate around the vertical axis and therefore self-align against the main wave front direction. The VAWT is generating a substantial oscillating yaw moment (moment around the vertical axis) (Figure 20), which needs to be counteracted by the mooring system. Therefore a further recommendation is that the P80 WEC mooring system needs to be modified.

As regard the configuration of the PTO system, several solutions have been investigated. For concept 1 and 2, the load will be transmitted in a same way as in the previous concept, but rather than using a poor efficiency system to transfer the energy from the rotor shaft of the turbine to a generator, a gearbox will be required. The frame support for the integration to the P80 will be similar and will require additional housing. The main issue of these two concepts is the introduction of either a generator vertically (first concept- Figure 20) or a 90º angle gearbox (second concept –Figure 21)), which will require a high level of maintenance and replacement over the targeted lifetime of the VAWT (25 years).

The last concept is based on the solution adopted by a current very large VAWT concept by Vertax Wind Ltd. (UK), and it appears to be the best solution, as it would require few modifications of the P80 structure for incorporation of the VAWT on the WEC. Even if a wind tunnel test of the VertAx wind turbine has been performed, more simulations and physical testing will be required to validate the concept. This solution needs to be further investigated.

6. A set of recommendations for installation requirements on platform have been presented, resulting in the proposal of three potential solutions to integrate the PTO in the upper deck of the P80 WEC platform (PTO housing box).

For the present project, due to the lack of data for the concept 3, concept 2 (90º gearbox) will be adopted in the model to assess the environmental impact of the VAWT.

7. Using the in-house software FloVAWT (Cranfield University) the aerodynamic loads acting on the platform and the global response of the coupled WEC+VAWT system, for a selected set of load cases have been evaluated.

The developed wind-wave power open-sea platform is intended to be deployed at deep water offshore sites; this will inevitably have a high energy density due to exposure to extreme metocean conditions. Environmental loading on the device has a significant impact on the design. The environmental loadings to be considered will include maximum wave, wind and current design loads adhering to classification standards from bodies such as DNV.

IT Power has identified suitable combinations of wind, wave and current metocean conditions according to relevant DNV standards. These identified load cases are not only used in the structural design of the platform but are also considered in planning maintenance strategies, as environmental loading will reduce working time on the platform due to the exceedance of maximum platform accelerations.

Using the in-house software FloVAWT developed in Cranfield University to study the coupled model of dynamics of floating VAWT (see D4.1) Cranfield University has evaluated the aerodynamic loads acting on the platform and the global response of the coupled WEC+VAWT system for a selected set of load cases.

Considering the loads acting on the coupled WEC-VAWT system, IT Power has outlined steps to be taken to evaluate the operational safety and efficiency of the coupled WEC-VAWT system.

A description of the modular approach to the development of a coupled model of dynamics for VAWTs will be presented called FloVAWT. At this stage of the development the whole structure is considered to be rigid (i.e. omitting an elastic deformations module) and no control system is currently included. Due to a lack of experimental data on offshore floating VAWTs the model has been validated at the module level using existing experimental data.

The current semi-coupled model is represented in Figure 22. The first step is an initialisation of the aerodynamic module, in which an initial induced wind velocity field is calculated using the BEM DMST approach for the turbine in the upright position. These induced velocities are not updated during the simulation, since it is assumed that the platform oscillations are relatively small. Consequently for each time step, the aerodynamic loads are calculated and added to the external forces used by the hydrodynamic module. This module solves the 6 DOF equations of motion (using the MATLAB Simulink ode4 Runge-Kutta solver, with a fixed step size of 0.1 s), also taking into account the following forces:

• Hydrostatic loads: calculated considering the changes of displaced volume due to heave, roll and pitch displacements, with constant hydrostatic coefficients calculated for the upright position (small angle approximation, valid up to ±10-15 deg). Change of displaced volume due to the waves is not considered,
• 1st order wave loads, including diffraction and Froude-Krylov forces,
• 2nd order wave loads,
• radiation loads,
• hydrodynamic viscous forces, estimated with a critical damping ratio of 5%,
• current forces (not used in the present simulations),
• mooring loads, and
• Gyroscopic loads.

