# Chapter 1
# Multi-Purpose Platforms

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## 1.1 Introduction

### *1.1.1 Context*

A multi-purpose platform is an offshore system designed to serve the purposes of more than one offshore industry. Indeed, a number of industries have expanded, or are expanding, from onshore to offshore locations, adapting to the harsh environment in order to extract energy (conventional or renewable) or useful materials (deep mining), to produce food (aquaculture), nutraceuticals and pharmaceuticals (blue biotechnology), to expand the urban areas, or to simply develop the local tourism, to name a few. This process starts to appear like, and certainly has the potential to become, a further ”agricultural/industrial revolution”, characterized by:

- a substantial shift from “gathering of resources where available” to the systematic, settled use of the resources offered by the ocean,
- a shift from offshore facilities of a specific industry operating independently to an “ecosystem” of offshore industrial activities,
- the resulting development of new technologies.

Expanding the above mentioned industries towards this new frontier can help to respond to two of the main challenges facing mankind: the sustainable, safe, and reliable production of 1) energy and 2) food, driven by an increasing population and rising prosperity [1]. For these reasons, and also due to the huge potential to create jobs and revenues, many countries around the world are proposing and implementing strategies to develop the so called “Blue Economy”.

In its communication entitled “Blue Growth - opportunities for marine and maritime sustainable growth” [2], the European Union (EU) formally acknowledged three important factors:

- rapid progress is being made in the development of offshore technologies, including those targeting deep waters,
- the finite nature of land and freshwater resources which are at an increased strain as a result of economic development,

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- the opportunity offered by offshore renewable energy resources to reduce the anthropogenic greenhouse gas emissions, which has been identified as the major cause of climate change [3].

The “Blue Economy” already accounted for 5.4 million jobs across the EU way back in 2011. It was generating a gross added value of 500 billion euro every year, with huge potential for innovation and growth [4] [5]. Therefore, a number of initiatives were funded (see section 1.2.1), furthering the knowledge and understanding in this field and to find sustainable, techno-economically feasible solutions.

Outside Europe, China is another example where the importance of the emerging “Blue Economy” is being recognised. The “Made in China 2025” strategic plan focuses on 10 priority sectors, highlighting areas of opportunity for economic growth [6]: within the marine resources priority sector, the focus is on ocean renewable energy (ORE) technologies. Furthermore, “The 13th five year plan of Marine renewable energy development” [7] is promoting the use of a combination of renewable energy technologies to provide at least 60% of the total energy demand of the Shandong, Zhejiang, Fujian, Guangdong island communities. In fact, in China a number of small/isolated communities do not have a reliable access to basic utility services (fresh water, energy), due to the remote nature of their location, and are being abandoned by the local communities. The sustainable, local production of basic utility services is seen as a promising approach to solve this issue.

The further development of the aquaculture sector is also high in the agenda: the “Outline of the National Marine Economic Development Plan” [8] specifically targets the development of novel ocean farming methods that are not only more productive but also more socially and environmentally compatible.

### *1.1.2 Why Multi-Purpose Platforms?*

Usually, due to the distance from the shore and to the though meteocean conditions, an offshore system needs to be self-sufficient in many aspects for a certain period of time (sometimes extending to several weeks). For example, oil and gas platforms located in far offshore and deep water locations need to be self-sufficient from a basic utility services point of view (energy, water), and need to have a minimum set of skills covered by their crew: not only the technical staff to operate and maintain the oil & gas related operations, but also catering staff, security staff, fully qualified medics, radio operators, and others.

Based on the Blue Growth strategy, and on the current trend of the offshore wind and aquaculture industries, it is likely that a number of offshore facilities will be co-located in the same offshore area. It follows that, rather than having the necessity to be self-sufficient at single platform level, there is an opportunity to create an *”industrial (sustainable) ecosystem of offshore facilities”*, where the common services will be shared and provided by specialised systems.

The multi-purpose platform concept is a possible implementation of this ecosystem: in this case, the facilities of this ecosystem are based on the same platform or closely co-located, exploiting the specific potential synergies, and avoiding by design the arising tensions.

| No. | Synergy |
|---|---|
| P.1 | Encouraging a common regulatory framework |
| SE.1 | Lower CAPEX/system due to shared infrastructure |
| SE.2 | Lower OPEX/system due to shared O&M facilities, vessels, and staff |
| SE.3 | Provision of local, sustainable source of energy, food, fresh water, to isolated/remote communities |
| T.1 | Enhanced renewable energy yield / more energy per unit area |
| T.2 | Smoothed and more consistent power output |
| T.3 | Common grid infrastructure |
| T.4 | Shared mooring system/connection to seabed |
| T.5 | Wave energy converter wake effect creating milder wave conditions for other systems and services |
| L.1 | Encouraging a coordinated plan over the marine and coastal regions |
| L.2 | Encouraging a common licensing procedure |
| E.1 | Reduced environmental impact compared to single systems |

*Table 1.1 Some of the main synergies that can be enabled by a Multi-Purpose Platform, PESTLE approach - P Political, SE Socio-Economic, T Technological, L Legal, E Environmental (expanded from [9])*

### 1.1.2.1 Potential synergies

Many of the potential synergies identified for hybrid wind-wave energy devices (e.g. [9]) can also be applied to a generic multi-purpose platform concept. These synergies are not only at technological level, but also at political, economic, social, and environmental levels (PESTLE approach).

