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MULTI-PURPOSE OFFSHORE-PLATFORMS: PAST, PRESENT AND FUTURE RESEARCH AND DEVELOPMENTS

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ABSTRACT

Energy, fisheries and transport infrastructures are increasingly being established offshore. Facilities such as offshore wind farms may occupy large areas and compete with other users of the maritime space. Accordingly, offshore platforms that can combine many functions within the same infrastructure could offer significant benefits. This applies to economy, optimization of spatial planning and minimization of the impact on the environment.

In the present paper, some proposed innovative designs for multi-use offshore platforms are described. The technical, economical and environmental feasibility of designing, installing, operating, servicing and maintaining such platforms are discussed. The relevant platforms under consideration are targeted towards ocean renewable energy (in particular offshore wind), aquaculture and related transport maritime services.

Innovative designs for multi-use offshore platforms that intend to allow optimal coupling of the various activities and services are highlighted. Issues such as safe and efficient installation, operation, maintenance and monitoring are also briefly discussed in the paper.

INTRODUCTION

Increasingly, energy, fisheries and transport infrastructures are being established offshore. Offshore platforms that can combine many functions within the same infrastructure could offer significant benefits in terms of economics, optimising spatial planning and minimising the impact on the environment.

In the present paper some proposed innovative designs for multi-use offshore platforms are described. The technical, economical and environmental feasibility of designing, installing, operating, servicing and maintaining such platforms are discussed. The platforms are targeted towards ocean renewable energy (in particular offshore wind), aquaculture and related transport maritime services.

Determination of the optimal locations for multi-use offshore platforms requires that a number of different aspects are taken into account. This comprises e.g. renewable (in particular wind) energy resources, feasibility of aquaculture, transport issues, and other platform-related activities including accessibility and possible use as offshore terminals. In determining locations, the following needs to be taken into account: (i) Ocean renewable energy resources and seabed characteristics (ii) Hydrodynamic dispersion models (iii) Hydrodynamic conditions for logistic, transport and installation purposes (iv) Impact analysis on the environment, social acceptance and other users (e.g. vibrations, noise, radar interference, shipping, tourism, fishing).

Innovative designs for multi-use offshore platforms that intend to allow optimal coupling of the various activities and services are highlighted herein. Issues such as safe and efficient installation, operation maintenance, risk and reliability level, design guidelines, and monitoring are also briefly discussed in the paper.

Several different branches of development towards multi-purpose platforms can be foreseen, such as the following: (i) A continuous upgrade of the size of aquaculture plants which in the intermediate and long-term perspective can include renewable energy supply components. Additional activities such as multi-trophic farming are readily included, and harbour/housing facilities will gradually increase in size. (ii) A continuous upgrade of the size of wind-farms comprising bottom-fixed and/or possibly floating turbines. In an intermediate and long-term perspective these farms can include other activities such as multi-trophic farming and/or harbour/housing facilities. (iii) Genuinely new types of multi-purpose platforms possibly with

focus on “hub-related facilities” (i.e. transit-harbour and housing facilities) also combined with energy, ocean farming and recreational facilities.

In the present paper, focus is on the first of these options.

HISTORICAL BACKGROUND

Multi-purpose floating platforms have a long history of proposed concepts which have not yet materialized into realized projects. As a first example, the proposed floating ecopolis “Lilypad” outside Monaco and Monte Carlo is presented in Figure 1.

Figure 1 Example of Multi-purpose platform: Lilypad (http://vincent.callebaut.org/object/080523_lilypad/lilypad/projects)

As a second example, the so-called Energy Island is shown in Figure 2.

On the other hand, there are a number of so-called very large-scale floating facilities that have already been realized, e.g. the floating stadium in Singapore which is shown in Figure 3. Located in Marina Bay, The Float as it is called, measures 120 m in length and 83 m in width.

Another example is the the floating airport test facility in Tokyo Bay (which was dismantled once the testing phase was completed).