As output, displacements, velocities and accelerations in the 6 DOF are calculated. The displacements and velocities are then passed to the aerodynamic module and used to update the relative position and velocity of the structure with respect to the wind velocity so that aerodynamic loads can be updated for the current time-step and passed back to the hydrodynamic module, closing the process loop.

8. A Hazard and Operability review for the process systems, and in particular for the 12 units/process facilities including utilities and interconnections has been written, with the objective of identifying, recognizing and recording causes and consequences of deviations from the standard process expected behaviour, from the point of view of both Safety and Plant Operability. In parallel, general principles and results for the safety assessment, have been produced to ensure safe operation of the energy system during the offshore platform operations, mainly based on generally accepted procedures for HAZOP (Figure 23), codes and standards applicable to offshore operations in combination with existing codes and standards for hydrogen production, storage and transport.

The analysis of the 12 nodes identified is resulted overall (across the two workshops in 2013 and 2014) in 66 recommendations for Project improvement, agreed by the HAZOP Team. Out of these, 36 Actions were identified during the October '13 main workshop and other 30 Actions were added during the May '14 update. Also, during May Workshop some of the previously identified actions had been already closed by that time, whilst dome others were superseded by the

advancements in Design. Overall, out of the 66 actions, 9 of them were already closed and 4 other actions were superseded. The remaining 53 Actions have been addressed afterwards and the overall updated status of recommendations is available in the Updated Risk Register reported in Appendix C.
In Figure 24, a short statistic on the assigned actions and of their current status is given.

9. Lab tests showed that the anaerobic digestion of seaweeds and dead fish is feasible also in saline medium. Designing a FAD was not initially requested. As a result of the basic research conducted on anaerobic digestion of marine waste biomass resulting from the multithrophic chain and from marine traffic too, a novel type of digester, suitable for offshore operation, has been identified as potentially patentable. A patent expert is studying the prior art and exploitation possibilities.
The overall aspect of the FAD is that of a two-hulled barge at least 12 m wide and 39 m long. The containers holding the battery bank and the CHP generator can be mounted on one of the ends the torch will be placed on the opposite side by safety reasons. Figure 25.shows the general FAD layout.

10. Report on security risks, hardware/software requirements and procedures for risk mitigation has been finished, as well as the Software tool to manage security risks inflammable gases carrying (both on time) (See Figure 26, 27 and 28). The Conceptual Maintenance Manual has been completed in draft format and is currently under review by the project coordinator and other partners.

11. A complete Environmental Impact Assessment (EIA) has been produced along with a Matrix of Impacts (see Table 4), with the goal of assessing the feasibility of installing a 500MW array of combined technology platforms at various sites in Europe, as well as Environmental Recommendations for the Installation of Platforms, Discharge Pipelines and Moorings. Regarding the impacts of the proposed multi-trophic integrated aquaculture system, these have been analysed and reported, concluding that the proposed mitigating devices, based on the biological features of algae and bivalves, appears to be insufficient to a quantitative extraction, due to the intense currents spreading nutrients and particles on very large ocean areas.
The highest risk potential for the environment is clearly from the Construction and operation phases. The most significant impacts stem from the towing of the devices to and from the site (tug moorings, traffic, fuel and energy use). Oil spill is a significant impact and can only be assessed as high risk regardless of the mitigation plans put in place. Oil spill would be of prime concern in the construction and decommissioning phase since this is the point where oil will be transferred into the devices which require hydraulic or lubricating oils. During operation the risk is minimised since the failure will be localised. Cable laying and removal will require trenching and significant machinery and is therefore the other high risk.
The most significant factor to consider is the operational impact upon Fauna.