A high-level list of potential synergies, divided by discipline, is provided in Table 1.1. At the moment the experience with these platforms is quite limited, since these concepts have only been investigated at numerical level or tested at small scale, in indoor experimental facilities. No fully commercial multi-purpose platform is available, with the only small scale prototype, tested outdoor, being the hybrid wind-wave energy device developed by Floating Power Plant [10]. Therefore this table should be considered as non-exhaustive and likely to expand.

In the UK, the Energy Act 2004 [11] and the Climate Change Act 2008 [12] have created a framework that have allowed the British Offshore Renewable Energy sector to lead at an international level. A similar common regulatory framework (P.1), establishing a common reference for the development of all these systems using the ocean resources, would substantially increase the development of both single-purpose and multi-purpose platforms.

A key performance indicator of any ORE system is the CAPEX per MW of rated power. By utilising the same platform for multiple uses, the total CAPEX cost should be lower than the sum of the CAPEX where the different devices are built as separate systems (SE.1). Furthermore, this consideration can be extended also to the OPEX (SE.2): as already mentioned, the costs associated with the daily operation and maintenance can be shared, since the majority of the ports, vessels, and staff could provide this service to multiple offshore systems.

From a social point of view, an important consequence of providing a sustainable, local source of energy, food, fresh water should be considered: the sustainment of isolated/small communities. Although this aspect has not been properly considered in the EU, where the focus has mainly been on "farms" of large, multi-MW multi-purpose platforms, in other countries like Indonesia and China, and continents like Africa, the possibility to provide local, sustainable basic utility services (and the jobs linked to these) is seen as a key factor to enable the development of these isolated communities (SE.3).

As far as the technological aspects are concerned, several potential synergies have been identified ( [9] [13] and others). Similarly to hybrid wind-wave, wind-tidal, wind-wave-tidal offshore renewable energy devices, the rated power per unit of area is higher when multiple ORE devices are co-located. This, in general, also leads to an enhanced energy yield (T.1). On top of a quantitative enhancement, from a power quality point of view the energy produced is smoother (short term) and more consistent (longer term) (T.2), thanks to the different physics underpinning the different energy sources. This is beneficial not only for the national/international energy grid, but also to the co-located systems relaying on the provided energy, as for example the aquaculture systems present in the multi-purpose platform.

Furthermore, the needed infrastructure to export the energy produced can also be shared - sharing therefore also its costs (T.3). The same consideration can be extended to the mooring system (floating platform), or the connection to seabed (fixed platform) (T.4). In addition to these aspects, there is an evident synergy between WEC and aquaculture systems. On one side, WEC are designed to absorb wave energy, therefore creating milder wave conditions in their wake. Aquaculture systems, especially those systems used to produce finfish, are negatively impacted by waves, and for this reason so far they have been installed only in sheltered and shallow waters in the nearshore. Therefore, if properly located, WEC systems can open new areas for aquaculture systems. In addition to this, the milder wave conditions are also beneficial for the maintenance operations of the various systems (T.5).

There have been some initiatives aiming at creating a coordinated planning framework for the utilisation of marine and coastal regions resources, such as the Maritime Spatial Planning and the Integrated Coastal Protection Management EU initiatives [15]. Furthermore, the MUSES project (Multi-Use in European Seas, 2016-18) [14] explored the opportunities for multi-use of the ocean resources across five EU sea basins (Baltic Sea, North Sea, Mediterranean Sea, Black Sea and Eastern Atlantic), and presented a series of case studies, identifying both the main drivers justifying a multi-use of the ocean space and the perceived barriers to be considered. Nonetheless, a well defined framework able to coordinate all the activities taking place in an offshore environment (L.1) is still lacking. In general, the necessary licensing procedures tend to be different for each offshore system typology, making the transfer of knowledge from the most mature industries to the new players in the offshore scenario difficult.