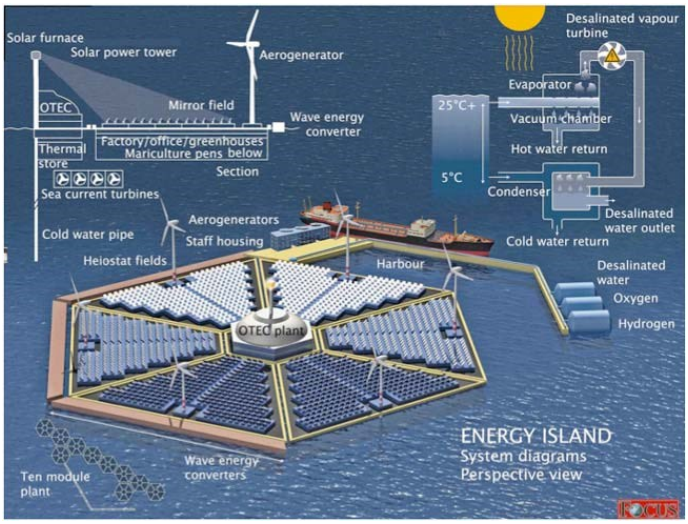

Figure 2 Example of Multi-purpose platform: Energy Island (http://www.livescience.com/3063-floating-energy-islands-power-future.html)

Figure 3 Example of VLSF: Floating stadium in Singapore (http://www.architectweekly.com/2014/02/the-floating-stadium-singapore.html)

Figure 4 Example of VLSF: Floating airport at Tokyo Bay, Japan. (http://db.flexibilni-architektura.cz/o/32)

It is anticipated that plans for VLSFs will continue to grow in number during the coming decades.

GENERAL DESCRIPTION OF PAST EU-PROJECTS

As part of different research projects initiated by the European Commission, multi-purpose platform concepts have been considered. A general description of three such research projects is first given. Subsequently, some particular developments related to these projects are considered.

The H2Ocean project

A one-page summary of the H2Ocean project is given in Annex B (see also http://www.h2ocean-project.eu/). The aim of this project is to develop an innovative design for an economically and environmentally sustainable multi-use platform for operation in open seas . Wind and wave power will be harvested and part of the energy will be used for multiple applications on-site. This includes conversion of energy into hydrogen that can be stored and shipped to shore as a carrier of green energy. A multi-trophic aquaculture farm is also part of the concept.

The Mermaid project

A one-page summary of the Mermaid project is provided in Annex C (see also www.mermaidproject.eu). The main objective of this project is to develop concepts for a next generation offshore platforms for multi-use of ocean space. This comprises energy extraction, aquaculture and platform related transport. The project does not envisage building a new platform but aims at examining different concepts. This can be in the form of a combination of existing types of structures or completely new structures on representative sites under different conditions. The project aims to address the following key-questions:

- What are the best practices to develop multi-use platforms?
- What are the accumulated effects of multi-use platforms on the marine environment?
- What are the best strategies for installation, maintenance and operation of multi-use offshore platforms?
- What is the economical and environmental feasibility of multi-use offshore platforms?

Furthermore, four offshore test study sites with typical environmental characteristics are considered: (i)The Baltic Sea - a typical estuarine area with fresh water from rivers and salt water (ii) The trans-boundary area of the North Sea-Wadden Sea - a typical active morphology site (iii) The Atlantic Ocean - a typical deep water site (iv) The Mediterranean Sea - a typical sheltered deep water site.