12. The findings of the hydrodynamic modelling work of the dispersion of the high salinity brine (a product of the desalination unit) has been described and presented in D9.2. The release of both dissolved and particulate matters by the fish farm included in the offshore H2OCEAN installation has been discussed and simulated with the chosen modeling software AquaModel. Main conclusion is that brines released by the Desalination Unit are not appearing as a major concern.
For the final case, the sea depth was increased to approximately 3 times (200m) in comparison to Case 1. Due to the low penetration rate of the salinity plume, the results were identical between the two cases, as demonstrated in Figure 29.

13. Design definition including interfaces and functional requirements has been developed whose main result is the specific requirements for Portuguese offshore site focusing on functional requirements of units and their reciprocal interactions. Subsequently a systems engineering process were adopted in order to consider the interaction and varying requirements of these technologies individually and as part of the H2Ocean system. This approach is necessary as many of the technologies involved have conflicting requirements e.g. energetic seas provide favourable locations for wave energy converters whereas this may have implications on the performance of wind energy technologies.

14. Despite of a noticeable delay, a Plan for dissemination has been finally finished, which covers the actions planned from M01 to M12 of H2Ocean. The Draft exploitation plan was submitted and discussed during the meeting held in July 2014 in

Genova, Italy. A Report on the Communication and Dissemination Activities has been likewise produced during this period.
Potential Impact:

During the development of the project, the ethical issues concerning fish farm activities and wind farm activities carried out on the platform have been analysed, as well as the platform interaction with transportation. It has also been considered the impacts concerning the different stages of the exploitation. Some of these have already been highlighted in Deliverable 9.1 Environmental Impact Scoping Study .

The three proposed sites have been preliminarily selected to avoid designated areas (protected areas or areas of local interest); the offshore location means that the H2Ocean array is unlikely to affect any coastal areas of conservation importance. Designations will need to be taken into consideration to ensure that no conflicts of interests will be encountered during the exploitation, and that species or habitats for which designations exist are not significantly impacted (SAC, SPA, Marine Protected Areas, etc.), especially during O&M activities closer to shore.

Regarding the environment, an assessment of the impacts to any species on the list of threatened and declining species and habitats will need to be completed if the chosen site is within a region where this applies, and any cumulative impacts on conservation areas have to be considered.

A multi-use platform could be seen as socially beneficial, aquaculture in EU waters is a prominent industry, with an estimated turnover of roughly EUR 2.9 billion , generating approximately 65,000 jobs. But there are also concerns regarding potential negatives aspects of it. The development of a thorough stakeholder engagement plan is necessary to ensure that any potential conflicts are addressed at an early stage. It is also important to consider security measures and deterrents that might be required on the aquaculture cages as the fish stock could be targeted by both humans and marine mammals, and on the wind farm platforms that could be used by birds as resting sites and bird collisions could occur.

Some of the impacts that could concern a multioffshore platform are:

Access and benefit of public property: Some countries do have regulations and laws regarding marine property and use, others don't. In 1982, with the UN Convention on the Law of the Sea, the 200 nautical mile exclusive economic zone (EEZ) was formally adopted . In the exclusive economic zone, the coastal State has sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources - both living or non-living -, of the waters superjacent to the seabed and of the seabed and its subsoil, and with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents and winds. This has to be considered when planning the location of the exploitation, because the local community will have to be involved in all decisions regarding the private use of a public resource (offshore water column), and thus some kind of fare agreement with the locals will have to be achieved.

Another issue that has to be taken into account is that in mariculture different parties should enjoy the right of use of the resources within socially acceptable norms, where one party does not impose harmful social, economic or environmental impacts to other parties . The private use that a wind farm makes of the ocean resources (public resources), has to benefit all affected parties, and thus the local government has to be properly compensated for any private use of or harm to its public resources .