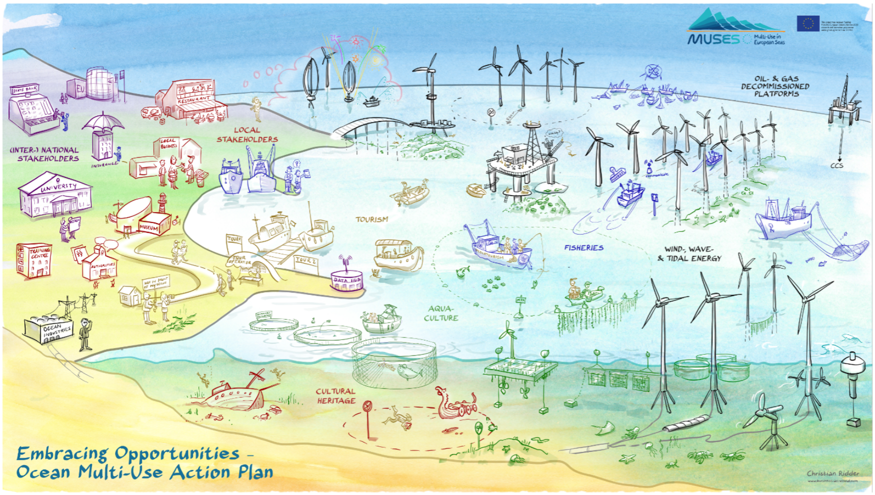


*Figure 1.1 Overview of the multifarious nature of systems, technologies, and stakeholders of the ocean space (courtesy of MUSES project [14])*

The environmental impact assessment is an important step of the overall licensing procedure, as it can determine the feasibility of a project. The environmental impact of a multi-purpose platform, where many of the infrastructures and services are shared, is likely to be reduced when compared to the installation of the single-purpose platforms [9] (E.1), since, fro example, some of the infrastructure will be shared, leading to less material used and smaller footprint. Furthermore, this effect can be enhanced if the by-product of one system can be used as input by another system: an example of this is the Integrated Multi-Trophic Aquaculture (IMTA) approach, where for example the waste nutrients from higher trophic-level species are used for the production of lower trophic-level crops of commercial value, enhancing the overall sustainability [16].

## 1.2 Multi-purpose platform projects and concepts

### *1.2.1 EU projects*

Between 2010 and 2013, "The ocean of tomorrow" calls [17] aimed at funding initiatives that encouraged the marine and maritime research and industrial communities to come together and develop concepts and technologies with a multidisciplinary, cross-cutting approach, facilitating cross-fertilisation and an holistic attitude. A Multidisciplinary approach does not only cover techno-economic aspects, but also the social, legal and environmental aspects from the early phases of the project.

Among the "Ocean of tomorrow call", one of the topic of the call FP-7-2011 was "Multi-use offshore platforms", and three projects were funded on this topic: H2Ocean [18], Mermaid [19], and Tropos [20].

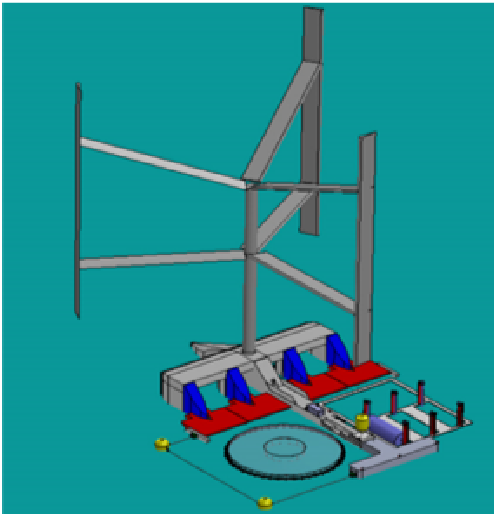

*Figure 1.2 A proposed wind-wave-aquaculture multi-purpose concept, from the H2Ocean project [18]. In the final version, a farm of hybrid wind-wave devices, with 5MW vertical axis wind turbines and ~~3.6~~MW WEC was planned, sheltering a separate but closely co-located aquaculture system (courtesy of Floating Power Plant [10] and Fusion Marine [22])*

The project H2Ocean [18] [21] focused on the *"Development of a wind-wave power open-sea platform equipped for hydrogen generation with support for multiple users of energy"*. A series of techno-economic feasibility assessments, complemented by environmental impact analyses, were performed considering far offshore, multi-purpose farms in the Mediterranean sea, North Sea, and North Atlantic Ocean. These farms include offshore floating hybrid-wind-wave energy units, aquaculture units, and a number of service platforms. The latter are used to coordinate all the activities, for the production of hydrogen, considered the energy vector of the future, and as environment monitoring station. In Figure 1.2, a 3D sketch of a part of a multi-purpose farm is represented.

The development of closely co-located offshore wind, wave, and aquaculture infrastructures, assessing also their environmental compatibility and their economic feasibility, was at the core of the Mermaid project [19]. Focusing on four areas (Baltic Sea, North Sea, Atlantic, and Mediterranean), this project performed an assessment at technical, environmental, and socio-economic level of the solutions proposed. One of the solutions proposed is the hybrid wind-wave multi-purpose platform, composed of a triangular floating platform with three vertical columns at the corners and one in the middle, which supports a 5 MW wind turbine, and an oscillating water column (OWC) WEC installed in each cornet column (Figure 1.3 [23]. As a final result, guidelines for the development, management and implementation of Multi-Purpose offshore platforms in these European scenarios were provided.