The Tropos project

A one-page summary of the Tropos project is shown in Annex D (see also http://www.troposplatform.eu/). The scope of this project seems to be somewhat wider than the two previous ones: To develop a floating modular multi-use platform system for use in deep waters, with an initial geographic focus on the Mediterranean, Tropical and Sub-Tropical regions. At the same time, it should be designed to be flexible enough so as to not be limited in geographic scope. A modular approach was intended to integrate a range of functions from 4 different sectors (TEAL): Transport (T), Energy (E), Aquaculture (A), and Leisure (L). Three different concepts were developed by combining particular TEAL functions. These are referred to as the *Green & Blue*, *Leisure Island*, and *Sustainable Production* concepts. Each platform concept consists of a central unit, fixed modules and free-floating satellites. The design of the central unit is similar for all scenarios, but they differ with respect to combination of modules and satellites. For two of the concepts, appropriate tentative sites were chosen based on numerical and physical modelling. These sites were Gran Canaria-Spain (Leisure), Crete-Greece (Green & Blue), and Liuqiu Island-Taiwan (Green & Blue).

THE COLUMBUS PROJECT

In order to facilitate adoption and implementation of the results from European Commission research projects related to the marine environment, the Columbus project was established (among other projects). A one-page summary of the Columbus project is given in Appendix A. Essentially, the objective of the project is as follows: ”COLUMBUS aims to ensure that applicable knowledge generated through EC-funded marine and maritime science and technology research can be transferred effectively to advance the governance of the marine and maritime sectors”.

The project is organized around a number of so-called "Competence Nodes", each with their own particular focus. As part of the project activity within one of the Competence Nodes, i.e. *Marine Physical Resources,* which is headed by Aquatera in Scotland, the three mentioned EC-supported project related to multi-purpose offshore platforms were considered. In the present paper, some further developments within these projects are outlined.

In the last part of this paper, a view is given of present trends and future developments related to multi-purpose offshore platforms.

PARTICULAR DEVELOPMENTS RESULTING FROM PAST PROJECTS

General

While there are a large number of developments achieved within each of the three different projects, some particular items are here discussed in some more detail due to their potential for future applications.

Floating vertical axis wind turbine (H2Ocean)

A summary of different types of floater concepts that can provide support for vertical axis turbines is given in Figure 5, see also references [9, 10].

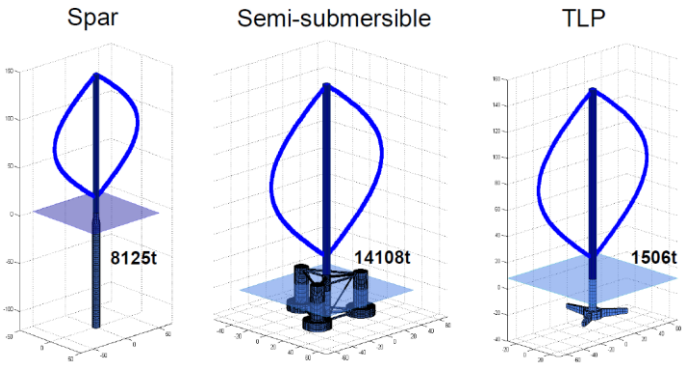

Figure 5 H2Ocean: Vertical axis wind turbine supported by three different floater types. (http://www.h2ocean-project.eu/)

Installation of jacket-supported turbines by a floating vessel

As part of the Mermaid project, installation of a jacket foundation for an offshore wind turbine by a floating vessel has been considered by means of numerical simulations. The crane operation for lowering a 10MW turbine jacket substructure through the wave zone down into the pre-installed foundation piles is studied. A coupled model, consisting of the floating installation vessel, the jacket substructure and the connection between them with lift wires, is built and analysed using the Marintek software SIMO.

Based on the defined operational criteria and the results that are obtained from the numerical simulations, a workability analysis is performed to identify the sea states suitable for the installation of the jacket. (Wave period,wave height and wave direction).

Wind, waves and currents have an impact on the installation time and thus on the project costs. It is therefore extremely important to know under which conditions the installation offshore can be carried out safely. The model aims at comparing the weather envelope of floating vessels, supposedly cheaper, to a fixed jack-up barge, see also Stettner [12] for further details.

ONGOING DEVELOPMENTS AND FUTURE TRENDS

General

In the present Section we consider particular trends within the Aquaculture industry that may have the potential to develop further into multi-purpose platforms in a natural way. As discussed above, other directions of approach might also be through consideration of multi-purpose developments within the wind industry, but this is not pursued in the present paper mainly due to space limitations.

