MERMAID

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Seventh Framework Programme
Theme [OCEAN.2011-1]
"Innovative Multi-purpose off-shore platforms: planning, design and operation"
Grant Agreement no.: 288710
Start date of project*: 01 Jan 2012 - Duration: 48 month*

Deliverable: D7.3	
Nature of the Deliverable:	Book
Due date of the Deliverable:	M48: 31.12.2015
Actual Submission Date:	M49: 26th of January 2016
Dissemination Level:	PU
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Version	**Date**	**Revised Pages**	**Description of Changes**
1.0	June 2015	-	1st Draft released
1.1	November 2015		Book finished
1.2	January 2016		Final version of D7.3

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1 Public Summary - The significance of the MERMAID project

European oceans will be subject to massive development of marine infrastructure in the near future. This change of infrastructure makes the concept of multi-use offshore platforms particularly interesting, especially in connection with the development of energy facilities, e.g. offshore wind farms, exploitation of wave energy, and also development and implementation of marine aquaculture.

The development of new concepts requires effective marine technology and governance solutions. Simultaneously, both economic costs and environmental impacts have to remain within acceptable limits. These concerns are at the core of the MERMAID project funded under ‘The Ocean of Tomorrow’ call for proposals.

The different nature and characteristics of industries challenge the idea of the multi-use concept, as most industries see the corporation as a complicating factor. Therefore, future developments have to address this concern and making the potentials clearer. Stakeholder involvement was more successful on multi-use mature sites. Therefore, a steady evolution towards a multi-use platform might be the most successful path to follow.

At the end of the project, a set of specific guidelines were produced in order to assist future stakeholders within the offshore industries with a view to planning, establishing and operating their businesses in the most optimal way. The multi-disciplinary and cross-sectorial approach of this project is very innovative and the EU benefit lies in the case studies that address four EU-regional seas.

This report consists of a concise report on the major findings of MERMAID with special focus on the four sites, and a more in depth descriptions of the findings on the four sites. The relative short concise report with the title “Go offshore – Combining food and energy production” has also been published by DTU under the ISBN: 978-87-7475-424-4 and distributed at the end-user conference. This part is in particularly relevant for the broader audience.

You can find a pdf version of the book on:
http://www.mermaidproject.eu/index.php?option=com_content&view=article&id=48&fromhomenews
and at:
http://orbit.dtu.dk/en/publications/go-offshore-combining-food-and-energy-production(7bb8c68e-eda9-4235-9059-2534084467da).html

Go offshore

- Combining food and energy production

INNOVATIVE
MULTI-PURPOSE
OFFSHORE
PLATFORMS

MERMAID

Content

The significance of the MERMAID project

European oceans will be subject to massive development of marine infrastructure in the near future. The development includes energy facilities, e.g. offshore wind farms, exploitation of wave energy, and also development and implementation of marine aquaculture This change of infrastructure makes the concept of multi-use offshore platforms particularly interesting.

The development of new concepts requires effective marine technology and governance solutions. Simultaneously, both economic costs and environmental impacts have to remain within acceptable limits. These concerns are at the core of the MERMAID project funded under 'The Ocean of Tomorrow' call for proposals.

At the end of the project, a set of specific guidelines are produced in order to assist future stakeholders within the offshore industries with a view to planning, establishing and operating their businesses in the most optimal way. The multi-disciplinary and cross-sectorial approach of this project is very innovative and the EU benefit lies in the case studies that address four EU-regional seas.

MERMAID established close links with the other projects, TROPOS and H2OCEAN, funded under the same 'The Ocean of Tomorrow' topic in order to enhance complementarities and synergies.

The different nature and characteristics of industries challenge the idea of the multi-use concept, as most industries see the corporation as a complicating factor. Therefore, future developments have to address this concern and making the potentials clearer. Stakeholder involvement was more successful on multi-use mature sites. A steady evolution towards a multi-use platform might be the most successful path to follow.

The MERMAID project began in 2012 and finalizes at the end of 2015. The project is comprised of 29 partners from across Europe, including 11 universities, 8 research institutions, 6 industries, and 4 small and medium-sized businesses. DTU Mechanical Engineering is coordinating the project.

Photo by Kelefonia Fisheries

What are the potentials and challenges for multi-use offshore platforms?

What will the use of the ocean space look like in year 2035?

As always, it is very difficult to make predictions - especially about the future. To get closer to the answer, facts about the previous 20 years of development in the offshore area provide some indications on the trend. We are back in 1995 when the offshore oil and gas industry had achieved a mature state. Many European countries had a major offshore oil and gas industry such as Norway, UK, Denmark, the Netherlands, and Italy, but before the development of the industry, the North Sea was exploited for fisheries, surface transport, and also, to some extent, mineral resources such as sand and gravel.

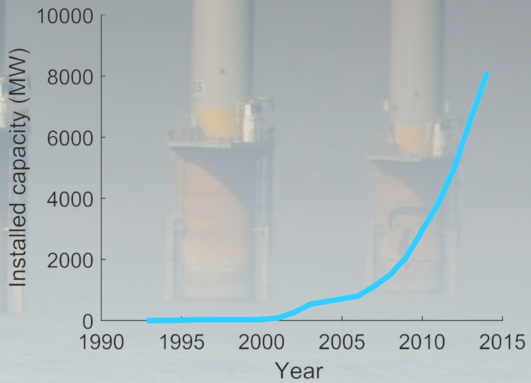
Offshore wind

At the beginning of the new millennium, this picture started to change. Exploration of offshore wind resources has been growing during the past 15-20 years. The figure shows the cumulative installed capacity indicating an industry under rapid development for the past two decades.

The first major offshore wind farms were Horns Rev 1 and Rødsand 1 in Danish waters with a capacity of 160 MW and 166 MW, respectively. Other countries initiated development in offshore wind and today, the UK has the largest installed capacity with a share of 56 per cent, followed by Denmark with 16 per cent, Germany with 13 per cent, and Belgium with 9 per cent (Corbetta et al 2015). The remaining capacity is shared by a number of countries - especially around the North Sea and the Baltic Sea. The relative shallow waters (15-40 m) makes it attractive to install offshore wind in these regions as wind turbines can be installed on bottom-mounted support structures. Monopiles are the most frequent type of foundation followed by gravity-based foundations.

The main challenge to offshore wind is the Cost of Energy (CoE). This is still high, and much research and development focuses on reducing CoE.

Photo: © Karl Van Ginderdeuren



Graph: Erik D. Christensen, DTU

Aquaculture

Marine aquaculture production is increasing in Europe - mostly due to salmon production in Norway. Other types of production are relatively stable or stagnating since the early 2000s. In the EU, the production of aquaculture products have actually stagnated during the latest decade. In 2012, by far the most cultivated species in Europe was Atlantic salmon, followed by mussels, rainbow trout, European sea bass, gilthead sea bream, oysters and carps, barbel, and other cyprinids. Finfish production accounts for the increase in European aquaculture, while shellfish production has been slowly decreasing since 1999. Aquatic plants production has been emerging since 2007.

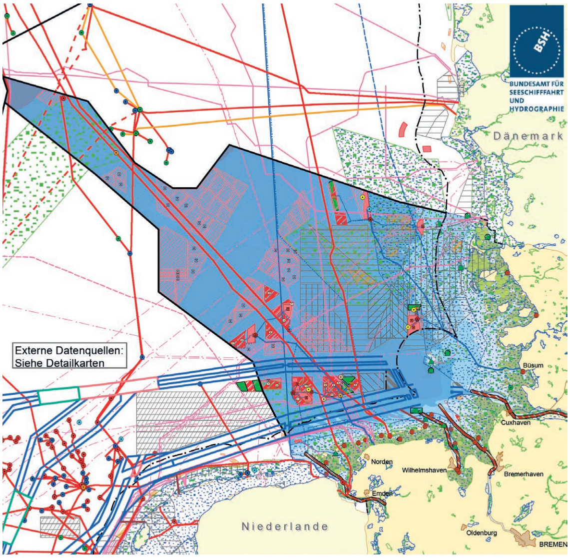
Photo: Casper Guldberg Petersen, Hvalpsund Net

The challenges for offshore aquaculture are twofold. Off shore, the wave climate becomes harsher which calls for new, improved technology. However, one of the main challenges to aquaculture is the difficulties in getting permissions to, for instance, exploit the ocean space for fish production. So what are the reasons for these difficulties? Are they related to the public's perception of a polluting industry - that the ocean space has already been taken up for other purposes - or is it that the legislation simple is not able to accommodate aquaculture? The environmental concern may be a key issue that has to be addressed to convince the public and legislative authorities to pave the way for a more fruitful development of the aquaculture industry.

Open sea or crowded sea?

You might think that the ocean has an unlimited amount of space. It is true that about 70 per cent of the Earth's surface is covered by water, but all of the ocean space is not equally attractive from a development point of view. Use of the ocean space at far distances as in the middle of the Pacific or Atlantic oceans is not attractive for many other purposes than sea surface transport. Any facilities that have to be operated and maintained face logistic problems when the distances become too large. Therefore, most ocean-based activities take place quite close to land, approx. 50-100 km from land. At these distances, sea surface transport is also often a bottleneck. Other industries such as the fisheries (as pointed out in Jentoft & Knol 2014) meet new challenges. The challenges include increasingly congested areas where open space is getting increasingly scarce. The congestion is caused by the expansion of existing usages as well as the introduction of new ones.

An illustrative example of the use of the ocean space is given in the figure below which shows different uses of the German part of the North Sea.



Nico Nolte, Bundesamt für Seeschifffahrt und Hydrographie (BSH).
http://www.bsh.de/de/Meeresnutzung/Wirtschaft/CONTIS-Informationssystem/ContisKarten/NordseeSaemtlicheNutzungenSchutzgebiete.pdf

The extended use of the ocean space therefore needs a fresh view on how the different functionalities are accommodated. For instance, when offshore wind farms are planned they typical get exclusive rights to a very large area. This excludes other uses for several decades ahead, and therefore could act as a limiting factor for emerging industries and uses.

Can different industries work together?

There is a large difference with respect to cost characteristics between the wind and aquaculture industries. In offshore wind, a very large part of the cost is CAPEX, (capital expenditure) that takes up of around 80 per cent of the cost of energy, while only 20 per cent is operating expenditures. In aquaculture the cost characteristics are close to be opposite where the operating expenditures are far highest (70-80 per cent). The spatial extent of a fish farm is in the order of 500 m x 500 m, which is substantially smaller than the size of an offshore wind farm which typically covers an area of 5 km x 5 km to 10 km x 10 km. So the two industries mainly have the use of ocean space in common.

The operational nature of the two industries is also quite different. The operating expenditure in mariculture are mainly fish and feed. The fish cages regularly have to be retrieved from site to land for maintenance and renewal of outworn parts, for instance annually. During the production period, an offshore fish farm is typically serviced every day. The staff operates the fish cages from a service vessel nearby. An offshore wind farm can be operated from land via sea or air-borne vessels, or from a local accommodation platform. However, in both cases, logistics planning is crucial for an offshore wind farm as distances inside an offshore wind farm are up to several kilometres. Service of wind turbines include planned maintenance, but also on unforeseen breakdowns.

The two industries are different, but have a common interest related to the operation of their installations. Here, common use of forecast and warning systems, accommodation platforms, and - to some extent - sharing of staff. However, as in many other industries both offshore wind and aquaculture have a high focus on their own needs and possibilities. This is seen as one of the main barriers to the development of a multi-use offshore platform.

Photo: Kelefonia Fisheries

Showstoppers

In the course of the project, critical issues that can hamper the combination of food and energy production were identified.

- Cooperation requires a positive attitude of the industries involved. This is not always easy as company cultures can differ.
- Industries need to see ‘what’s in it for them’, whether this is cost reduction, access to new markets, a good image, or easier permission procedures.
- Successful co-production requires a site suitable for both energy and food production. This is not self-evident and there might be a lack of suitable ocean space.
- European policy-makers show keen interest in co-production of energy and food but permitting procedures for upcoming industries, such offshore aquaculture, and co-production are lagging behind.
- Even if corporate and political goodwill is present, technical challenges can be difficult to solve. The harsh offshore environment is a serious challenge to new structures.
- Higher risks that negatively affect economic feasibility
- Change in European politics.