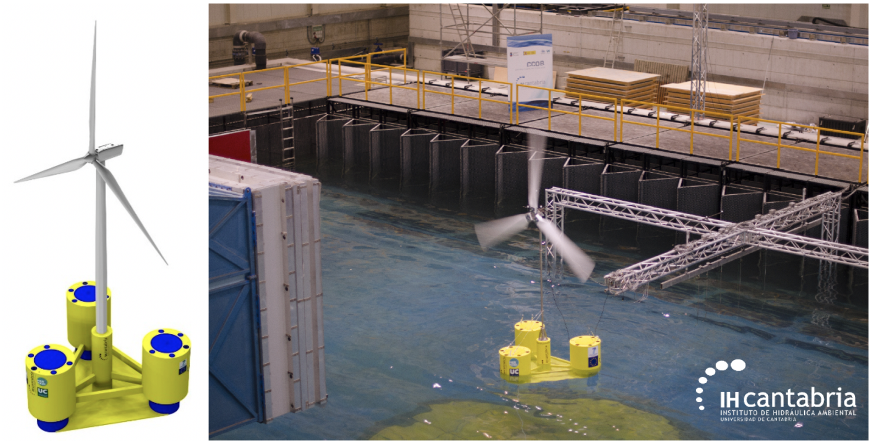


*Figure 1.3* *MUP platform developed by IH Cantabria within the the Mermaid project (FP7-28871), one of the multi-purpose platform concept proposed within the Mermaid project: a four column semisubmersible, with a triangular base plate, hosting a 5 MW wind turbine and three oscillating water columns WEC (one in each corner column). 3D model (left) and experimental test (right) [23](courtesy of IH Cantabria, Spain)*

The Tropos [20] [24] project, like the previous ones, looked at multi-purpose platform systems, but adopting a "modular" approach: the platform is composed of specialised modules and a central platform. The specific activities covered by the different modules are: maritime transport, renewable energy, aquaculture, and leisure. Three main multi-use platform concepts were defined and analysed [25] (Figure 1.4):

- the "Green & Blue" concept, located north of Crete, integrating offshore wind turbines and aquaculture (fish, algae) systems;
- the "Leisure Island" concept, off the coast of Gran Canaria, combining leisure facilities and solar energy systems;
- the "Sustainable Service Hub", located in the Dogger Bank (North Sea, UK), providing energy and transport services to the offshore wind farms planned in this region.

In parallel to these, other two projects were funded, focusing on multi-purpose platforms capable of utilising more than one offshore renewable energy source, but not including aquaculture systems: MARINA and ORECCA.

The MARINA platform project [26], or "Marine Renewable INtegrated Application Platform" project, brought together the offshore wind, wave, and tidal research and industrial communities, in order to assess the techno-economic feasibility of new systems, coupling multiple offshore wind and ocean energy converters. A number of concepts have been proposed and analysed, but eventually three main concep-

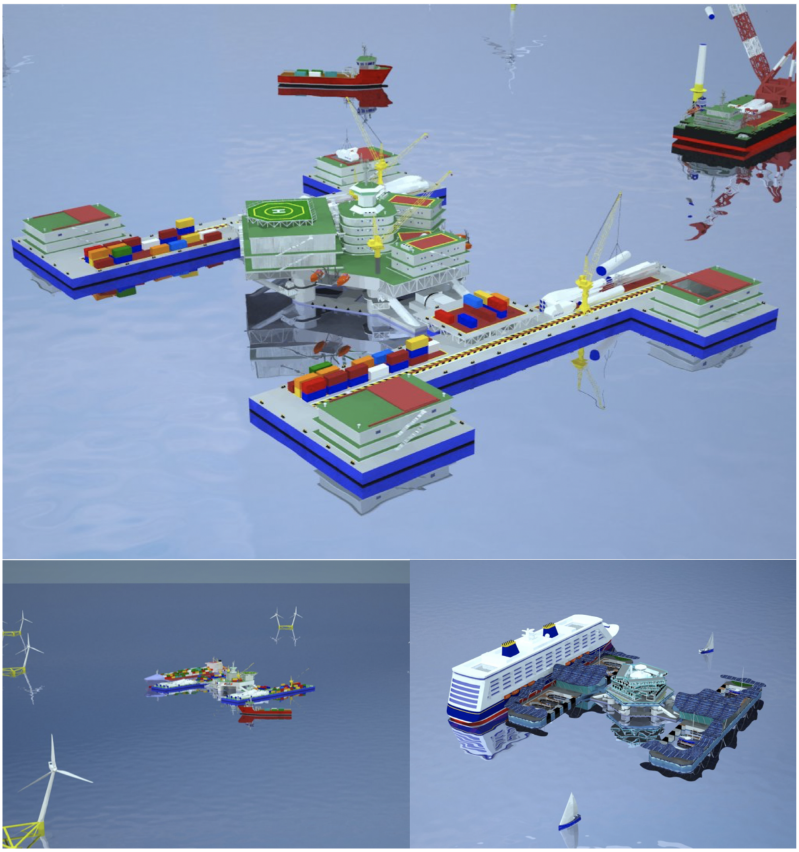

*Figure 1.4 (The three TROPOS multi-purpose platform concepts: service hub (top), green & bluse (bottom left), and leisure island (bottom-right) (courtesy of TROPOS Consortium)*