Combination of aquaculture and wave power

Marine Harvest's salmon farm off Muck, UK, has installed a new wave device to assist in generating electricity at the site, which relies on a diesel generator. The installation at the farm on Scotland's west coast is the result of a collaboration between renewable energy and aquaculture. The wave energy device WaveNET is created by Scottish marine energy company Albatern, and consists of a coupled array of three units known as Squids (see e.g. https://www.undercurrentnews.com /2014/05/23/marine-harvests-salmon-farm-to-test-wave-energy-device/). Installations at the test site are shown in Figure 5.

Figure 5. Combination of aquaculture and wave power supply (https://www.undercurrentnews.com /2014/05/23/ marine-harvests-salmon-farm-to-test-wave-energy-device/)

Aquaculture upscaling: Salmar platform and Nordlaks facility

The Ocean Farming facility is an innovative design, developed to overcome the challenges of more traditional inshore fish farming facilities by being located in deeper waters away from the coast. The submerged and anchored structure will float steady in the exposed ocean and is suitable for water depths of 100 to 300 meters. In these areas the aqua-biological conditions are more ideal for aquaculture then in more restricted waters. The benefits of fish farms at offshore locations are numerous, with conditions more suited to nurturing healthy fish, such as steady currents that limit exposure to sea lice infection. The facility is fully automated and normal operation will require a crew of just 3 – 4 people. It can also be remotely operated. This concept is shown in Figure 6.

Figure 6. Salmar Oceanfarming platform in elevated and submerged conditions (Photos: Ocean Farming and SalMar, see also http://www.salmar.no/en/offshore-fish-farming-a-new-era).

In Figure 7 the Nordlaks concept is shown. The length is 431 m and the width is 54 m. The draft is 10 m while the depth of each net is 60 m. The platform is intended for open waters with a mooring system based on technology from the offshore industry. It is equipped with rotating thrusters for the purpose of propulsion and positioning. The cost of the first plant is estimated as one billion NOK with anticipated cost reduction for subsequent installations.

Multitrophic farms - IMTA

Integrated Multi-Trophic Aquaculture (IMTA) installations consist e.g. of a combination of aquaculture plants in addition to components that carry e.g. mussels and seaweed/kelp. The proposed Ocean Forest concept is shown in Figure 8. A summary of the plant layout is given e.g. in Bellona (2013), [15]. The first test facility of this concept is located at the Lerøy Seafood Group locality at Rongøy in the Øygarden area (at the West Coast of Norway). Inclusion of wind-power turbines are also considered, which represents a further step towards fully integrated multi-purpose platforms.

Figure 7. Nordlaks aquaculture concept.
(Source: Dagens Næringsliv, April-2016)

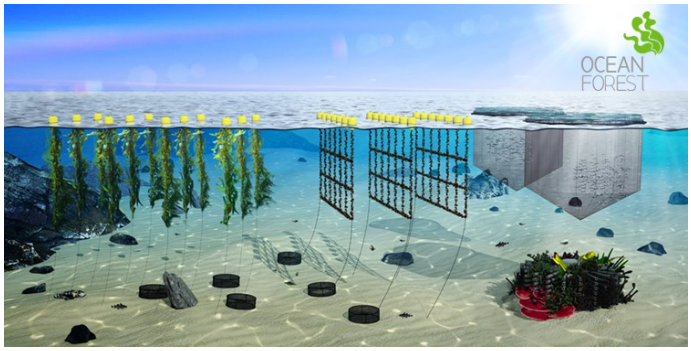

Figure 8. Ocean Forest. Bellona and Lerøy Multitrophic IMTA-concept (https://www.leroyseafood.com/no/Forbruker/Om Leroy/Nyheter/ocean-forest/)

Another example of an IMTA in the Bay of Fundy, New Brunswick, Canada is also given in Bellona (2015), [16]. Here, salmon is farmed in cages, blue mussels are grown in bags and on ropes and kelp is grown on ropes.