The next steps

The projects on multi-use offshore platforms have given momentum to the development of innovative concepts and already many new insights have been gained. However, there is still a substantial amount of work to be done and knowledge gaps to be filled. Among others, field demonstration of selected concepts, the filling of scientific and technical gaps, development of synergies, and new uses and applications in order to increase attractiveness, are needed.

From the studies, the most attractive way to implement the multi-use offshore concept is to use the same ocean space for several functionalities. The advantages are that the technical development is less cumbersome as they can build on previous experiences. The concept also addresses the challenge of the crowded sea. In connection with multi-use offshore platforms (MUOPs), collaboration on a common accommodation/service platform seems to be an attractive way to initiate collaborations across industries.

Consideration should also be given to ‘nearshore’ developments. Large parts of the ocean space that are suitable for industrial development, economically and spatially, are located at the boundaries of coastal and offshore regions. Utilization of these regions is more optimal and holds very significant potential for the multi-use concept.

There is a need for more focused research related to multi-use offshore platforms. The outcomes of the projects have revealed specific research needs, such as the need for studying

1. flexible offshore structures in oceanic conditions
2. husbandry tools and procedures for offshore aquaculture,
3. the role of legislation and socio-economic impact on the development of the industries, and
4. the optimization of cost-efficiency through the development of innovative technologies related to moorings, operations, reliability, safety, and security.

The prospects for the future use of ocean space

The momentum in developing the use of the ocean space is already very strong. Therefore, it is likely that the use of the ocean space will continue and increase. The optimal solution depends on a number of aspects, such as sufficient development of new technologies, effective planning and legislation, and improved understanding of different industries. The use of ocean space for many purposes will be beneficial to European societies.

What can we learn from study sites around Europe?

Introduction

In order to contribute to real design concepts and industrial application, four pilot study sites with different environmental characteristics have been identified (see the map on page 7).

1. Baltic Sea site - Krigers Flak, Estuarine site
2. North Sea site - Wadden Sea, Gemini site
3. Atlantic Ocean site - Ubiarco and Santoña, Cantabria Offshore Site - Far offshore area
4. Mediterranean Sea site - Area offshore Venice

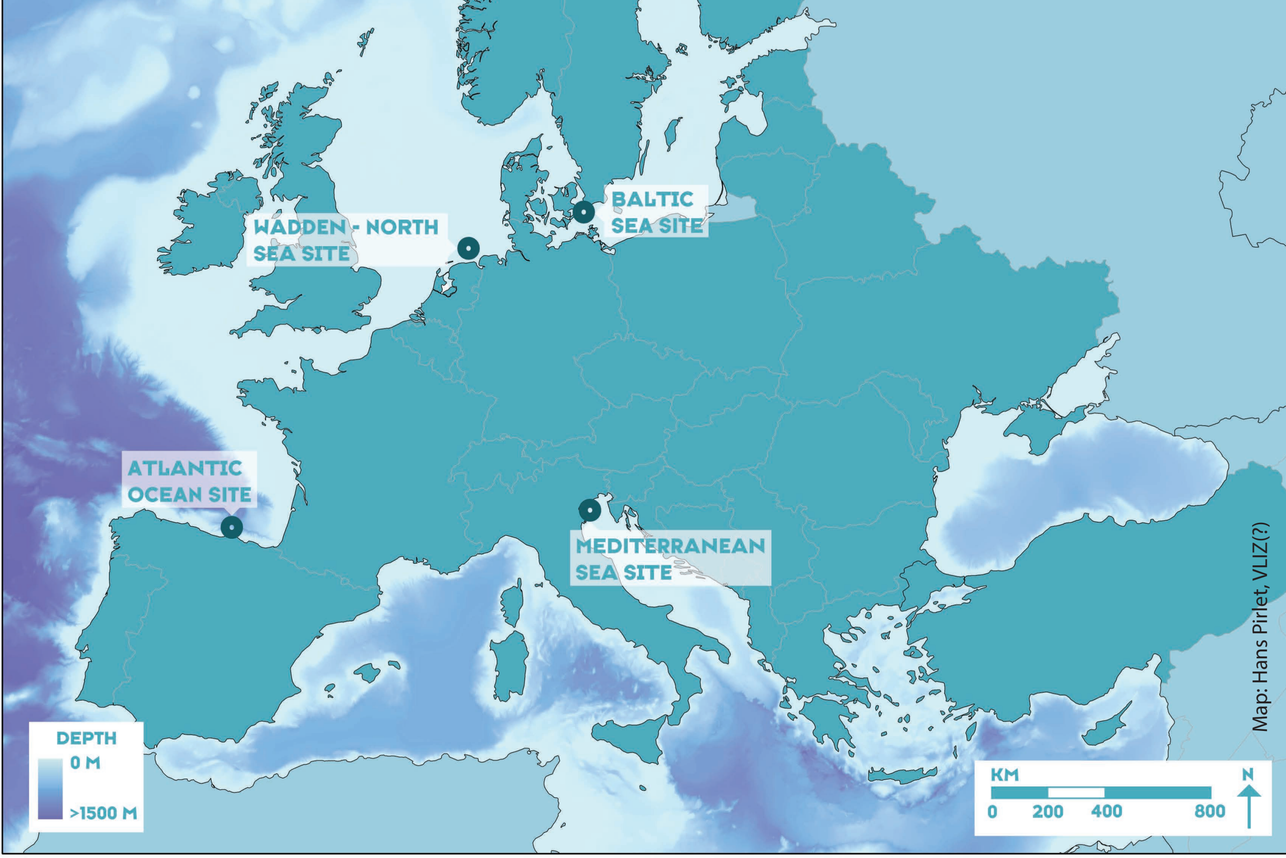
The sites represent specific challenges in relation to environmental, social, and economic conditions (as shown in the table) as well as the availability of data and the opportunity to link directly to local research teams, stakeholders, policy managers, SMEs, and industrial networks.

A series of possible design options and industrial interaction were scoped and conceptually designed on a site-by-site basis.

The selected conceptual design of the multi-use platform (MUOP) was an iterative participatory process with stakeholders. The participatory process depended on the existence and/or flexibility of policies and socio-economic and environmental management schemes or constraints.

For the design and the planning, the following were included

- Assessment of the site conditions and requirements (stakeholders requirements; local demand for energy, food; spatial study of the resources)
- Preliminary design of MUOPs (technical evaluation; energy and food production performance; construction, installation, operation, servicing, maintenance)
- Evaluation of MUOP designs (environmental impact assessment, economic evaluation, benchmark to single-use solutions)
- Selection of the preferred design based on a multi-criteria analysis aiming to assure sustainable development of the area;
- Evaluation of possible consequences on policies, and specifically on marine spatial planning.



Map: Hans Pirlet, VLIZ(?)

Main characteristics of the four study sites analysed within MERMAID project.

Site, sea	Environmental characteristics	Design type	Specific issues
Baltic Sea site - Krigers Flak, Estuarine site	High wind energy potential Optimal conditions for temperate fish Baltic and North Sea flow exchange	Wind turbines Gravity based foundations Extensive mariculture	Dredging Mariculture spills
North Sea site - Wadden Sea, Gemini site	High wind energy potential Optimal conditions for seaweed North and Wadden Sea sediment exchange	Wind turbines Gravity-based foundations Extensive aquaculture	Economic feasibility Scour and backfilling processes Environmental impact
Atlantic Ocean site - Ubiarco and Santoña, Cantabria Offshore Site, Far Offshore area	Very high wind and wave energy potential	Wind turbines Wave energy converters Floating platform	Grid connection Moorings
Mediterranean Sea site - Area offshore Venice	Mild wind and wave energy potential Good conditions for mussels and fishes	Wind turbines Gravity-based foundations Fish farming	Grid connection Environmental impact Economic feasibility

The Baltic site

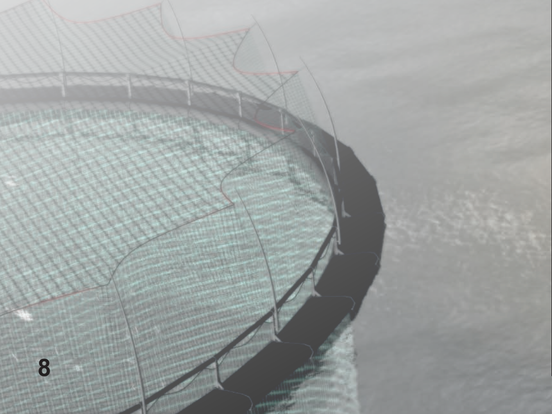
Kriegers Flak - a shallow ground within the Danish Exclusive Economic Zone EEZ in the estuary of the Baltic Sea - provides an excellent site for harvesting of multi-use offshore platform synergies, combining a 600 MW offshore wind power plant, 10000 tons salmonid aquaculture and possibly biomass production from seaweed.

The Baltic Sea is the world's largest estuary, comprising salty North Sea water mixed with freshwater from rivers in Russia, Scandinavia, the Baltic countries, and a large part of Northern Europe. Kriegers Flak is a shallow (25 m) ground situated at the confluence of the Danish, Swedish, and German economic interest zone, approximately 15 km from Danish and Swedish coasts. Studies within MERMAID have indicated that the site is very well suited for MUOP development, the site being characterized by medium, but high-quality, wind resource, moderate exposure to waves, and currents and salinities and temperature being close to optimal for salmonid aquaculture.

Wind and fish farms

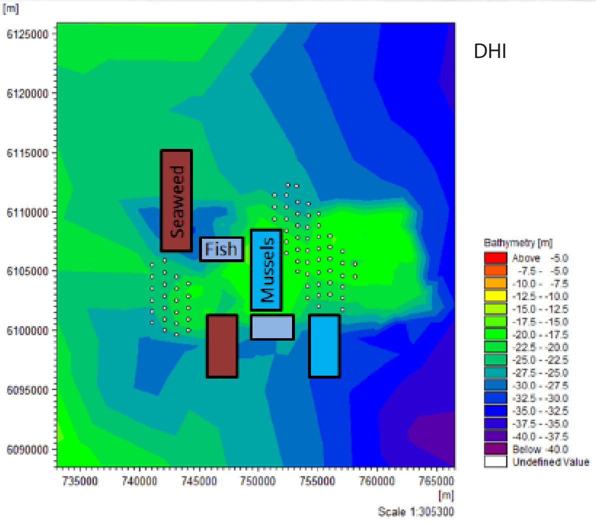
The wind farm is estimated to consist of two areas with a total of 80 8 MW turbines. The seabed conditions are good, thus foundations may be of gravity-based type or driven monopiles. In addition to the turbines, two 220 kV substations and required submarine cables to onshore connections are planned.

In the Baltic Sea, an important shared resource is ocean space. Therefore, more efficient utilization of the space by co-locating aquaculture and wind energy plants is an important feature of an MUOP here.



Optimal conditions for fish farms

Analyses indicate that fish farms with an annual production at 10,000 tons of salmon or trout will be feasible. The fish farming is planned as two separate facilities located between the two groups of turbines to gain some physical protection from the foundations and the wind turbines. Each fish farm section will consist of 12-14 round cages with a diameter of 45 m and a feeding barge delivering feed by means of compressed air through tubes to each cage. The depth of the net cages will be 12-15 m and the cages may be either floating or submersible. The conditions at the site are favourable in terms of dilution of losses from the farm and optimal conditions for fish growth and quality.



Spatial layout of multi-use platform with wind energy plant and fish farming.