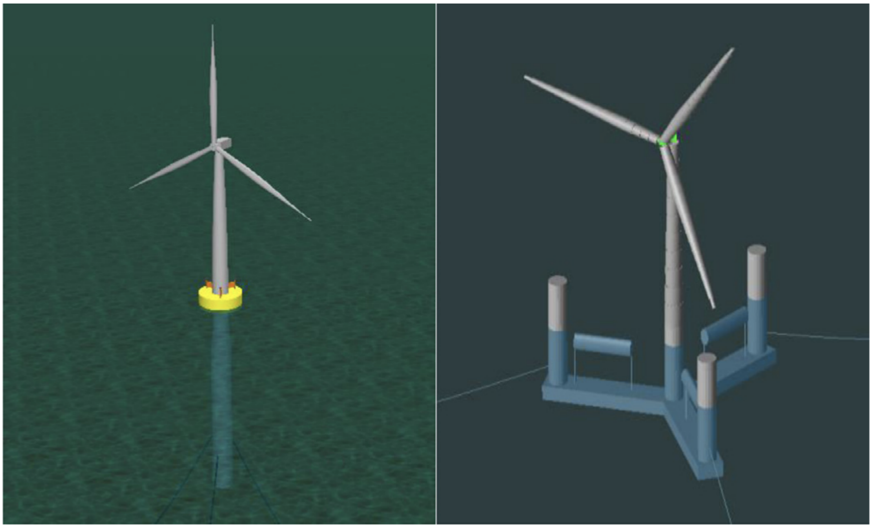

*Figure 1.5 MARINA Platform project [26], two hybrid wind-wave energy devices: (left) the Spar-Torus Combination (STC), and (right) the Semisubmersible-Flap Combination (SFC), 3D numerical models (courtesy of NTNU, Norway)*

tual designs have been proposed, coupling floating offshore wind turbine systems and wave energy converters: the “Spar Torus Combination (STC)”, the “Semisubmersible Flap combination (SFC)”, and the “Oscillating Water Column (OWC) array with wind turbines” (Figure 1.5).

The STC concept couples a 5MW Spar floating offshore wind turbine with a torus-shaped, coaxial body oscillating vertically with respect to the main spar body. This oscillation, through the use of a suitable power take-off system, can be used to extract energy from the waves [27]. The numerical analyses conducted suggest that, if compared with the separated systems, the STC combined wind-wave concept can reduce the total capital costs and increase the energy yield. The SFC [28] is a three-column, semi-submersible wind turbine combined with a rotating flap-type wave energy converter, hinged at the submerged pontoons of the semi-submersible. Based on the configurations analysed, comparing the platform with and without the wave energy converters, the dynamics of the floating wind turbine does not seem to be substantially affected, while the total power can be up to 8% higher. The OWC array consists of a large floater having multiple wave energy converters, and supporting a single wind turbine.

The ORECCA project [29] focused on bringing together the offshore renewable energy communities (wind, wave, tidal), in order to assess the state of the art in this field. It also prepared a roadmap for the further development of these technologies, trying to identify synergies whenever possible.

More recently, the European Commission funded two projects under the topic “Multi-use of the oceans marine space, offshore and near-shore: Enabling technolo-

*Figure 1.6 Photos of the Floating Power Plant P37 hybrid wind-wave platform: the turret mooring system (top-right in the picture) allow the platform to align perpendicularly to the main wave direction, enhancing the efficiency of the dynamically ballasted oscillating floaters. Three 11 kW wind turbines are coupled with the WEC system. IN this (courtesy of Floating Power Plant [10])*

gies (H2020, BG-04-2017)": Space@Sea [30] and The Blue Growth Farm [31]. These two projects build upon the experience and results accumulated in the previous initiatives, by proposing innovative multi-purpose platform concepts and testing them in a relevant environment, therefore bringing the technical maturity to TRL 5 [32].

There have been a number of companies proposing multi-purpose offshore platform concepts. A notable example is provided by Floating Power Plant [10], which claims to operate *"the world's only offshore-proven and grid-connected combined floating wind and wave device"*. Their P37 platform (Figure 1.6 is 37m wide and is grid-connected. It combines flap-type wave energy converters, with a total rated power of 134kW, to three 11kW wind turbines [33]. This platform has been operated since August 2013, and equipped with a number of sensors to assess its performance and to support the numerical modelling and analyses activities [34]. The full-scale concept proposed by the company is the P80, an 80m wide platform capable to combine wave energy converters with a total rated power between 2 and 3.6 MW (depending on location) and a wind turbine with a rated power between 5 and 8 MW.

he worlds only offshore-proven and grid-connected combinedfloating wind and wave device

Another concept, proposed by Pelagic Power AS, is the W2Power plant [35]. It combines a three-floater semisubmersible floating offshore wind turbine platform, accommodating two wind turbines with a rated power of 4-6 MW each, and a number of hemispherical point absorbers actuating hydraulic pumps, for a total rated power up to 3 MW, for a potential total rated power of 2x6 + 3 = 15 MW. A number of numerical analyses have been conducted, complemented by small scale ocean basin tests [36].