The development of IMTA in Norway seems to be lagging as compared to other pioneering countries like China, Japan and Canada, although we are one of the main producers of fish food in the world. This will likely change once these developments start to expand.

ASPECTS RELATED TO RISK, STRUCTURAL RELIABILITY AND MONITORING.

General

Multipurpose platforms represent novel types of structural concepts. The reliability and risk levels associated with these concepts accordingly need to be taken care of in an adequate manner.

Refinement of hydrodynamic and structural calculation methods

Already existing technological solutions which are applied within the aquaculture industry call for highly refined analysis methods. There is a need to account for very non-linear effects which are due e.g. to finite surface effects and hydro-elastic interaction, see e.g. Fredheim and Faltinsen, [18], Kristiansen and Faltinsen, [19], Thomassen and Leira, [20].

Development of design guidelines, standards and codes

Although refinements of calculation methods are continuously being implemented, such novel types of structures still imply increased model uncertainties related to the applied numerical calculation models. This applies e.g. to representation of the environment, the environmental loading, the behavior of the structure itself as well as capacity formulations. This implies that a careful calibration of computational tools needs to be performed.

At present there exist separate design documents for offshore structures, aquaculture plants and renewable energy production units. Harmonization and possibly merging of these documents will be required as part of future efforts related to multi-purpose platforms.

Risk and reliability assessment

In light of the novelty of the present category of structures, dedicated risk and reliability analyses are generally required. This also includes consideration of e.g. the following topics:

- Verification of design procedures based on model testing and full-scale monitoring.
- Improved knowledge of uncertainty related to environmental parameters at a given site.
- Quantification of improved accuracy based on calibrated numerical models for representation of loading and structural response behavior.
- Reliability updating based on accumulated data records.
- New types of structural connections implies detailed assessment of capacity formulations.
- Life-cycle cost reduction based on continuously more accurate information.

In order to quantify the effect of these developments on the overall design procedures, the framework of structural reliability analysis offers a powerful tool in such a context, see e.g. [21] for examples of application.

Structural monitoring systems

As an integral part of some of the upscaled structures, rather comprehensive monitoring systems are planned to be implemented. As an example, the Salmar Ocean-farming facility will be equipped with a large number of different sensor types, see Figure 9 for a general outline of the monitoring system.

A large number of sensors and other types of systems are going to be placed at the plant itself and in the surroundings in order to monitor environmental parameters such as oxygen level, water salinity, temperature and water current velocity. .

Echo sounders , hydrophones and cameras above and below the ocean surface are also components in the system. In addition, navigation, communication, fishery and power control systems are also included.

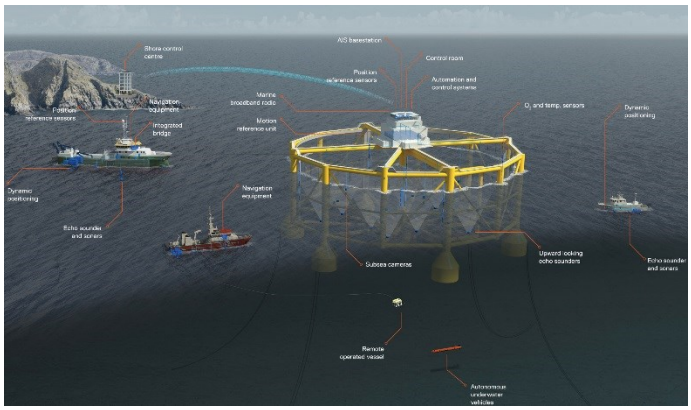

Figure 9. Monitoring system associated with Salmar-Oceanfarm platform. (https://www.km.kongsberg.com/ks/web/nokbg0238.nsf/AllWeb/7C0B0102D79C3321C1257F8C00219350?OpenDocument)

SUMMARY AND CONCLUSIONS

In the present paper, an overview was given of past, present and future research and development related to multi-purpose floating platforms.