Baltic Site Factsheet	
Geographical location	Kriegers Flak, Western Baltic Sea
Offshore distance	15 km east of the Danish coast
Depth	18 - 40 m
Substrate	Sandy layer (thickness of up to 8 m)
Surface water temperature	0 - 20°C
Salinity	7 - 9 psu (upper 15 - 18 m)
Currents density	Variable currents driven by wind, gradients & differences in sea level
Mean tidal range	No tides present
Wave height	Mostly moderate (1 - 1.5 m)

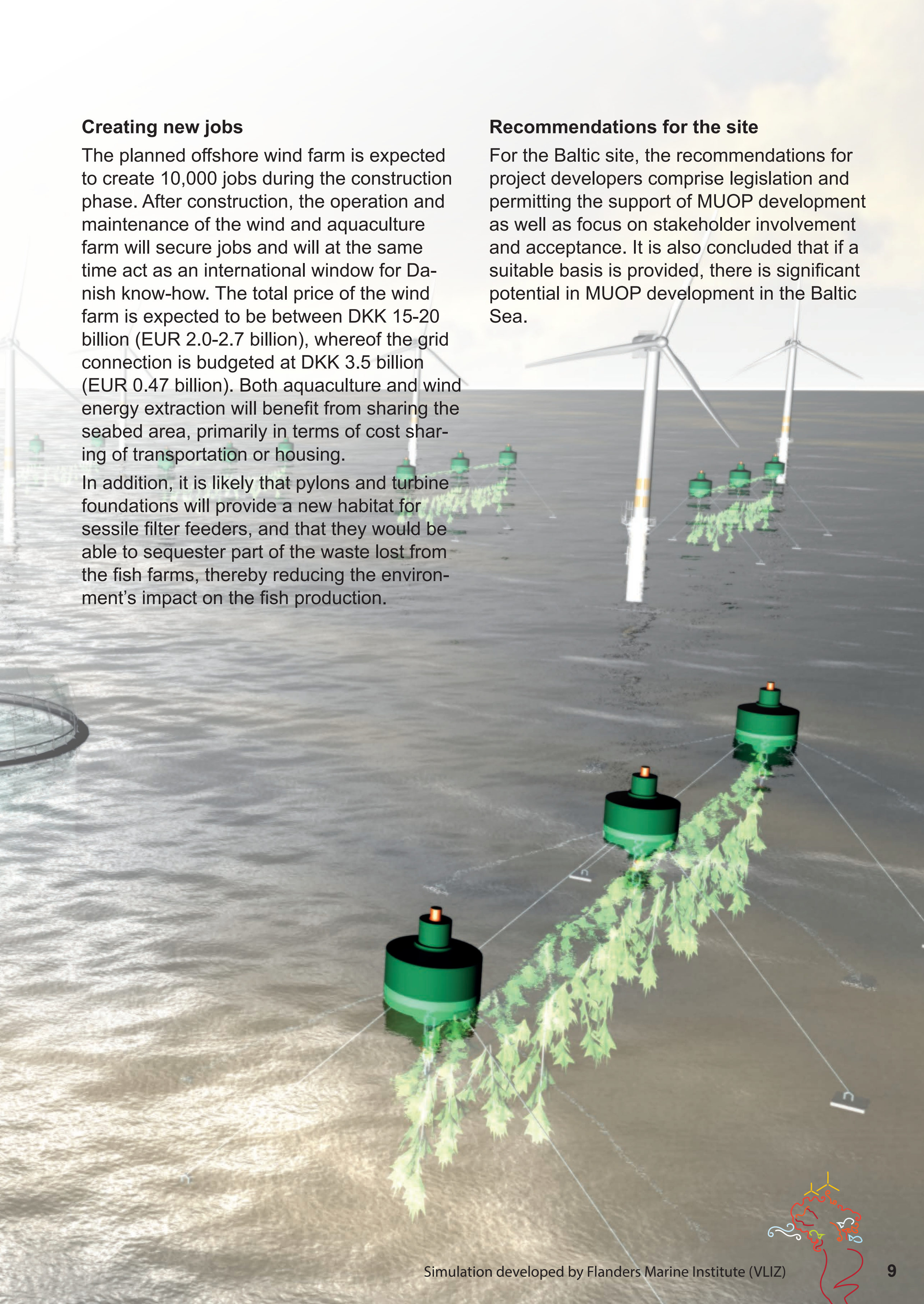
Creating new jobs

The planned offshore wind farm is expected to create 10,000 jobs during the construction phase. After construction, the operation and maintenance of the wind and aquaculture farm will secure jobs and will at the same time act as an international window for Danish know-how. The total price of the wind farm is expected to be between DKK 15-20 billion (EUR 2.0-2.7 billion), whereof the grid connection is budgeted at DKK 3.5 billion (EUR 0.47 billion). Both aquaculture and wind energy extraction will benefit from sharing the seabed area, primarily in terms of cost sharing of transportation or housing.

In addition, it is likely that pylons and turbine foundations will provide a new habitat for sessile filter feeders, and that they would be able to sequester part of the waste lost from the fish farms, thereby reducing the environment's impact on the fish production.

Recommendations for the site

For the Baltic site, the recommendations for project developers comprise legislation and permitting the support of MUOP development as well as focus on stakeholder involvement and acceptance. It is also concluded that if a suitable basis is provided, there is significant potential in MUOP development in the Baltic Sea.



Simulation developed by Flanders Marine Institute (VLIZ)

The North Sea site

The North Sea is characterized by relatively shallow waters and excellent wind conditions that are ideal for offshore wind development. Therefore, the largest installed capacity of offshore wind in the world is found in this area. Even larger offshore wind farm developments are proposed for the coming decades, significantly increasing spatial claims of already one of the busiest seas in the world. Furthermore, the North Sea waters contain relatively high values of nutrients, calling for the combination of different types of aquaculture with offshore wind farms as a promising multi-use concept.

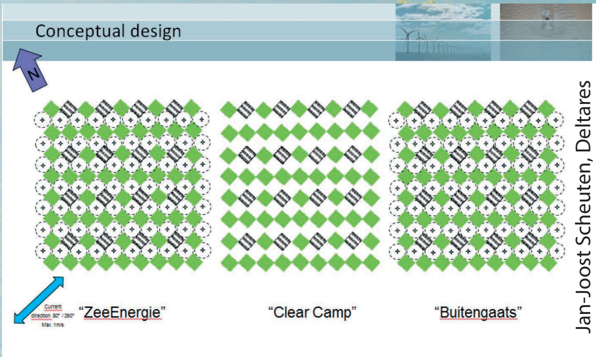
The Gemini project

The MERMAID project focused specifically on the study area located 55 km north of the Wadden Sea Islands north of the Netherlands - called the Gemini site. This site consists of three permits, from which two sites of 300 MW of installed capacity are under construction during the MERMAID project, enabling broad involvement of stakeholders.

The wind farm consists of two areas with a total of 150 4 MW Siemens turbines and will be fully operational in 2017. The seabed conditions are excellent and monopiles are selected as foundations. In addition to the turbines, two 220 kV substations and two required submarine cables to the onshore connection at Eemshaven are developed.

Seaweed, shellfish and wind

Although these offshore wind farms only have licenses for single use, more stakeholders in the Netherlands are starting to discuss multi-use possibilities, such as regional fishermen and entrepreneurs for aquaculture and tourism. In collaboration with the identified stakeholders, offshore wind farms combined with seaweed and mussel aquaculture was identified as the most promising conceptual multi-use design, see the figure below. Seaweed will increasingly gain importance as a raw material and the most relevant benefit of local cultivation is the possibility to offer wet seaweed on the local market.



Jan-Joost Scheuten, Deltares

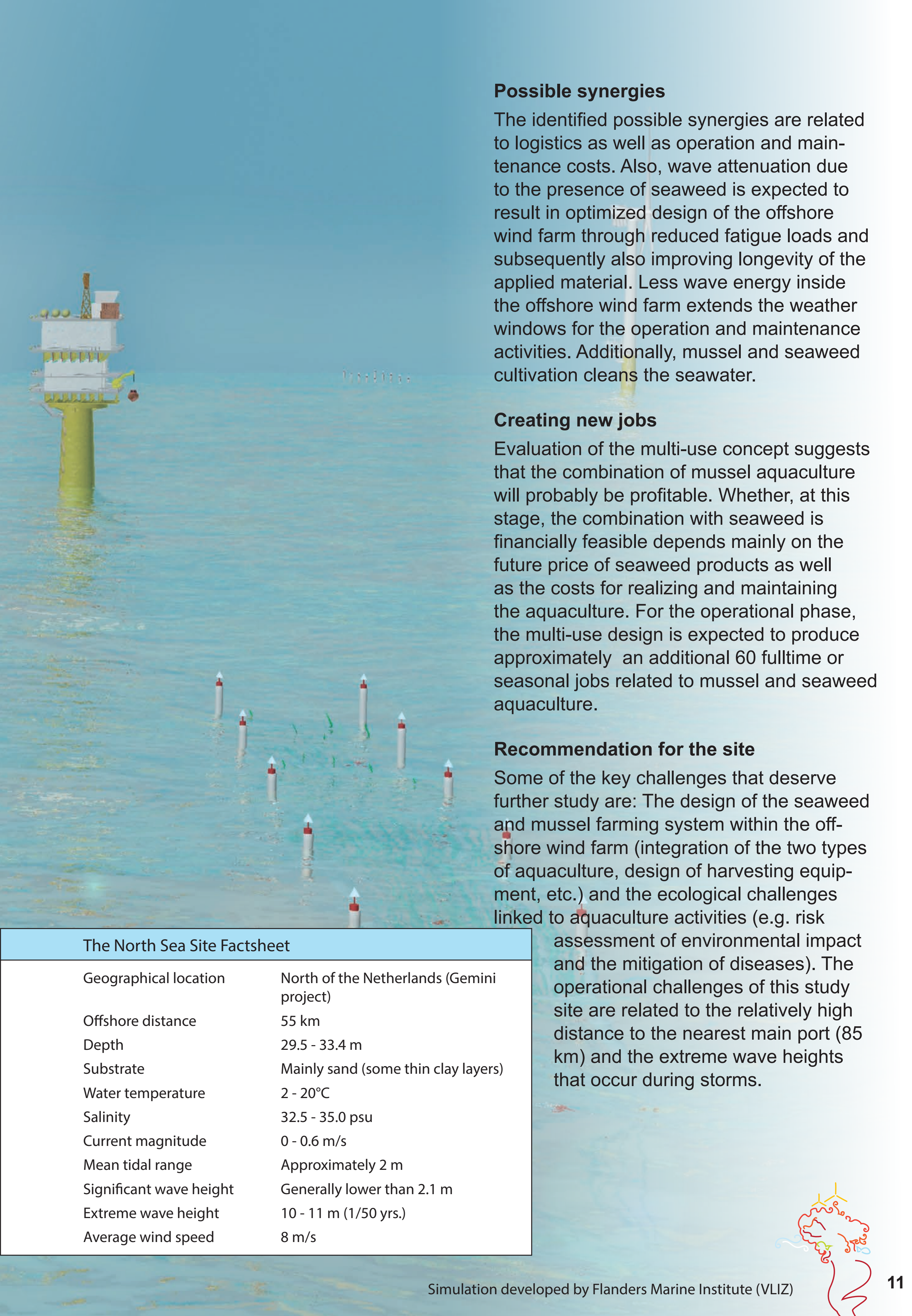
The shellfish industry is looking for additional fishing grounds for mussel seed collectors and cultivation of mussels on long-lines. The market demand for the blue mussel is twice the current Dutch production.

Fish aquaculture was excluded from the design due to relatively high water temperature peaks during the summer. Currently, no native species are expected to survive under these circumstances while being in a relatively shallow cultivated environment in the North Sea. Wave energy convertors were initially considered, however due to the low efficiency in combination with limited availability of wave energy in the North Sea, it was concluded that this function is currently not feasible.

Based on the technical feasibility analyses followed by the (socio-)economic analyses, the capacity and production per function are estimated as follows:

Function	Capacity	Production
Wind energy	600 MW	2,600 GWh
Mussels	3 kg WW/m2	48 kton WW
Seaweed	10 kg WW/m2	480 kton WW

Photo: © Henrice Jansen IMR



Possible synergies

The identified possible synergies are related to logistics as well as operation and maintenance costs. Also, wave attenuation due to the presence of seaweed is expected to result in optimized design of the offshore wind farm through reduced fatigue loads and subsequently also improving longevity of the applied material. Less wave energy inside the offshore wind farm extends the weather windows for the operation and maintenance activities. Additionally, mussel and seaweed cultivation cleans the seawater.

Creating new jobs

Evaluation of the multi-use concept suggests that the combination of mussel aquaculture will probably be profitable. Whether, at this stage, the combination with seaweed is financially feasible depends mainly on the future price of seaweed products as well as the costs for realizing and maintaining the aquaculture. For the operational phase, the multi-use design is expected to produce approximately an additional 60 fulltime or seasonal jobs related to mussel and seaweed aquaculture.