Table 1.2 summarises the discussed Multi-Purpose Platforms and their main functions.

*Table 1.2 Overview of multi-purpose platform concepts and their multiple functions*

| Concept | Aquacul. | Wind | Wave | Other ORE | Tourism | Transport |
|---|---|---|---|---|---|---|
| H2Ocean [18] | ✓ | ✓ | ✓ | | | |
| MERMAID (IHC) [19] [23] | | ✓ | ✓ | | | |
| TROPOS [20] Green & Blue | ✓ | ✓ | | | | |
| TROPOS [20] Leisure Island | | | | ✓ | ✓ | |
| TROPOS [20] Sust. Service Hub | | ✓ | | | | ✓ |
| MARINA (STC) [27] | | ✓ | ✓ | | | |
| MARINA (SFC) [28] | | ✓ | ✓ | | | |
| MARINA (OWC) [26] | | ✓ | ✓ | | | |
| Floating Power Plant P37 [10] | | ✓ | ✓ | | | |
| Pelagic Power AS W2Power [36] | | ✓ | ✓ | | | |

## 1.3 Design and analysis of Multi-Purpose Platforms

### *1.3.1 Multidisciplinary design methodology*

As reported by Zanuttigh et al. [13]: "*The design of these (multi-purpose) solutions is a complex interdisciplinary challenge, involving scientists and technical experts with different backgrounds*". Although the same can be stated for any offshore systems, in the case of multi-purpose platforms, the multidisciplinary aspect of the challenge is enhanced by the number of different systems considered, usually designed and analysed by different research and industrial communities. For example, the aquaculture community and the ORE community have been working independently until few years ago.

A detailed multi-criteria design methodology, suitable for closely co-located rather than integrated multi-purpose concepts, is presented by Zanuttigh et al. [13], based on four main steps:

- Pre-screening phase;
- Preliminary design of single-use platforms;
- Ranking phase;
- Preliminary design of the selected multi-use platform.

In the pre-screening phase, the importance of a combined resource assessment approach, to identify locations suitable from a multi-renewable energy point of view is highlighted (see section 1.3.2). In the second step, based on the pre-screening results, single-use platforms are designed at a preliminary level, assessing the potential overall production, and combining the single-use platforms in different multi-use layouts. In the third step, the different multi-use concepts proposed are evaluated against a set of multidisciplinary criteria, producing a ranked list of the proposed concepts. It is noteworthy to mention that, among the several criteria considered in the ranking phase, the "synergy with other uses" is considered. This is highlighted as an important aspect for the final choice. In the fourth step the selected optimum multi-use concept is further developed, refining some of the approaches adopted in the previous phases.

### *1.3.2 Resource assessment: combined wind-wave resources*

Multi-purpose platforms which can exploit multiple forms of renewable energy must be located at sites which fulfill several criteria:

1. all of the resources in question are available, at levels which can be economically exploited,
2. the platform can survive the worst environmental conditions,
3. the water depth and/or soil conditions are conducive to the platform,
4. and power can realistically be delivered to users, also considering important environmental consequences of cabling.

Furthermore, since one advantage of multi-purpose platforms is that they may be able to provide more uniform power output - for example, by producing electricity from waves during periods of low wind speeds - it is interesting to examine the temporal correlations among different electricity resources. For wind-generated waves, one can expect there to be a strong correlation between wind and waves. This would imply high variability in the power production, while a location which is exposed to swells or very long fetch would imply a lower correlation and lower variability in the total power production [37].

Several authors have studied the wind and wave resource at European locations, using either measured metocean data (typically at ORE tests sites, e.g. [38]) or hindcast data [37,39,40]. Hindcasts are numerical atmospheric and ocean models which use available historical measurements as inputs or boundary conditions to the simulations. Measurement data are also used to calibrate and check these models. Due to the limited number of co-located and temporally synchronized long-term measurements of wind and wave conditions, hindcasts are often used to obtain the necessary long-term statistics for different locations.

Kalogeri et al. studied a range of European sites with promising wind and wave resources and found some locations where the wind and wave power have reasonably low correlation (0.5-0.6) and good seasonal stability [37]. The power at each site was estimated using the power curve of a representative wind turbine and representative wave devices. The most promising locations were all sites which are exposed to Atlantic swells. The correlation $C$ for different time lags $\tau$ was defined as:

$$C(\tau) = N^{-1} \sum_{i=1}^{N-\tau} \frac{(x_i - \mu_x)(y_{i+\tau} - \mu_y)}{\sigma_x \sigma_y} \tag{1.1}$$

where $\mu$ represents the mean value, $\sigma$ represents the standard deviation, and wind and wave power are represented by $x$ and $y$. The index $i$ refers to the $N$ available observations.