Communication/engagement local communities: An ethical approach encourages participation, and thus ethical solutions cannot be presented from above, but they need to be evaluated by those that are affected in an open and free discussion.

Public awareness, people's participation and negotiation are central to equity issues and should be encouraged. The wide availability of quality information and effective dialogue are parts of the solution . All aquiculture and wind farm projects will be improved by the involvement of local communities in the early planning stages and by consulting with them on the social and cultural aspects of the fishery; this may avoid any collision with cultural sustainability and local interests.

Tourism and urban development: Aquaculture infrastructures may have interactions with other coastal resources such as tourism and urban development interests. In an offshore aquaculture platform such as the H2OCEAN platform, set in waters from the EEZ, most affections (if not all) are going to be solved and thus there will not be a conflict of interests. The solution is mainly because the platform is out of reach of coastal view.

As stated in deliverable 9.1 Environmental impact scoping study3 the distance of the H2Ocean array from shore means that tourism is unlikely to be affected neither positively nor negatively and so will not need to feature predominantly in the EIA.

Regarding recreational activities as stated in deliverable 9.1 the hybrid unit is designed to harvest wind and wave energy but

the proposed distance of the H2Ocean array from the coast makes it unlikely that its presence will impact recreational activities such as sailing and surfing including on the Portuguese coast where offshore water sports are popular.
It will however be imperative to consult local recreational groups such as sailing clubs and diving schools to discuss the implementation of an exclusion zone.
An ethical solution regarding the distance at which a wind farm should be located to a coastal region dependant on tourism revenue has to be reached. Even though there is a negative visual impact when placed at a close distance, there is also a net benefit of a clean and renewable source of energy for the region. The H2OCEAN wind farm is located at a distance to which no visual impact is going to take place .
Impacts of H2OCEAN platform on transportation routes in European: Caution should be taken to prevent collision of marine vessels travelling the coastal waters. Some solutions have been proposed by simply adding brightly coloured or reflective material to the turbines to increase their visibility during the day, as well as lights for hours between dusk and dawn should be mandatory for all offshore turbines.
As stated in deliverable 9.1 where the relation of the platform with navigation shipping is covered (ferries commercial shipping ports and harbours and military activity) the implementation and management of an exclusion zone around the H2Ocean array is likely to have an impact on shipping and navigation. A navigational risk assessment will need to be completed and appropriate navigation aids deployed around the site. The requirements should be informed via consultation with the relevant international and national shipping organisations. Recommendations are likewise made in this document (e.g. consult with European Maritime Safety Agency (EMSA) and relevant national shipping consultees and complete a navigational risk assessment; consult with local port authority at chosen site; consult with relevant authority for military activity to discuss the implementation of an exclusion zone).

1.4.2. Analysis of a mariculture platform impacts

An ethical approach to aquaculture is being integrated by some aquaculture industries regarding social and environment principles, and thus six criteria for an ecological aquaculture has been set : preservation of natural ecosystems form and function; trophic level efficiency; nutrient management and absence of harmful chemicals and antibiotics; avoidance of farmed fish escapes; community participation in production systems; and contribution to social welfare globally without proprietary control over the resources.
Social and economic factors: Policies promoting the sustainable development of mariculture using valuable and renewable local resources can improve the economic and social development of rural communities through enhancing employment levels, reducing emigration and facilitating improvements in infrastructure . Efforts have to be made to communicate the beneficial effects for local communities of having a mariculture platform nearby. The implication of these will determine its acceptance and support towards mariculture development in the region.
The overall environmental impact of the fish farm and related mitigating devices included in the offshore H2OCEAN installation has been discussed in deliverable 9.5 Analysis of the Reduced Environmental Impact of the Proposed Multi-trophic Integrated Aquaculture System .