Recommendation for the site

Some of the key challenges that deserve further study are: The design of the seaweed and mussel farming system within the offshore wind farm (integration of the two types of aquaculture, design of harvesting equipment, etc.) and the ecological challenges linked to aquaculture activities (e.g. risk assessment of environmental impact and the mitigation of diseases). The operational challenges of this study site are related to the relatively high distance to the nearest main port (85 km) and the extreme wave heights that occur during storms.

The North Sea Site Factsheet

Geographical location	North of the Netherlands (Gemini project)
Offshore distance	55 km
Depth	29.5 - 33.4 m
Substrate	Mainly sand (some thin clay layers)
Water temperature	2 - 20°C
Salinity	32.5 - 35.0 psu
Current magnitude	0 - 0.6 m/s
Mean tidal range	Approximately 2 m
Significant wave height	Generally lower than 2.1 m
Extreme wave height	10 - 11 m (1/50 yrs.)
Average wind speed	8 m/s

Simulation developed by Flanders Marine Institute (VLIZ)

The Atlantic site

The Atlantic site presents deep sea and harsh ocean conditions. To be more precise, by the Cantabria Offshore Site (COS). COS is characterized by a moderate wave and wind energy resource. The available mean wave energy resource is 25-30 kW/m and the mean available wind power is 600 W/m2. The high energy content makes the site very attractive for developing multi-use offshore platforms.

The Cantabrian Sea is a small part of the Atlantic Ocean. It consists of an area between the Biscay Gulf at the East and Galicia at the Western part of the Iberian Peninsula. A narrow continental shelf combined with open sea conditions exposed to northwestern storms lead to a severe ocean environment.

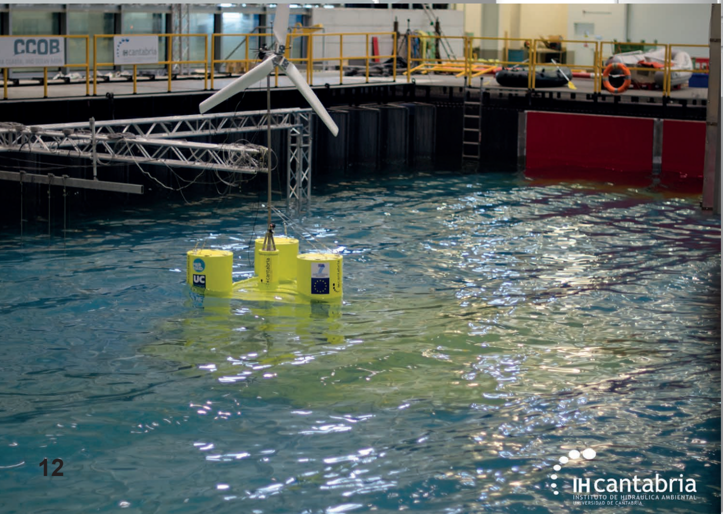
COS is situated 10 km North from the coast of Santander (Cantabria) and it covers to 60 km2 of sea. COS ocean conditions are severe and challenging. The 50 year return period significant wave high and average expected wind speed will be around 9m and 27m/s respectively. A number of 77 units of multi-use offshore Platforms are expected to be installed. Based on the wave and wind energy availability, each unit will be equipped with a 5 MW wind turbine, as well as a wave energy concept based on Oscillating Water Colum (OWC) technology. The expected average annual power production is around 80 GWh.

Innovative ocean energy harvesting: Wave and wind energy synergies

The MUOP farm proposed will be integrated in a site characterized by a wide range of water depths comprehended between 40 and 200 meters where floating structures are the most suitable technology for ocean energy harvesting.

The multi-use offshore platform developed is a novel concept based on a triangular concrete made semisubmersible. It is equipped with four columns, three at each vertex and one at the centre of the triangle. The three outer columns are equipped with the OWC technology already mentioned, and the central one supports the 5 MW wind turbine.

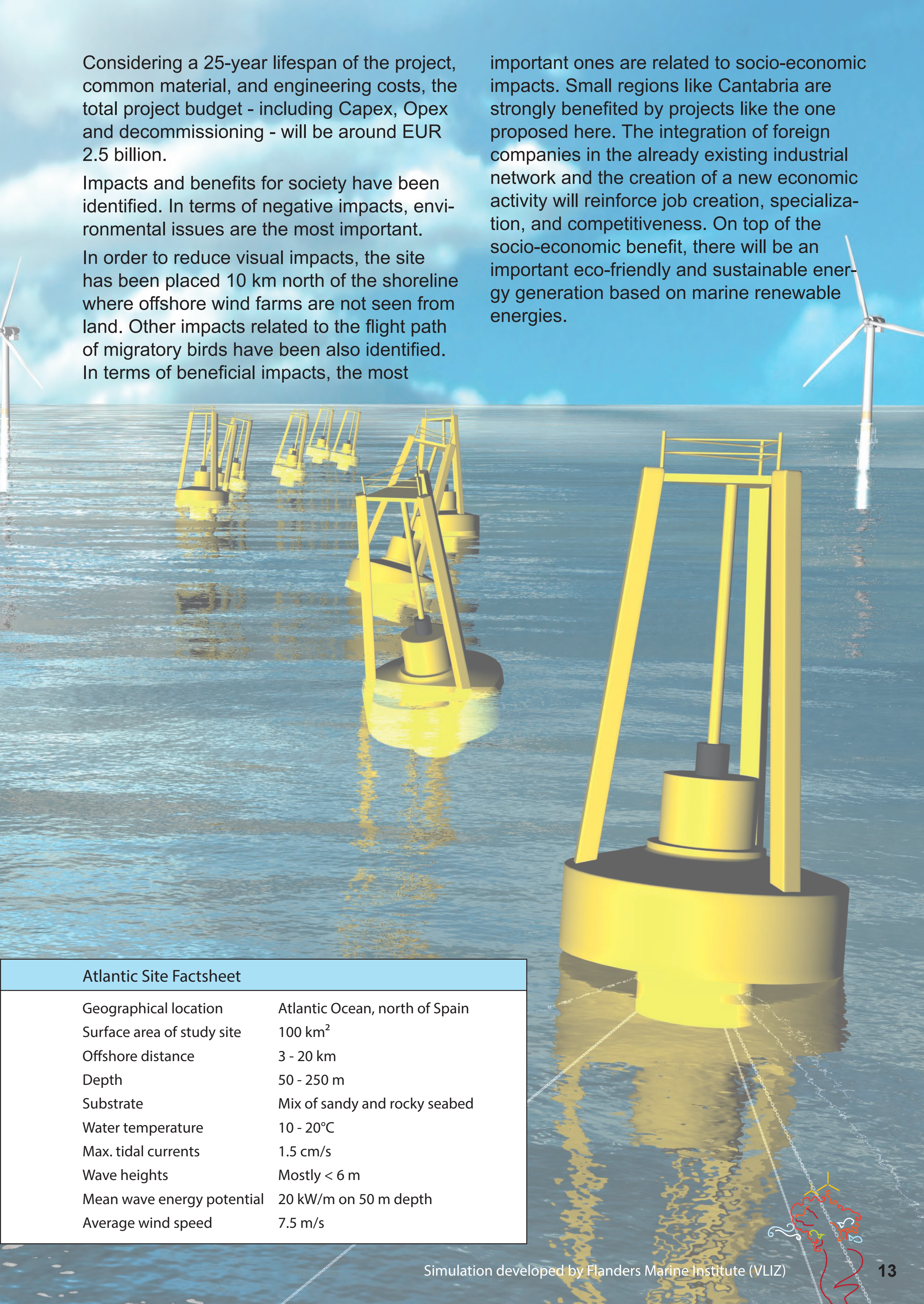
The mooring system will be based on conventional catenary mooring lines in order to reduce technical risks and lower costs.



Considering a 25-year lifespan of the project, common material, and engineering costs, the total project budget - including Capex, Opex and decommissioning - will be around EUR 2.5 billion.

Impacts and benefits for society have been identified. In terms of negative impacts, environmental issues are the most important.

In order to reduce visual impacts, the site has been placed 10 km north of the shoreline where offshore wind farms are not seen from land. Other impacts related to the flight path of migratory birds have been also identified. In terms of beneficial impacts, the most important ones are related to socio-economic impacts. Small regions like Cantabria are strongly benefited by projects like the one proposed here. The integration of foreign companies in the already existing industrial network and the creation of a new economic activity will reinforce job creation, specialization, and competitiveness. On top of the socio-economic benefit, there will be an important eco-friendly and sustainable energy generation based on marine renewable energies.



Simulation developed by Flanders Marine Institute (VLIZ)

Atlantic Site Factsheet

Geographical location	Atlantic Ocean, north of Spain
Surface area of study site	$100\ km^2$
Offshore distance	3 - 20 km
Depth	50 - 250 m
Substrate	Mix of sandy and rocky seabed
Water temperature	10 - 20°C
Max. tidal currents	1.5 cm/s
Wave heights	Mostly < 6 m
Mean wave energy potential	20 kW/m on 50 m depth
Average wind speed	7.5 m/s

The Mediterranean Sea site

The Northern Adriatic Sea, East of Italy and especially off the shore of Venice, is a test area presenting a set of complex challenges.

These challenges include:

- lowest marine renewable energy potential in the Mediterranean;
- mild slope of 0.35 m/km and peculiar circulation patterns with a high seasonal variability;
- large anthropogenic development, which leads also to erosion and land subsidence;
- strategic area for marine fauna conservation, sheltering relevant seabird populations and endangered marine mammals.
- vicinity to the city of Venice, with the associated high social sensitivity to the construction of new marine infrastructures.

Multi-use design

Placing the platform will be a key challenge. The location of the MUOP will influence potentially conflicting user needs such as the harbors with their commercial and tourist maritime routes, the fisheries, the oil and gas platforms, the natural habitats, and the restricted areas (see fig. below).

The assessment of the available resources at the site in terms of wave, wind, and aquaculture potential leads to an economically ineffective single purpose.

The selected MUOP includes wind turbines and fish farming (see bagground).

Wind and fish farms

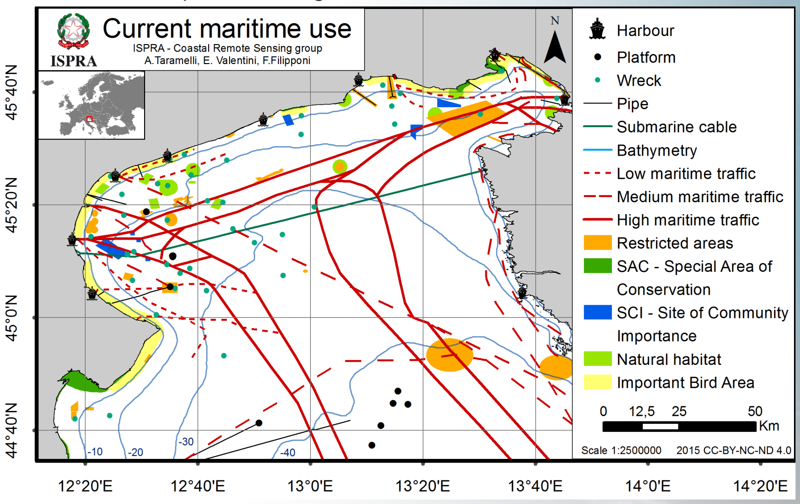
The fish farm is designed to support annual production capacity of 2,000 tons, equally divided between the sea bream and sea bass species. The fish farm is made of 56 sea cages of 32 m in diameter. To assure good fish health, the bottom depth at the installation is 25 m, i.e. around 3 times the depth of the nets (9 m).

The wind farm consists of 4 VESTAS V112, which have a 112 m rotor diameter and a rated power of 3.3 MW. The total production is 12.7 GWh/y, with around 1,000 equivalent hours. To reduce wake effects, a spacing of 7 rotor diameters (distance of around 800 m) around each wind generator is assumed.

Occupied space is a square area of 0.64 km2 where the wind turbines are placed at the corners and the fish farm in the middle. This configuration allows sufficient spacing around the cages for water circulation and sailing.