Higher correlations between the wind and wave conditions were seen in closed or semi-closed basins (such as the Baltic Sea) where the waves are primarily wind-driven. Fig. 1.7 illustrates some of the results of their study: very high correlations can be seen for the Baltic Sea and English Channel, and those sites also show small variations in the time lag at maximum correlation. The more exposed sites have lower correlation - though the correlation can vary significantly during the year - and larger variations in the time lag which corresponds to maximum correlation. It is important to note that the mean wind and wave power both tend to be largest during the autumn (SON) and winter (DJF) for the selected sites.

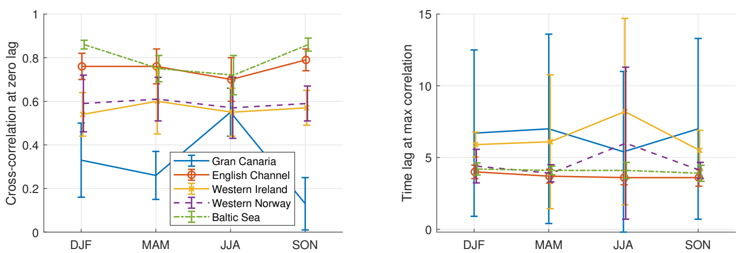


*Figure 1.7 Seasonal correlation between wind and wave power at selected sites (left) and time lag between wind and waves at maximum correlation (right). Selected European sites, data from Kalogeri et al. [37].*

Qualitatively, measurement data agree well with the hindcasts regarding the temporal correlation between wind and waves: the seasonal correlation between wind and wave power on the West and South-West coast of Ireland was estimated to be significantly lower (0.2-0.35) compared to the East coast (0.6-0.7) [38].

An evaluation of the joint probability distribution of the wind and wave conditions for similar European sites suggested that the extreme wind speeds do not vary significantly over the region, but the extreme wave conditions differ significantly [39]. The sites with the best wave power resource also tended to have the most severe extreme sea states: Atlantic sites had generally higher wave power potential and larger extreme significant wave heights than the North Sea sites [39].

### *1.3.3 Modelling and analysis*

*Table 1.3 Numerical modelling approaches*

| Platform | Aerodynamics | Hydrodynamics | Structural dynamics | Mooring model | PTO |
|---|---|---|---|---|---|
| H2Ocean [41] VAWT-WEC | BEM+DS | PF | All rigid | LM [42] | N/A |
| MERMAID IHC [23] | QST [43] | P: PF<br>W: PF [44] | All rigid | QS | LD+DP |
| MARINA SFC [46] | BEM [45] | P: PF+ME+NA<br>W: PF+ME | P: Rigid<br>T: FE<br>W: Rigid/FE | FE [45] | LD [45] |
| MARINA STC [27] | QST | PF+ME | T: Rigid<br>W: Rigid | QS | LD+LS |
| FPP - P37 [34] | BEM+DS | PF | MB | LM/Dyn | N/A |

T Turbine, P Platform, W WEC, PTO Power Take Off, MB Multi-Body
BEM Blade Element/Momentum, DS Dynamic Stall, QST Quasi-static Thrust
PF Potential Flow, ME Morison Eq., NA Newman's Approx
FE Finite element, Rigid rigid bod
LM Lumped mass, QS Quasi-static, Dyn Dynamic
LD Linear damping, LS Linear stiffness, DP Dynamic Pressure, N/A Not available

An overview of the main characteristics of some of the numerical approaches applied for the modelling of multi-purpose platforms is given in Table 1.3. Five main aspects have been analysed: aerodynamics, hydrodynamics, structural dynamics, mooring models, and the Power Take Off (PTO) system dynamics.

Two main approaches are adopted for quantifying the aerodynamic forces acting on the platform, and in particular on the wind turbine sub-system: a quasi-static thrust approach (QST), and the well-known Blade Element/Momentum approach (BEM) [36], which is corrected in some cases to take into account the effects of dynamic stall and dynamic inflow/wake. The QST is a simplified approach whereby the aerodynamic thrust acting on the wind turbine, at hub level, can be calculated at each instant of time (time domain simulation) as the product of the air density $\rho$, the velocity of the wind relative to the wind turbine, at hub level $V_{R,HUB}$, and a thrust coefficient $c_T$, a function of the tip speed ratio ($\lambda$) and of the angle between the average wind speed vector and the vector perpendicular to the rotor plane $\psi$:

$$T = 1/2\rho V_{R,hub}^2 A c_T(\lambda,\psi) \tag{1.2}$$

A number of approaches are adopted to quantify the hydrodynamic forces acting on the multi-purpose system. For large volume structures, a linear potential flow (PF) approach is used, complemented by a Morison equation (ME) approach to take into account viscous forces, especially for the small volume components of the platform. A Newman's approximation approach has been adopted to model the slowly varying force and moments acting on the support platform in the analysis of the MARINA - SFC system [46]. In general, the codes are limited when evaluating the hydrodynamic interactions between the platform and the elements of the WEC moving relatively to the platform - this is an active area of research. Furthermore, the PF numerical implementations and solvers are subject to numerical instabilities and errors, especially when there are some narrow gaps between the main platform body and the WEC elements, forcing to simplify the overall geometry of the multi-purpose platform (e.g. [41] [34]).