Jobs and income: When an offshore aquaculture activity is in place, the coastal area near to it is bound to have an increase in jobs offers related to it. This benefit is controversial, some jobs are going to be on the offshore platform but most of the newly created jobs are going to be in processing industries along the coast. Grow-out facilities of the aquaculture industry are hardly ever on the coast, they are usually placed in land, and thus jobs related to it are not considered to be beneficial for the coastal communities .
The EU announced plans in 2003 to create 10,000 more jobs, mainly in areas where commercial fishing is in decline. Voices have arisen because there is no guarantee that these fishermen will move into the aquaculture industry. And thus, efforts have to be concentrated to address this.
Jobs in the platform are going to be much specialised and skilled workers are going to be needed, thus if no specific action is taken (education programs, etc.), the personnel will probably not be from the zone. Jobs on the processing industries are thought to be widely distributed among coastal communities that may have lost jobs from the decline of the fishing sector, but

arguments arise against this statement. Intensive aquaculture production that lacks community roots and which depend on supplies and human expertise imported from distant areas does not have an income multiplier effect on the coastal area. There appears to be limited overlap of skills between local communities and those needed for mariculture, thus major cultural shifts are needed if rural people are to adjust to a culture mode of production .
For a coastal community to access jobs related directly or indirectly to the placement of an offshore aquaculture activity, some training has to be foreseen among the coastal community prior or in parallel to the start of the exploitation. This will ensure that the new jobs are going to be covered by the local community. However, circumstantial evidence suggests that several forms of activity can provide local opportunities for part-time seasonal employment, thereby stabilizing income among workforce groups at time of low tourist activities .

Health: Regarding the effects of aquaculture on human health several issues have been detected as a concern. On the one hand the human benefits of consuming omega-3 polysaturated fatty acids is now widely accepted and thus aquaculture can secure a supply of the fish demand that is predicted to be 161 million tonnes by 2022 an increase of about 18% above the average for 2010-12 with an annual growth of 1.3%; and that will not be achieved by the wild fishing industry alone (projected to increase up to 96 million tonnes). On the down side health risk for humans can come from the consumption of farmed fish that is high on the food chain (such as tuna...) when farmed on contaminated waters it bioaccumulates organic contaminants (including PCB’s) and dioxins also consumers’ concerns arise when added chemicals and colorants to the diet of farmed fish.

Right of food: The availability of fish for human consumption is likewise of great concern during the last decades. A FAO report predicts an increase on fish demand of 161 million tonnes by 2022 , from which 96 million tonnes are expected to come from wild fish and the remaining from aquaculture. Roughly 40% of all fish directly consumed by humans worldwide in 2005 were farmed13. In many areas and in most of the poorest areas of the world, the main source of protein in human diet comes from pelagic fish.

Animal welfare: The species chosen for farming in the Portuguese H2OCEAN system cages is Sea Bass (Dicentrarchus labrax Linnaeus, 1758). This species is commonly found wild along Portuguese coasts and also farmed in land- based aquaculture facilities (D9.5 An analysis of the reduced environmental impact of the propose multi-trophic aquaculture system) .
During the different stages of the fish farm, the three ethical principles defined by The Food and Ethics Council regarding animal welfare have been considered:
- Breeding
- Feeding
- Disease/Treatment

Environment: The environment impacts of a mariculture platform are discussed in length in deliverable 9.5 “Analysis of the Reduced Environmental Impact of the Proposed Multi-trophic Integrated Aquaculture System”18.
The large deposition of organic matters in one of the proposed sites, characterised by intense currents, make the proposed mitigating devices based on the biological features of algae and bivalves apparently insufficient to a quantitative extraction3.

1.4.3. Analysis of the impacts of energy production through offshore renewable sources

Certain sensitive lands, such as parks, monuments and wildlife conservation areas, and ecologically sensitive marine areas are not (a priori) the most indicated sites for energy development. In some of these places, energy development is prohibited or limited by law or policy, and in others it would be highly controversial. Protection groups and many associations do not endorse locating energy facilities or transmission lines in such areas. Siting decisions must always be made extremely carefully, with impacts mitigated and operations conducted in an environmentally responsible manner.
While aquaculture practices have been performed for centuries, wind farming has been developed during the last decades; this could explain why ethical codes and guidelines regarding wind farms are scarce compared with those on aquaculture.
This section follows the same structure of the aquaculture analysis, and the same aspects are discussed.