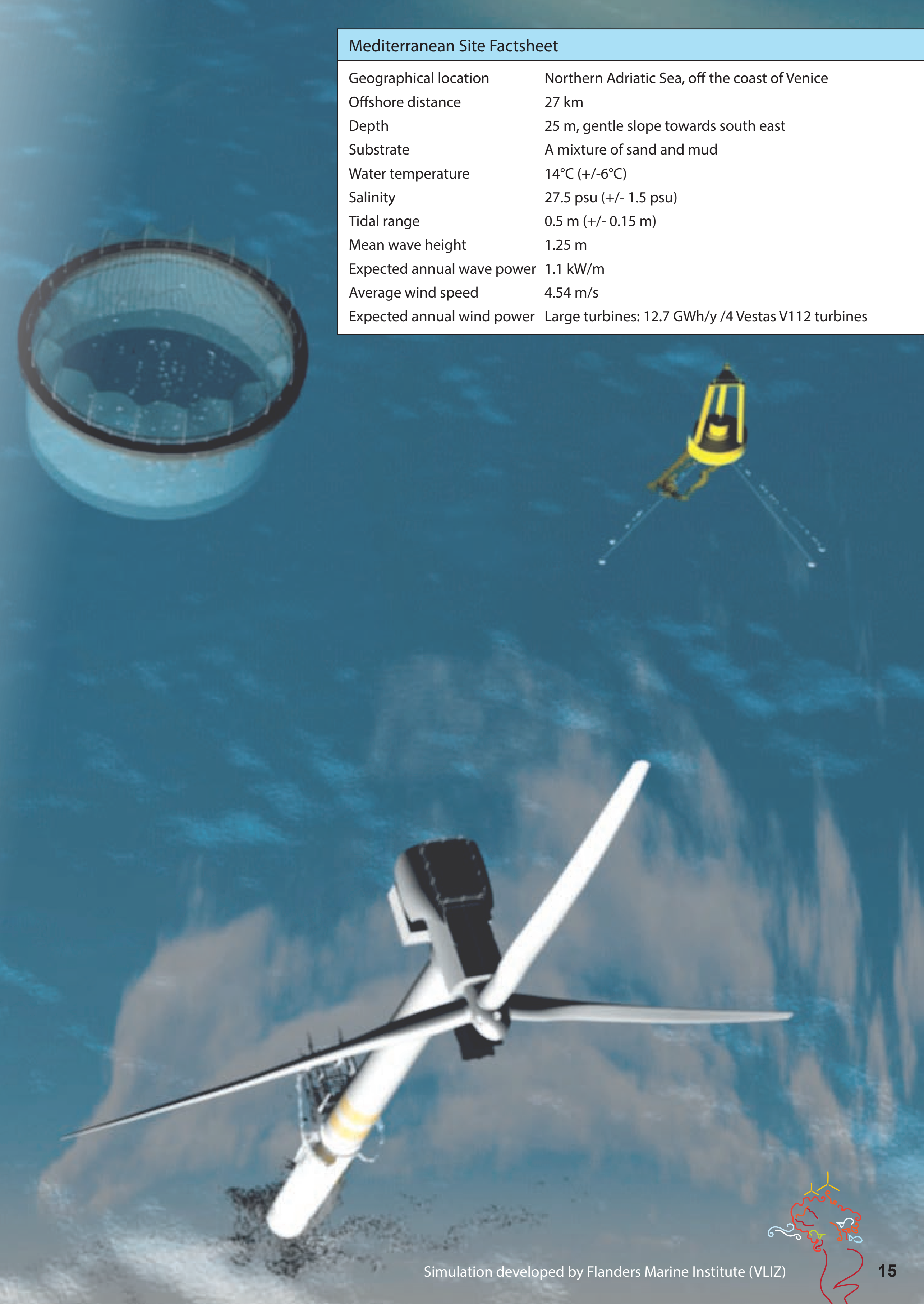
One of the main challenges of this MUOP is connection to the grid, due to the costs induced by the long distance to shore (27 km from the closest harbour) and the environmental impacts of the cables on the soft bottom.

Map of the existing conflict of uses. Source ISPRA.



Mediterranean Site Factsheet

Geographical location	Northern Adriatic Sea, off the coast of Venice
Offshore distance	27 km
Depth	25 m, gentle slope towards south east
Substrate	A mixture of sand and mud
Water temperature	14°C (+/-6°C)
Salinity	27.5 psu (+/- 1.5 psu)
Tidal range	0.5 m (+/- 0.15 m)
Mean wave height	1.25 m
Expected annual wave power	1.1 kW/m
Average wind speed	4.54 m/s
Expected annual wind power	Large turbines: 12.7 GWh/y /4 Vestas V112 turbines



Simulation developed by Flanders Marine Institute (VLIZ)

Perspectives learned from the four sites

Making MUOPs possible: Technological barriers to be overcome

Extensive investigations and investment in marine renewable energy utilization worldwide and large progresses have been achieved over the last years. However, there are still some technological barriers to overcome such as:

- the production of energy in ordinary conditions while devices should withstand extremes;
- the need for harvesting energy in deeper areas and with low environmental impact, while the design of moorings has often proved insufficiently reliable;
- financial feasibility due to the lack of innovative and highly efficient technology for energy conversion;
- the huge energy losses and costs related to energy transfer to shore;
- the immature technologies for local energy storage.

The use of resource diversity can develop promising technical synergies, reduce the variability of renewable power, and lower system integration costs.

The integration of marine renewable devices with aquaculture and transportation can lead to shared infrastructures and greener solutions, such as the design of stand-alone MUOPs where the energy produced is used to support the different MUOP functions.

The design and construction of MUOPs is a multi-expert, multi-stakeholder participatory process. While the technological knowledge and the selection and planning methodologies are transferrable, the use of the methods has to accommodate site-specific conditions. The application of the technical methodologies are strongly dependent on the social component (public perception) and on the legislation framework (licensing regulations).

A significant challenge is the lack of the definition of standards and standard procedures. This is a challenge not only for the design, but also for the assessment of (environmental) impacts, for the identification of the optimal site location (taking into account the conflict with other applications), and for the selection of the MUOP scheme that is better suited to a given site.

MUOP design

The selection of the MUOP design at the sites was a complex process (see figure) based on expert assessment of selected criteria including:

- maturity of technology in terms of reliability, performance, and technological innovations;
- environmental impact, accounting for the use of marine space, the impact on native species, and maintenance requirements;
- enduced risks, including geotechnical failure, hazard for maritime activities, pollution, power take-off failures, and structure modularity;
- costs as a function of installation depth, power take off, mechanical complexity of the overall system, and maintenance.

While the methodology depends on assessments of experts with different backgrounds, it offers the possibility to combine these assessments in a systematic and transferable procedure. It can be therefore adopted to elicit a participatory design approach to identify the most suitable MUOP for the given offshore site.

The viability level of MUOPs in the different sites also depends on:

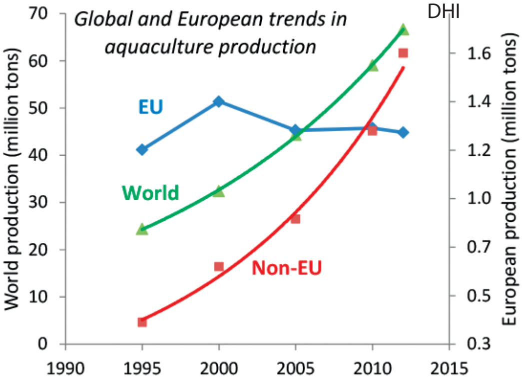
- the national level of power grid development (is the grid ready for receiving local and variable inputs?),
- the national technical skills of the managers (who need interdisciplinary skills, besides technical ones, to understand the projects before approval),
- the sensitivity of the population to environmental issues (in both terms of potential environmental impacts produced by the installation and of preference towards greener solutions rather than traditional fuels).

Photo: Colourbox, Simulation Hans Pirlet VLIZ, © Henrice Jansen IMR, HSN

How can aquaculture become a part of an MUOP?

Sustainable aquaculture

In contrast to a global aquaculture production growing 6 per cent annually and an even higher growth of 8 per cent in non-EU European countries aquaculture in the EU has been stagnating for the past 25 years (see graph below. EU producers cannot satisfy consumer demands and EU is facing a trade deficit of aquaculture products amounting to about EUR 7 billion annually. Environmental sustainability and fish welfare have been 'trademarks' of EU aquaculture, however with economic sustainability including investor interests lagging behind.



With a reform of the Common Fisheries Policy along with specific aquaculture initiatives, including simplification of administrative procedures and reduction of licensing time for aquaculture farms, the Commission strives to boost aquaculture production in the EU - while maintaining eco-friendly production practices.

There is growing interest in moving coastal farming to offshore sites because it would reduce constraints related to competition for space with other activities and reduce environmental and aesthetical impacts. Because of fewer conflicts at offshore sites, the administrative licensing for new aquaculture farms would probably run more smoothly that in the crowded coastal waters. Another means to mitigate spatial conflicts could be coexistence with other activities because it will increase the 'returns' from a given seabed area already occupied for other purposes, such as offshore energy renewables.

Both aquaculture and energy extraction will most likely benefit from sharing seabed areas, e.g. in terms of cost-sharing related to operation and maintenance, i.e. transportation and housing.

Surface area efficiency expressed by the net economic gain per unit area occupied is highest for finfish aquaculture, intermediate for bivalve production and lowest for seaweed production because self-shading sets an upper boundary for production.

Finfish production

Despite roots dating back several thousand years, modern finfish farming in marine waters began its expansion in 1960s, and the annual production has now reached 2 million tons in Europe (430,000 in the EU). Five finfish species - in decreasing order: salmon, seabream, seabass, rainbow trout, and turbot - dominate the marine production in the EU, accounting for 85 per cent of the production volume and value. The cold-water salmon and trout are produced in the NE Atlantic region while seabream and seabass are produced in the Mediterranean.

After raising larval and juvenile stages in land-based facilities, salmon, seabream, seabass, and trout are grown in cages in the sea. Depending on species, feed quality and environmental conditions - primarily temperature - outgrown fish can be harvested from eight months to 2-3 years after they have been stocked in cages. Grow-out of turbot can take place in sea cages or in recirculated systems on land.

The majority of EU fish farms are located


©FAO/Aquaculture photo library/F. Cardia

Seabream (Sparus aurata) grown in cages in the Mediterranean.

near the shore, typically in embayment's offering some wave protection. Over the past decades, both cage and farm sizes have increased, and the producing companies have increased by consolidation and acquisition. In the largest salmon-producing country, Norway, the typical cage size has increased from 75 m3 in 1980 to more than 85,000 m3 in 2012. A similar - albeit less dramatic - trend is seen in the Mediterranean fish farms. But here the proportion of family-owned farms is still significant, which is vital for supporting high product diversity and maintaining the integration in the local community.

To avoid competition for space with other coastal activities, large fish-farming companies move their farms to offshore locations where environmental conditions can support large farms. Such large farms can further increase efficiency by adopting automated or semi-automated feeding from barges and online monitoring of environmental conditions, feed loss and fish well-being.

Juveniles grown in land-based facilities and feed are the dominating costs in cage culture, and every mean to improve feed utilization will increase the economic sustainability, paving the way for expansion.

Bivalves

Small-scale oyster production was already practised by the Romans, but it was French fishermen that reintroduced oyster culture to compensate for a dramatic decline in stocks in mid-19th century. Today, oyster culture along the French Atlantic coast is one of the most valuable aquaculture assets in the EU. Today, three species groups dominate the EU bivalve production: mussels, oysters and clams. The total value of EU bivalve production is EUR 1.2 billion with about 90 per cent being consumed within the EU. Besides the local production, annual MS import bivalves are valued at EUR 250-300 million.

Depending on tradition and local conditions - e.g. tidal range - mussels, oysters, and clams are produced on the seabed, on poles (‘moule de bouchot’), in small cages (oysters and scallops), or suspended in the water column attached to ropes or nets. Handling (e.g. seeding, thinning) is required during the production cycle, with the production of larvae and seed of oysters and clams in hatcheries following conditioning and spawning of brood-stock. In contrast to oysters and clams, mussel seeds (juveniles) are collected and grown in coastal waters involving much lower investments and workforce. Bivalve production is a non-feed aquaculture where bivalves ingest naturally occurring organic particles - primary phytoplankton. Therefore, grow-out farms should be sited where the flux of phytoplankton is high to replenish the continuous loss due to consumption.