Several level of approximations are adopted for representing the structural dynamics of the platform. The support structure is usually represented as a rigid body. The WEC system can, at the simplest level, be considered as a rigid body, or modelling the main body interacting with the waves as a rigid body, while modelling with a Finite Element (FE) approach the connection of the WEC with the main platform (e.g. [46]). The wind turbine has been modelled as a rigid body or as a flexible body (FE), depending on the main aim of the analyses conducted: when evaluating the global response, the elasticity of the rotor and the tower of the wind turbine can be neglected.

The mooring line dynamics can be represented, at the most basic level, with a constant stiffness matrix, evaluated at a suitable position, ignoring any dynamic effect due to the inertia of the lines and the hydrodynamic forces (mainly viscous drag and added mass), therefore adopting a quasi-static approach (QS). The inertia of the lines can be considered when adopting a lumped mass (LM) approach, and when also the hydrodynamic forces are considered an LM/Dyn approach is adopted. A more accurate, but more computationally expensive, approach is the fully finite element representation of the lines (FE).

In a WEC, a Power Take Off system is, in general, defined as the system which converts the power absorbed by the main element interacting with the waves into useable power (electricity or others). Depending on the type of WEC, different models are adopted to represent this effect. In the case of OWC, as in [23], a linear damping approach (LD) to simulate the hydrodynamic viscous forces and a dynamic pressure (DP) approach to evaluate the pressure inside the chamber. When, instead, the relative movement between the WEC system and the main platform is exploited to produce power, the PTO is modelled as a linear damping force, or a linear damping plus linear stiffness force (e.g. [27]).

## 1.4 Conclusions

The terms "Blue Economy" and "Blue Growth" are now widely accepted terms. The World Bank defines these two terms concurrently as the *"sustainable use of ocean resources for economic growth, improved livelihoods and jobs, while preserving the health of ocean ecosystem"* [47] [48], while the World Wildlife Fund (WWF) states in its report "Principles for a sustainable Blue Economy" [49] that the *"Blue Economy means the use of the sea and its resources for sustainable economic develop-*

*ment. For others, it simply refers to any economic activity in the maritime sector, whether sustainable or not. "*

While there are still no commercially mature products, and just a few prototypes proposed by the industry, several research initiatives have been funded in this area, aimed at investigating the feasibility and sustainability of a number of multi-use concepts, adopting a multidisciplinary approach, i.e. considering the Political, Economical, Social, Technological, and Environmental (PESTLE) relevant aspects. Among these innovative concepts, an offshore multi-purpose platform can be defined as a platform (or a number of closely co-located platforms) that serves (or serve) the purpose of multiple offshore industries (Aquaculture, Biotechnology, Maritime Transport, Tourism, Renewable Energy, and others).

In the present chapter, first of all the potential synergies arising when closely co-locating these offshore activities, as identified in the literature, are summarised, highlighting the fact that these synergies emerge at different disciplinary levels (PESTLE). Then, an overview of the main multi-purpose platform projects and concepts is given: while the majority focused on hybrid offshore renewable systems, others also proposed concepts integrating aquaculture, tourism, and maritime transport systems.

Focusing on the design and analysis of multi-purpose platforms, the main differences and challenges when compared to the design and analysis of single-purpose systems are discussed. The enhanced multidisciplinary nature of the process, due to the number of different systems considered and to the legacy of sectors that have been evolved, so far, independently, is still perceived as one of the main challenges in this field. Furthermore, the necessity to perform a combined resource assessment is highlighted, providing as example an overview of the methodologies adopted to perform a combined wind-wave energy resource assessment.

Although this is a relatively new and rapidly evolving research field, an overview of the so-called aero-hydro-servo-elastic engineering approaches, which model the aerodynamic and hydrodynamic forces acting on the platform, as well as their structural dynamics response and the control strategy adopted, is presented. A number of numerical approaches, ranging from quick, robust, low accuracy techniques to high-accuracy but computationally expensive methodologies, are discussed, also highlighting the emerging research gaps.

To summarise, the "Blue Growth" can be a further agricultural/industrial revolution, with its potential to provide (in a sustainable manner) food, energy, jobs, economic prosperity to a world population that is both increasing and demanding higher living standards. Multi-purpose platforms could very well be one of the optimum way to unleash this potential, but the focus has to be on identifying the synergies and tensions arising when closely co-locating these offshore activities, and find a way to maximise the first while eliminating or minimising the last.

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