Particular issues related to structural monitoring, reliability and risk assessment as well as design guidelines and standards are also addressed. It is believed that the latter will be important topics for future research and development within this area.

ACKNOWLEDGMENTS

Support from the Columbus project is greatly acknowledged and forms the basis for some of this work. The opinions stated in the present paper are those of the author and should not be construed as representing the views of the participants in any of the projects which are described, or those of the European Commission.

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[5] http://www.h2ocean-project.eu/

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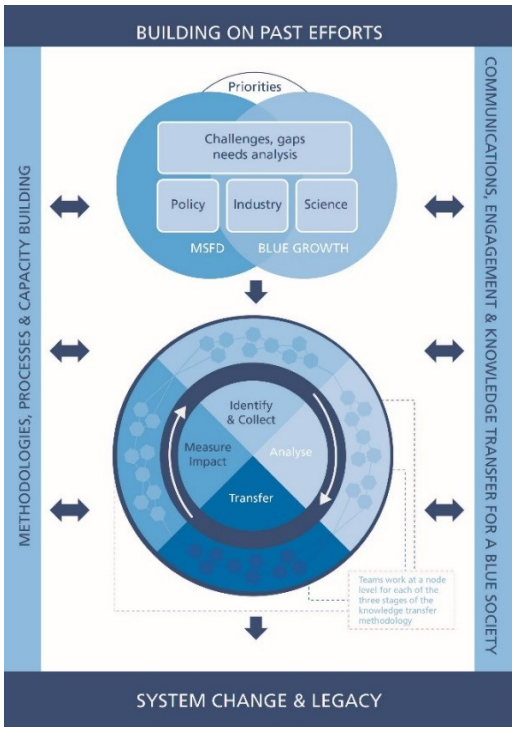
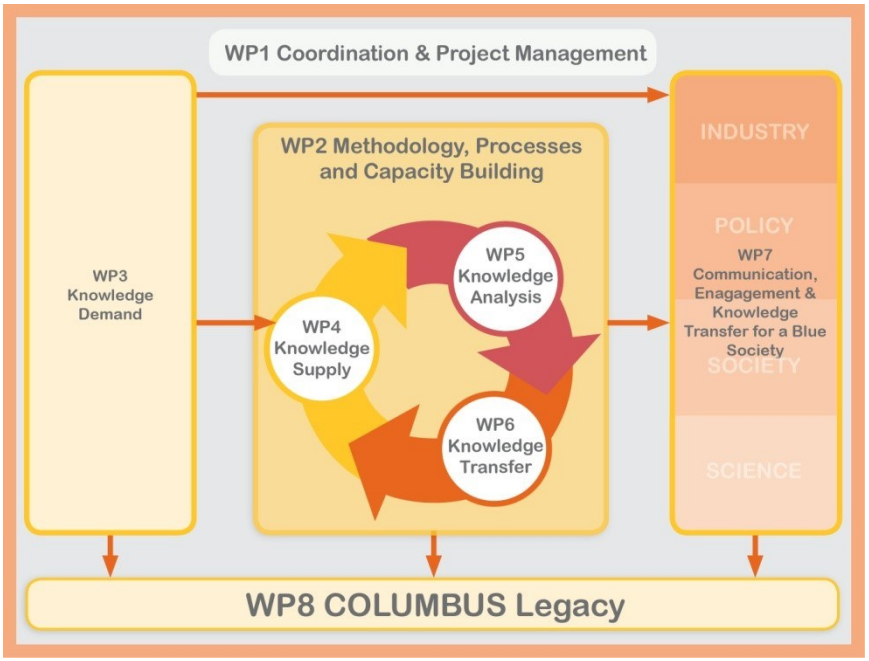
ANNEX A
ONE-PAGE SUMMARY OF COLUMBUS PROJECT (http://www.columbusproject.eu/)





ANNEX B

ONE-PAGE SUMMARY OF H2OCEAN PROJECT (www.h2ocean-project.eu)