Harvest of mussel seed collectors

Photo: © Henrice Jansen IMR

Suspended culture of mussels can be established at offshore locations provided that equipment and anchoring are scaled to the harsh offshore exposures. Except for high investment and operational costs, reduced fouling and lower risks for harmful algal blooms are some of the advantages of offshore production. Commercial offshore production of mussels takes place in France, Italy, UK, and in several non-EU countries.

Mussel farms placed near fish farms have been suggested as a means to sequester part of the particulate waste lost from fish farms. However, only a few percentages of the waste are available to mussels because the bulk consists of large particles outside the size range for ingestion, and the residence time is too short in the water column because of high settling velocities. Therefore, small-scale mussels farms may benefit from the additional food present around the perimeter of fish cages, but mussel farms are insignificant as a means to mitigate environmental impact from particulate waste.

Seaweed

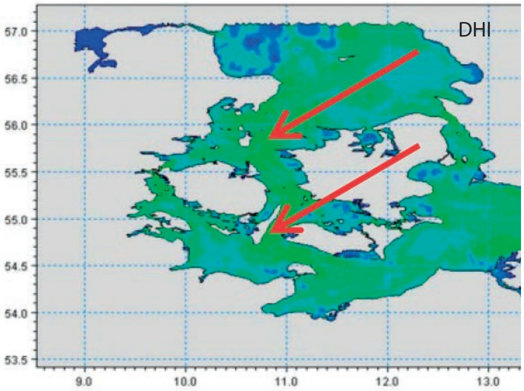
Exploitation of seaweed has a long history along the European Atlantic coasts. For centuries, seaweed beds were harvested during low tide or detached seaweed accumulated on the shore was gathered. Seaweed was used as food, feed for livestock, and as fertilizer. Later, Norway industrialized the use of seaweed by producing potash, exported widely and used in production of glass, soap, iodine, etc. For the past 50 years, harvested seaweed from natural populations has been used in the production of hydrocolloids (e.g. alginate and agar) that are used as stabilizers in food and cosmetics.

Photo: Hortimare.

Mermaid partner Hortimare participated in offshore test of new patented farming system enabling autonomous submergence during storms

The global seaweed market has a value of EUR 8 billion with farmed seaweed for human consumption in SE Asia accounting for EUR 6 billion. In Europe, the harvest of natural populations amounts to 250,000 tons annually, but with a declining trend for the past decade due to declining stocks and harvest regulations caused by concerns of habitat damages. In comparison, only 1,000 tons are farmed annually in the EU, primarily in pilot-scale farms established in coastal waters.

Most farming tests have used nets or rope systems arranged horizontally or vertically, seeded with small sporophytes in land-based facilities. Currently, two brown seaweed species, Saccharina latissima (native to Europe), Undaria pinnatifida ('Wakame' imported from SE Asia) and the red seaweed, Palmaria palmata (native) dominate in the various farming efforts.



Numerical model results identifying nutrient upwelling areas in the Belt Sea, Denmark

As with other aquaculture systems, selection of optimal sites is critically important for new seaweed farms. To this end, numerical models can be applied to identify natural nutrient upwelling areas. In such areas a maximum harvest of 60-120 tons wet weight per ha can be expected annually. Compared to finfish farming, the area efficiency of seaweed production is very low, and large-scale seaweed farming is almost deemed to take place at offshore sites where competition for space is low.

Using current farming methods European producers cannot compete with seaweed producers in Southeast Asia, South America and Africa. Therefore, a future role for farmed seaweed in Europe depends on technological breakthroughs in farming and harvest methods in addition to developing value-added products based on seaweed, e.g. targeting health and disease issues in humans and farmed animals.

Challenges and showstoppers

The challenges for combining aquaculture with energy extraction at offshore sites are severalfold:

- Improved technology and sturdier equipment will be needed to cope with offshore wave climate and escapee risks. Rough estimates predict that investment cost of offshore equipment (cages, anchoring, long lines) easily can be doubled compared to coastal aquaculture, making it difficult to attract investments unless other restrictions are solved.
- Another set of challenges include unclear and lengthy licensing procedures in most EU countries, legal uncertainties with respect to property rights to production sites, balancing the access for the different activities (i.e. energy extraction and aquaculture), and uncertainty with respect to insurance and liability issues at multiuse sites.
- Social obstacles to offshore aquaculture constitute a third group of challenges that can limit the establishment of MUOPs. The EU public perceives negative effects of marine aquaculture without accounting for positive effects - such as the potential relaxation of the exploitation of benthic fish stocks and habitats. Persistent opponents to marine aquaculture include 1) coastal residents who fear impairment of waterfront views and waste accumulation on beaches, and 2) environmentalists in a broad sense, who are concerned about pollution, interbreeding between natural populations and escapees, impact on the ecosystem or pressure on wilds fish stocks for the production of fish meal and oil for feeding predacious farmed fish.

Addressing challenges

- Improved technologies for offshore production are underway, but successful in situ testing of full-scale aquaculture farms is the ultimate proof needed for attracting investor interests.
- As repeatedly pointed out in the EU reports, member state governance of aquaculture must be reformed and de-bureaucratized to reduce licensing time for new farms. With few exceptions, marine aquaculture activity in the EU is so limited that only a small fraction of the populations has a direct stake in it. Therefore, few (public and civil servants) understand, are interested in, and eventually advocate for aquaculture.
- The environmental concerns are real, and farmers must improve their communication efforts quantifying the local impacts, insist that scale of impact becomes an integral part of an impact assessment, and that alternatives to new farms are found, such as increased imports from countries with less strict environmental regulation and animal welfare.

Assessment tools for EIA

Every human activity - including food production and industrial production - impacts the natural environment.

The environmental conditions, features, and biological components that may be affected by an aquaculture farm include surrounding water (chemistry, quality, pollutants), seabed (sediment including content of organic matter, nutrients, oxygen condition), seagrass, macroalgae, fauna (benthic invertebrates, fish), and seascape in a broad sense. Overall, impacts from fish farms will be higher than those from bivalve and seaweed farms; however, at comparable production volume such farms will occupy 20-100 times the area of a fish farm.

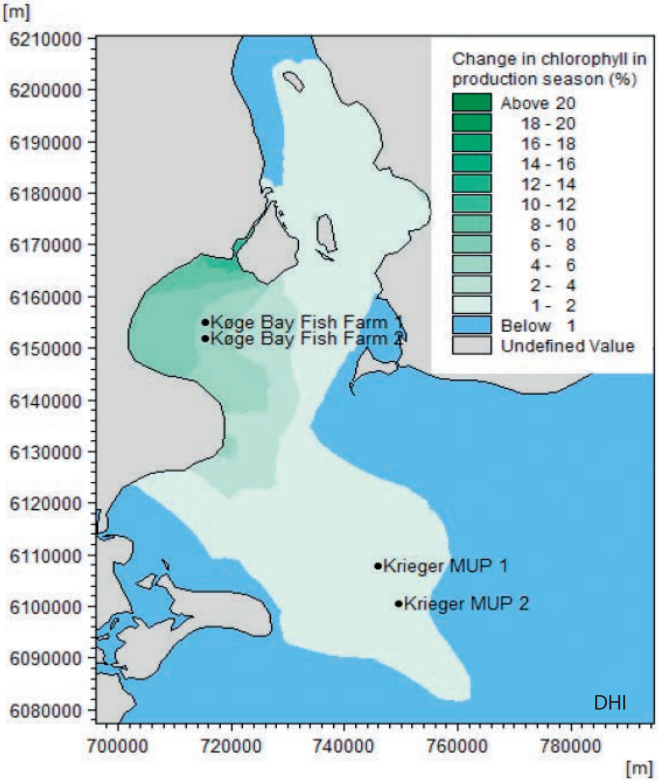
Example: EIA for fish farming

Being a feed aquaculture, main fish farming impacts are related to:

- Organic load of sediments with particulate waste;
- Release of dissolved nutrients;
- Loss of pesticides, medicine, and biocides;
- Loss of farmed fish (escapees);
- Release of pest agents from infected fish;
- Attraction of wild fish.

Generally, when fish farms are properly sited and managed, the impact levels can be low and reversible. Selecting sites with regularly occurring near-bed current speeds exceeding 0.15 m/s and average surface speeds in the range of 0.1 – 0.4 m/s will prevent organic waste accumulation below farms and disperse soluble nutrients in surface waters to levels not exceeding the assimilative capacity of the pelagic ecosystem.

Often, environmental impact assessments (EIA) will be mandatory for new fish farms exceeding a yearly production of 100 tons - which roughly is equivalent to the release of 5 tons N, 0.8 tons P and 100 tons particulate organic waste. The impact of such release will depend on whether local conditions and impacts can be predicted using integrated models simulating hydrodynamic and biogeochemical fluxes and conditions. Briefly, results from a calibrated model without fish farm are compared with results from a model where additional sources (organic particles, N, P) are included. Such models can also be used for comparing impacts from coastal and offshore farms (see figure below).



Predicted chlorophyll increase around four 5,000-ton fish farms (2 coastal and 2 offshore).

Photo: Kelefonia Fisheries

How can wind and ocean energy extraction be part of an MUOP?

Wind and wave energy resources

Ocean energy resources are becoming an interesting contributor to the European energy Mix. In particular, offshore wind and wave energy.

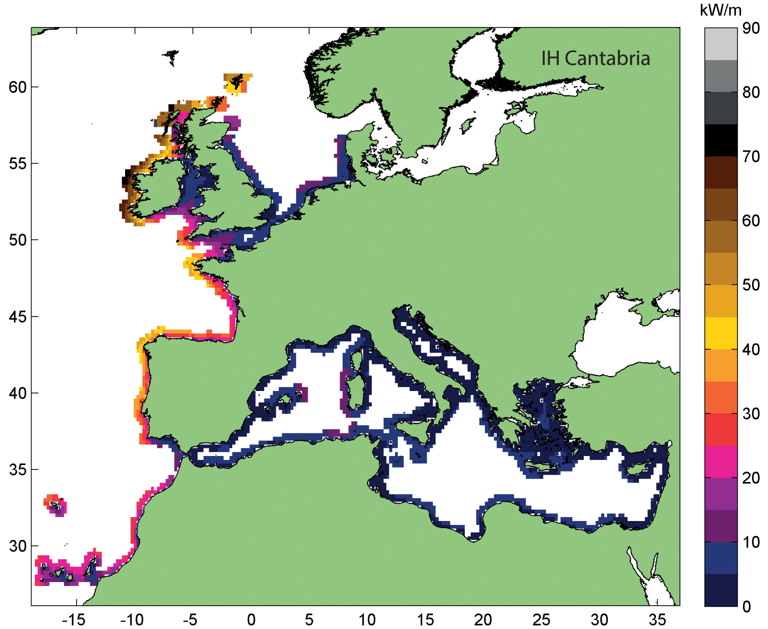
Offshore wind energy is currently growing dramatically worldwide, motivated by its many benefits:

- Wind energy is a clean and renewable source of energy available worldwide.
- Wind energy costs are becoming competitive.
- Socio-economic benefits (job creation, new industrial activities) at local and regional levels are attractive.
- Environmental benefits are also significant in terms of noise pollution and visual impact, together with less bird injuries.

Europe shows an uneven spatial distribution of the wind resource. Very high resource rates are located in the North Sea, the Atlantic Ocean, and some parts of the Baltic and Mediterranean Sea.

Wave energy conversion is at a relatively immature stage. However, it could be considered one of the most promising renewable energy forms for several reasons:

- Wave energy is a clean and renewable source of energy available worldwide.
- It is a predictable resource, as waves can be accurately forecasted from a short-term point of view (3 to 5 days).
- Wave Energy Converters offer a very environmentally benign form of power generation: low visual impact, low biological impacts, etc.
- Wave energy shows a high social acceptance due to its low environmental impact. Therefore, it is a potentially new sector suitable to be developed at local or regional scale.



Wave energy is also not equally distributed along European coasts. Enclosed seas (i.e. the Mediterranean) are low energetic seas, while exposed Atlantic coasts are high suitable locations from a wave energy conversion point of view.

Stability of power production

Wind and wave energy show high synergies between them. Furthermore, large infrastructures are required for both developments. Therefore, economies of scale benefits are clearly identified. Moreover, power production peaks and troughs of both sources of energy do not always coincide. This means there are times when there is an abundance of wave energy and little wind resource. Thus, the combination of both sources of energy helps in the reduction of the short-term variability of power production.