Jobs and income: A wind farm, on average, generates approximately 1,070 jobs per 100 turbines constructed, which could benefit the regional economy. Although these would be mostly skilled jobs, education programs could be planned and designed with the local community in advance, being promoted in the designated area to cover some of the jobs that will be available in the wind farm .

Health: Large wind turbines experience turbulent winds that can produce low frequency noise (< 20Hz infrasound) which are inaudible to humans. Such infrasound can potentially cause significant sound-related hearing loss as well as more immediate health problems (headaches, increase stress levels) overtime. The possibility of a hazardous health problem on humans is of great concern. Even though long term exposure to low frequency has not been studied, it is thought that it can pose some health problems when being close to human settlements9.

Animal Welfare: Mid-air collisions with avian species have been documented in offshore wind farms. A solution would be to construct the turbines away from known migratory patterns.
In deliverable 9.3 birds collision has been considered as an environmental impact, and solutions have been proposed (avoiding sensitive sites, avoiding installation work during scarce visibility periods, and increasing visibility of installation vessels and devices, avoiding Sodium or bright lights, red flashing lights should be preferred to continuous white lamps, proposed area for the ecology of bird populations should be assessed before the installation activities taking place).
Aggregation of fish around the aquaculture cages is likely to attract seabirds hunting for food supply, and the WECs may also encourage seabirds to congregate and use the devices as a rest site. Consideration should be given to the possibility of seabird collision with the VAWT. It has been found that seabirds have a lower collision rate with VAWTs than HAWTs. Further research is recommended on the impacts of WECs on seabirds as it is currently largely unknown7, in addition to a survey to inform of bird usage at the chosen site, taking into account seasonal variations in breeding, wintering and migrating.

1.4.4. Conclusions and Recommendations

• A multi-use platform can be a very good alternative to secure food sources and energy supply when these are done ethically. Additionally, a multi trophic aquaculture where fishes from different trophic levels are farmed eliminates the pressure on wild pelagic fish stocks and thus doesn’t compete with the local pool of wild fish. It is recommended that an Ethical and Social Impact Assessment Plan should be done prior to the placeman of the platform in collaboration with the local community, and thus preventing and correcting any possible collision of interests with the local communities.
• Prior to the placement of a platform, involvement of the coastal community and stakeholders has to be done from the early stages. Stakeholders and the local community will have to be involved in all decisions regarding the private use of a public resource (offshore water column), and thus some kind of fare agreement with the locals will have to be achieved.
• For a coastal community to access jobs related directly or indirectly to the placement of an offshore aquaculture activity or an offshore energy activity, some training has to be foreseen among the coastal community prior or in parallel to the start of the exploitation.
• Any activity that could pose a threat or that could have a negative impact on human health (fish feeding additives, pesticides, wind turbines noise, etc.) as well as any negative impact to the environment should be considered and addressed. Therefore guidelines of good practice should to be followed.

List of Websites:
Meetings held (Figure 30, 31, 32 and 33)
Logo of the project (Figure 34)
Figure 35
Brochures and leaflets (Figure 36, 37 and 38)

Related information

Result In Brief	Renewable energy and fresh fish from offshore platforms
Documents and Publications	final1-figure11.pdf
	final1-figure28.pdf
	final1-figure34.pdf
	final1-figure17.pdf
	final1-figure10.pdf
	final1-figure33.pdf
	final1-figure16.pdf
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	final1-figure-31.pdf
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	final1-figure24.pdf
	final1-figure18.pdf
	final1-figure19.pdf
	final1-table2.pdf

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