THE PARTNERSHIP

- AWS Truepower, Spain.
- Virtualpic Ltd, UK.
- Universidad de Valladolid, Spain.
- Fraunhofer, Germany
- Chiamys, Italy.
- Viking Fish Farms Ltd, UK.
- Institut für Seeverkehrswirtschaft, Germany.
- Danmarks Tekniske Universitet, Denmark
- SITA, Spain.
- Fusion Marine Ltd, UK.
- Tecnalia, Spain.
- D'Appolonia, Italy
- Universidad de Oviedo, Spain.
- IT Power, UK.
- Cranfield University, UK
- Sustainable Technologies SL, Spain
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www.h2ocean-project.eu

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H2Ocean

H2Ocean – Sustainable Harvesting of the Ocean

Developing an open-sea platform for energy conversion and use in hydrogen generation and aquaculture

www.h2ocean-project.eu

This project is supported by the European Union through the 7FP Ocean of Tomorrow, "Multi-use offshore platforms" Theme (Grant No 288145).

A project implemented by AWS Truepower, BHR Group, D'APPOLONIA

THE PROJECT TEAM

H2OCEAN brings together 17 partners from 5 countries around Europe, who are leaders in the fields of renewable energy, hydrogen generation, fish farming, maritime transport and related disciplines. The project also builds on the commercially available products, emerging product developments and leading edge research activities that are already being carried out by the partners.

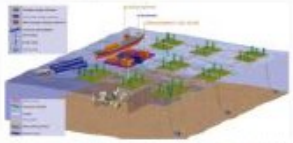
H2OCEAN started on the 1st of January 2012 and lasts 3 years.

Objectives

The concept of the project is to develop a flexible design for a multi-component and multipurpose wind-wave farm based platform, 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: support for aquaculture, communications, etc.

THE CHALLENGE

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



The unique feature of the H2OCEAN concept, besides the integration of different activities into a shared multi-use platform, lies in the novel approach for the transmission of offshore-generated renewable electrical energy through hydrogen. This concept allows effective transport and storage of the energy, decoupling energy production and consumption, thus avoiding the grid imbalance problem inherent in current offshore renewable energy systems. Additionally, this concept also eliminates the need for a cable transmission system which takes up a significant investment share for offshore energy generation infrastructures, and so increasing the price of energy.

RESULTS ACHIEVED

- ✓ Conceptual design and assessment of technology integration to meet the functional specifications.
- ✓ Development of a web-based software tool for the assessment of optimal locations and corresponding platform specifications (www.h2ocean-project.eu).
- ✓ Development of an integrated wave-wind coupled model of dynamics, with mechanical and structural assessment (VAWT), environmental loading and shipbuilding considerations.
- ✓ Development of appropriate safety measures, devices and procedures.
- ✓ Development and dimensioning of offshore desalination units for a hydrogen generator.
- ✓ Adaption and optimisation of state-of-the-art hydrogen production technology to off shore environment.
- ✓ Design of an autonomous offshore aquaculture system, including service facilities and operating specifications, stressing novelty of the multi-trophic approach that encompasses production of various species in the different locations.
- ✓ Design of a floating anaerobic digester (FAD) for both marine biomass and organic waste from human activities.
- ✓ Development and evaluation of procedures for deployment and decommissioning of the platform, including operating logistics, servicing and safety.
- ✓ A complete assessment of the environmental impact has been performed, including Life Cycle Assessment (LCA) and recommendations.

H2Ocean

www.h2ocean-project.eu

ANNEX C

ONE-PAGE SUMMARY OF MERMAID PROJECT (www.mermaidproject.eu)

THE MERMAID PROJECT

INNOVATIVE MULTI-PURPOSE OFFSHORE PLATFORMS: PLANNING, DESIGN AND OPERATION

Hans Pirlet[1], Simon Claus[1], Jan Seys[1], Jan Mees[1], Barbara Zanuttigh[2] and Erik Damgaard Christensen[3]

INTRODUCTION

Increasingly, European seas and oceans are subject to the development of marine infrastructure:

- Massive **offshore wind farms** are being constructed (1371 turbines installed and grid connected in European Seas by the end of 2011)
- New prototypes for marine renewable **energy extraction** from **tides** and **waves** are tested
- Offshore facilities are required to explore the vast potential of **marine aquaculture** in European waters
- Offshore platforms are needed to address the demands of **maritime transport**.