Wind turbines

Wind turbines have been developed for decades. Currently, it can be said that it is largely a mature sector thanks to the previous experience acquired in onshore wind activity. Wind turbines can be classified based on different criteria:

- The number of blades,
- The energy extraction mechanism, or
- Wind turbine axis orientation.

The air flow over an object generates two forces named drag and lift. Lift-based devices are the most efficient and used ones. In those cases, wind energy is obtained through the creation of a lift force, which is perpendicular to air direction. The blade shape is key to the lift forces generation and therefore in the energy conversion efficiency of the wind turbine.

In terms of number of blades, the three-blade type turbine is currently the most tested and used one within the different types of turbines designs. However, other existing concepts based on two blades have shown some promising results.

The wind turbine axis can be whether horizontal or vertical: Horizontal Axis Wind Turbines (HAWT) or Vertical Axis Wind Turbines (VAWT). The turbine axis is defined as the main shaft about which the rotating parts rotate.

Principal parts of a wind turbine:

- The tower, which sustains the rotor and the nacelle. The tower is at least as high as the radius of the rotor.
- The rotor, which includes the blades, the hub, and the aerodynamic control surfaces. The blades are connected to a central hub, which rotates with them and they make the shaft rotate. The essential parts of the rotor are the blades. They convert the wind force into the torque to generate power.
- The drive train: Includes the gearbox (if any), the generator, the mechanical brake, and the couplings connecting them.
- The yaw system: The turbine may use a free or driven yaw. Its function is to align the turbine with the wind direction.
- The nacelle: The structural element located at the top of the tower. It supports and protects the gearbox, the generator, and the brake.

The most successful technology for offshore wind applications is the three-blade horizontal axis turbine. It has three blades on top of a mast or tower and it is called a propeller turbine. A propeller turbine is a lift-type turbine since it works based on the lift force on the blades. In a propeller turbine, wind flows along the turbine shaft and blows perpendicular to the blade plane.

Wave energy converters

The possibility of harvesting energy from the oceans was identified long time ago. The first wave energy patent was presented in 1799 in France by Girard, father and son. However, it was not until 1973 that the interest in wave energy increased because of the oil crisis. Between the 80s and the 90s wave energy developments, without considering some exceptions, has been developed under a R&D scenario. Since 1991, wave energy is included on the European Commission renewable energy portfolio, and then it started to grow constantly.

In order to extract energy from waves, it is assumed that the device needs to create a wave that interferes destructively with the incoming wave. To describe this it is widely said that: “In order for an oscillating system to be a good

wave absorber, it should be a good wave generator”.

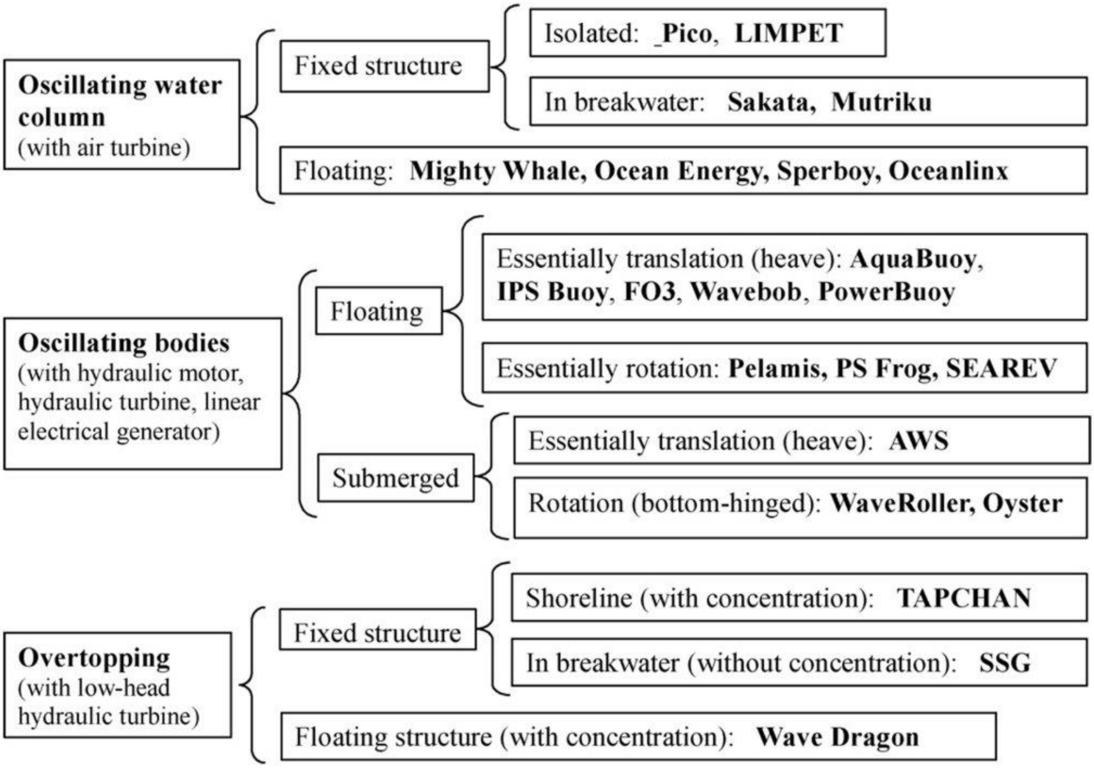
Then, it is clearly stated that in order to absorb the wave in an optimum way, the device has to oscillate with a certain amplitude and phase.

Floating bodies move in 6 degrees of freedoms. In order to obtain optimum absorption, different forces should be applied for the different degree of freedoms. Therefore, the wave energy conversion process can be explained in two steps:

1. the energy is transferred from the sea to the oscillating system and
2. this mechanical energy is converted by a machinery into a useful one (i.e. electricity).

The great variety of wave energy conversion prototypes being tested nowadays shows that no convergence has been achieved yet by the wave energy sector. In fact, currently there is still a great variety of wave energy converters under development, which is a clear sign of an immature sector.

As a consequence of this variety, there are also several ways to classify the converters based on the locations (nearshore-offshore) or based on their size principle (point absorbers-attenuators-terminator). Probably, the most used classification is based on the working principle, Falcao 2010. The classification by Falcao 2010 is shown below and is based on three main types of converters: Oscillating water columns, Oscillating bodies and overtopping converters.



By Falcão 2010 http://dx.doi.org/10.1016/j.rser.2009.11.003. (http://www.sciencedirect.com/science/article/pii/S1364032109002652

Simulation developed by Flanders Marine Institute (VLIZ)

Stakeholder involvement in the design process

What is interactive design and why is it useful?

The MERMAID project aims to develop concepts for the next generation of offshore activities for multi-use of ocean space. It proposes new design concepts for combining offshore activities, like energy extraction, aquaculture, and platform-related transport at various ocean areas. The combination of these activities is referred to as a Multi-Use Platform (MUOP). In the MERMAID project, four different MUOP sites were used as case studies.

To achieve feasible designs, endorsed by stakeholders, MERMAID puts the integration of technical, economic, ecological, spatial, and social aspects at the heart of the development of MUOPs. It does so in two ways.

- First, these different aspects are analysed and integrated in the entire design process.
- Second, all relevant stakeholders are involved throughout the entire design process.

A participatory design process is developed to involve, consult, and give feedback to relevant stakeholders in the entire design process.

Participatory Design values the perspective, knowledge, skills and involvement of different categories of end-user and other stakeholders. Participatory design is not new (Reed 2008, Franzen 2012) and fits well in the 10 guidelines of Marine Spatial Planning (Ehler et al 2009). This social shaping of technology is important for innovation processes (Schot and Rip 1997). Designs are not just technical devices or market objects; they are actually combinations of hardware, software and ‘orgware’ (Smits 2006:2). The selection, improvement and diffusion of designs on MUOPs will be channelled in emerging technological trajectories - perhaps leading to a technological regime (Nelson & Winter 1977).

Participation is required to develop a shared knowledge reservoir (Wenger 1999). Two processes are essential for creating mutual understanding. Participation implies that the members of the community get a sense of relationship, either based on conflict and harmony (Wenger 1999). Reification means that the bits and pieces of knowledge that are learned are communicated in a reified form (in this case reports, tables and design wishes). Reification refers to actions within the community of practice like designing, naming, encoding, interpreting and describing (Wenger 1999).

The MERMAID participatory design process focused on a cyclical, iterative, and participatory process of scoping, envisioning, and learning. Through the participatory design process, a shared interpretation of MUOPs is developed and applied in an integrated manner. The communities of end users stakeholders were invited to comment and reflect on the designs proposed by the scientists of the MERMAID project.

Modifications and adaptations of the original ideas on the design took place in different consultations, i.e. in three design rounds. Mermaid developed communities of practice around the four designs, one for each site. The communities were formed by people who were deliberately invited to engage in a process of collective learning and have a shared domain of interest: namely MUOPs development.

The participative methodology

The participatory design was developed to involve stakeholders in the process of designing the MUOP. Two principles underlie this approach:

The principle of non-linear knowledge generation. This principle acknowledges that knowledge is developed in a complex, interactive process of co-production with a range of stakeholders involved (Gibbons et al. 1994; Rip 2000).

The principle of social learning. This principle states that all one can do in complex and uncertain search processes for sustainable designs with no ready-made solutions at hand, is to experiment and learn from these experiments in a social environment through interaction with other actors and learn from each other's behaviour (Bandura,1971).

The Figure below gives an overview of the participatory design process applied in these four case studies in the MERMAID project. The design process of MUOPs in the four cases is organized in three steps:

STEP 1
Prepare the designs by identifying the views and needs of all stakeholders with interviews (Result: D2.2; Rasenberg et al. 2013)

STEP 2
Designing the MUOP by organizing a round table session involving all stakeholders (result D2.3; this report)

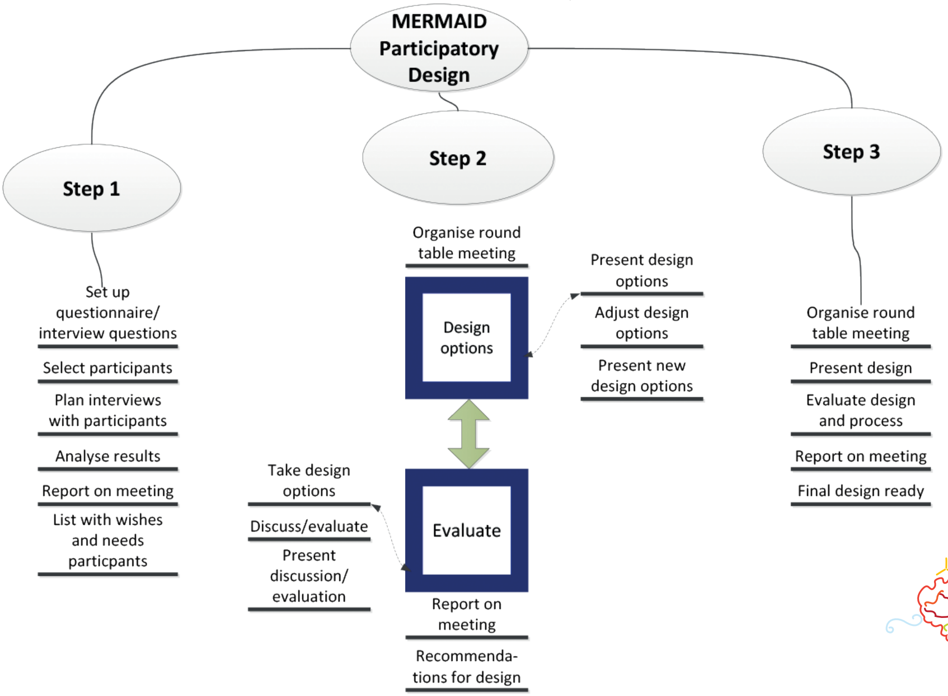
STEP 3
Evaluate the design by organizing interviews and a session with all MERMAID stakeholders (result D2.4)

A group of representatives of all major types of stakeholders are invited for the participatory design process, where six stakeholder categories were identified:

- Governing bodies/policy makers such as regional, national and European officers
- End users of the MUOP, e.g. energy companies and aquaculture entrepreneurs
- Suppliers of the MUOP such as cable companies and construction businesses
- Representatives of other offshore activities such as fisheries, shipping, and mining sectors
- Discourse community, including e.g. (environmental) NGOs, local citizens
- Universities and research institutes

The work that was performed in the participatory process is not to make the final design, but to organize the input of the stakeholders that can be used to make the final design. The final design was the responsibility of the site managers of the MERMAID project. Central in this approach were the interviews in step 1 with all the stakeholders and the round table session in step 2. Step 1 focused

Overview of the MERMAID participatory design process



By: Stichting Dienst Landbouwkundig Onderzoek - DLO on identifying different views on ecological, economic, and social objectives of MUOPs, challenges and technical, social-economic, and ecological constraints faced. Equipped with a resulting wish list from this step, designers started working on developing the first MUOP design options. These design options were discussed later in step 2 at an interactive round table session involving all relevant stakeholders.