These novel offshore activities require specific technology and governance in order to address the challenges linked with the installation, operation and maintenance of these facilities. Moreover, the development and operation of marine infrastructure unavoidably exerts environmental pressure on the oceans, threatening marine ecosystems. In this regard, it is crucial that the **economic costs, use of marine space** and **environmental impacts** of these activities remain **within acceptable limits**. Hence, offshore platforms that combine multiple functions within the same infrastructure offer significant benefits in terms of economics, optimizing spatial planning and reducing the impact on the environment.

THE MERMAID PROJECT

The MERMAID project consists of a consortium of 28 partners. It will **develop concepts** for a next generation offshore platforms for multi-use of ocean space for energy extraction, aquaculture and platform related transport. The project does not envisage building new platforms but aims at examining different concepts, such as a combination of structures or complete new structures on representative sites under different conditions. The MERMAID project aims to address the following key-questions:

- What are the **best practices** to develop multi-use platforms?
- What are the **accumulated effects** of multi-use platforms on the marine environment?
- What are the **best strategies** for the installation, maintenance and operation of multi-use offshore platforms?
- What is the **economical and environmental feasibility** of multi-use offshore platforms?

OBJECTIVES AND OUTCOMES

The objectives and the expected outcomes of the MERMAID project can be divided under four areas:

- The **management and development** of novel innovative multi-use offshore platform
  (participative approach with procedures for involvement of all stakeholders; procedures to address variations in legislation and policies; guidelines for project development)
- **Innovative technology and design**
  (integrated concepts for marine renewable energy, offshore aquaculture technology, large scale platform design concepts)
- **The sustainable integration** of multi-use offshore platforms
  (integration with stakeholders; the socio-economic viability of multi-use offshore platforms; environmental and ecological sustainability; acceptable multi-use platforms for different social groups)
- The **integration** of management, technology, social-economics and governance requirements at **four contrasting test sites**
  (research suitable for immediate use; tools, techniques and decision support systems may be applied, tested and validated)

In the MERMAID project, four offshore test study sites with typical environmental characteristics are considered:

- The **Baltic Sea** - a typical estuarine area with fresh water from rivers and salt water.
- The trans-boundary area of the **North Sea-Wadden Sea** - a typical active morphology site
- The **Atlantic Ocean** - a typical deep water site
- The **Mediterranean Sea** - a typical sheltered deep water site.

Below: Map of the four study sites with their environmental characteristics. Countries participating in the MERMAID project are marked in yellow

Source: Lacroix and Pioch (2011) The multi-use in wind farm projects: more conflicts or a win-win opportunity? *Aquatic Living Resources* 24(2):129-135.

THE H2OCEAN AND TROPOS PROJECTS

Simultaneously with the MERMAID project, two other EU-FP7 projects on multi-use offshore platforms are ongoing (see below). Throughout the project, dissemination of results and interaction between the three consortia will be established.

- **The H2Ocean project** is about the development of a wind-wave power open-sea platform equipped for hydrogen generation with support for multiple users of energy.
  http://www.h2ocean-project.eu
- **The Tropos project** aims at developing a floating modular multi-use platform system for use in deep waters.
  http://www.troposplatform.eu

MERMAID PARTNERS:

GET MORE INFORMATION ABOUT THE PROJECT

Are you interested in the outcomes of the MERMAID project? Do you want to get involved as an end-user?
www.mermaidproject.eu

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ANNEX D

ONE-PAGE SUMMARY OF TROPHOS PROJECT (Website)