Step 2 was a round table session where the design was discussed and adapted according to the wishes of all stakeholders involved.

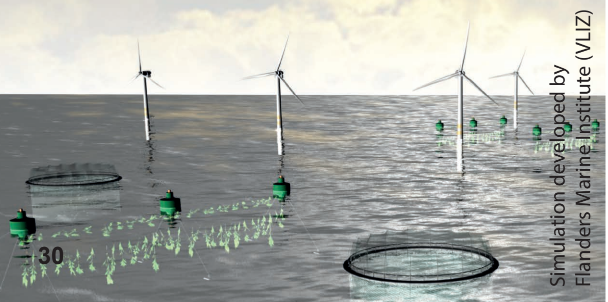
Step 3 comprised interviews and an internal consultation where the final design concept was evaluated with the participating stakeholders. This ultimately led to a design concept which was thoroughly analysed, technically feasible, and preferably supported by all the stakeholders represented at the round table.

Stakeholders views on MERMAID designs

Baltic Sea site

At Kriegers Flak, the combination of wind turbines and offshore aquaculture by floating fish cages with trout/salmon production is envisioned. This combination is interesting given the large-scale development of offshore wind – with subsequent spatial claims and the critical attitude towards nearshore aquaculture. In Denmark, the public image of wind turbines is positive while offshore aquaculture is more critically scrutinized due to its environmental effects.

The participants state that the wind turbines should not be visible from the shore. The stakeholders point out that there should be no negative effects on ecological conditions, and that the artificial reefs on the wind turbine foundations should be protected as they have positive ecological effects. As a consequence, fish cages should be placed at sufficient distance. Further, the entire wind farm area will be designated a cable protection area, and possibly, shipping lines which today pass Kriegers Flak need to be redirected.



Simulation developed by Flanders Marine Institute (VLIZ)

Stakeholders discussed technical aspects of design such as maintenance and monitoring, anchoring and transport, and associated risks. The combined use of marine space means that more ships will enter the area - with higher probabilities for accidents - and the combination of different technical constructions may create new risks. Therefore, a technical risk assessment of the MUOP is important and guidelines and rules to minimize risks must be developed to ensure the safety of people, vessels, cages, and wind turbines.

Entrepreneurs, discourse community, and researchers are willing to participate in an MUOP. Given the divergent public images of offshore wind energy and aquaculture, the stakeholders find it important to involve society in the development of MUOPs to promote the concept. Although this is partially covered in the Environmental Impact Assessment, this legal obligation alone is insufficient to bridge the gap between different sectors.

There is a high degree of knowledge among the stakeholders about the site and the MUOP concept, however alternative ways to develop an MUOP were discussed; to start with a single combination and to subsequently build on this, or to open up for more combinations from the outset. This is also related to the willingness to invest and participate: thinking business models for MUOPs is crucial.

North Sea site

The North Sea case study envisioned the combination of offshore wind energy and mussel and seaweed aquaculture in the Gemini wind park. The rapid development of offshore wind in the North Sea has triggered debate about competing spatial claims and the feasibility of combining functions. The Dutch mussel sector has a history of collecting mussel spat in the Wadden Sea. This has a negative environmental impact, and offshore alternatives are currently investigated. The fisheries sector is interested in the pos-

Simulation developed by Flanders Marine Institute (VLIZ)

sibilities to deploy low-impact bottom fishing techniques in the wind parks.

The potential wind energy producers are unambiguous regarding the conditions for design: multi-use should be no hindrance to wind turbines and no obstacle for O&M operations. Modular components and plug-and-play installations for multi-use activities are preferred. Being able to share infrastructure among energy producers and aquaculture producers (and others) to reduce O&M costs is crucial. For fishers, this is in line with a process to redesign fishing vessels for multipurpose activities in order for the sector to become more sustainable. Further, the shellfish sector is looking for additional fishing grounds.

It is acceptable that MUOP will cause negative environmental effects. However, marine protein production in open water systems will always interact with the surrounding aquatic ecosystem. The resulting effect depends on the type of culture and the combination of different culture types. Focus should preferably be on offshore shellfish culture and some form of bottom fishing in combination with wind farms.

Many stakeholders see the benefits in participating in an MUOP. The level of knowledge on the subject is high, and focus is on optimisation with regard to sharing infrastructures to reduce O&M costs and create win-win solutions. In order to create increased employment and to support the fisheries sector in its transition period to new demands on sustainability, it is important to consider their vessels, possibly redesigned, as part of an infrastructure.

The biggest challenge for the North Sea site is to find solutions that are profitable for all stakeholders. This includes analysis of risks and (extra) insurance costs. In order to find investors, the license procedure needs to be faster than today and uncertainties need to be minimised.

Atlantic Sea site

The Atlantic site is subject to harsh conditions – with waves up to a height of 20 m reported – leading to high technical demands. After discussions with the stakeholders, aquaculture was deemed very difficult and the focus instead lay on the combination of offshore wind and wave energy.

The stakeholders found it difficult to visualize an MUOP, but some ideas were single wind turbines with aquaculture cages attached to them and a floating construction on which various turbines are constructed and providing space for other uses. Offshore aquaculture is not seen as realistic; however, a temporal island for sports events was suggested.

The stakeholders also argued that it is important to select a good site where conflicts with other interests are minimal. In general, the stakeholders argued that the MUOP should be sufficiently far away from the coast. For the Ubiarco site, there was one other concern: that it is nearby the mouth of the Rio Saja River with its present port. Regardless of use, safety and robustness of the construction is required as well as a good signalling system to avoid accidents.

The safety and robustness of a challenging technical construction combining wind and wave/tidal energy production is at the heart of the Atlantic Sea site. The interviewed stakeholders are willing to participate in the participatory design process, but struggle to see how they can participate in an MUOP. It was found important that an MUOP should not cause negative impacts on the local fishing community, and that an MUOP can provide revenues to both the local fishing community and local businesses.

Simulation developed by Flanders Marine Institute (VLIZ)

Mediterranean Sea site

For the Mediterranean site, the proposed MUOP is a combination of energy generation by means of grid connected wind turbines and aquaculture. Synergy is induced by integrating wind energy production and fish farming. Several combinations were proposed and discussed. Due to the high costs and the immature technology, the wave energy conversion is abandoned.


Simulation developed by Flanders Marine Institute (VLIZ)

The stakeholders were very concerned about the location of an MUOP, and that this should be thoroughly investigated as a part of a design process. Potential conflicts with a planned offshore port and other activities as well as high costs associated with the large distance to the shore, were issues highlighted.

There are major concerns about negative impacts on the ecosystem, and all in all, the discussion is characterized by a large degree of uncertainty about costs and environmental effects.

Multidisciplinary cooperation was found essential for the design process, and as a combination of wave and wind energy and aquaculture is aimed at, a new aquaculture stakeholder who is willing to participate must be identified.

The stakeholders are in general positive about participating in an MUOP, but more reluctant to join a session for participating in an MUOP. The participating energy companies are willing to invest in wave energy. There is a high degree of uncertainty among the stakeholders about site location, environmental effects, and economic and social impacts.

Lessons learned on interactive design

The participatory design process of MERMAID coincided with real-life experiments at the different locations. All four sites followed the same MERMAID participatory approach (3 steps) despite being at different stages in real-life development of MUOPs when the MERMAID project started.

In terms of gathering stakeholder opinions on the technical knowledge and finding coherence in a final MUOP design, the process can be considered efficient. However, in terms of involving the relevant stakeholders and communicating with them transparently, the processes in the four case studies were constantly challenged with respect to the following issues.

Stakeholder representativeness

It proved difficult to get the relevant stakeholders in the North Sea case and the Mediterranean Sea case. In these cases, it was difficult to reach the right representatives as the MERMAID partners had to start the network from scratch. In the Atlantic Sea site workshop, all types of stakeholders participated. The approach in the Baltic case worked well; a more focused stakeholder group was selected with all participants having the resources to participate. This was also the case study that was best prepared from the start (round 1) for envisaging an MUOP.

Communication/Transparency

Communication between the MERMAID site teams and the stakeholders in the regions was poor in some cases. Reasons for that include that:

1. different stakeholders were involved in different rounds, which resulted in discontinuous communication and a need for repeating information and discussions,
2. some stakeholders were only involved in WP2 of the MERMAID project,
3. in some cases, none of the stakeholders were active partners in MERMAID, potentially lacking resources to participate, and
4. in some cases, stakeholders were not willing to share information due to business strategies and confidentiality, or because their knowledge about offshore or multi-use solutions was limited.

An exception is the involvement in the Baltic case. Here, all relevant experts of the different fields were involved in MERMAID and actively collaborating on all the necessary assessments (technical, financial, legal, environmental, social, and economic).

Efficiency in coming to a synthesis in the final design

The focus during the discussions of the different participatory rounds differed, depending on the project phase of the site. In cases where stakeholders needed more general information from the start to be informed about the concepts of MUOPs, discussions were naturally less focused on the design. The different organizers of the round tables also selected relevant stakeholders differently. This approach of selectively inviting different stakeholders at different stages can be considered helpful from a technical point of view as it helped to allow the participants to comment and agree on a final design. For example, for the North Sea and Baltic Sea sites, an agreement of the type of MUOP was found very quickly with the invited participants, all of whom were already informed about the general concept of MUOPs. Contrarily, for the Mediterranean site, the final MUOP combination was agreed on very late, with participants first having to get used to the very idea of MUOPs. Another reason for the less efficient synthesis in the Mediterranean case might have also been that the wind sector had not been involved from the beginning.

Recommendations for future MUOP projects

The aim was to facilitate coming processes of development and implementation of offshore MUOPs. Shared knowledge and experience can contribute to more efficient and sustainable design of offshore multi-use platforms. Additionally, acknowledging the stakeholders' perspectives enables surpassing potential obstacles or proceed timely with adjustments within the process. On the contrary, no dialogue or not considering stakeholders' point of view leads to risk of inefficient processes, the need to repeat procedures, or even sub-optimal solutions.

Suggested recommendations:

1. Start with an initial assessment of the context. It is important to investigate the situation and conditions of the site under consideration – what technologies are at all possible. Based on this:

   – Identify the stakeholders and their roles (take into account that important stakeholders are expected to be your business partners, your insurance company and bank, the environmental authorities, local NGOs, local or regional administration, and relevant professional associations).

   – Investigate in which project phase the proposed site is (MERMAID sites: real case - Baltic Sea Kriegers Flak wind park, North Sea Gemini wind park; exploring options - Atlantic case; idea from scratch - Mediterranean case).

2. Involve the relevant people for specific decisions. This means:

   - Do not always aim to involve all stakeholders. Define the moment for interaction for each one of the stakeholders selected. Limit the number of interactions not to overcharge them.

   - In early project phases, accept and take stock of differing views of the stakeholders.

   - In a technical scoping phase it makes sense to only involve a small group of relevant experts.

   - In later project phases, stakeholders should be asked to pronounce themselves about few and well-defined design options of the offshore multi-use platform.

   - Collaborate closely with the stakeholders already involved in an initiative (positive MERMAID examples: Baltic and North Sea case studies).

3. Be transparent in your communication with the stakeholders. That is, if you ask stakeholders for input or feedback, always report back to them what you have done with this input at each stage, not only at the very end. Only reporting back at the end of the process makes the process difficult to trace back for the stakeholders.

What is the socio-economic impact of MUOP?

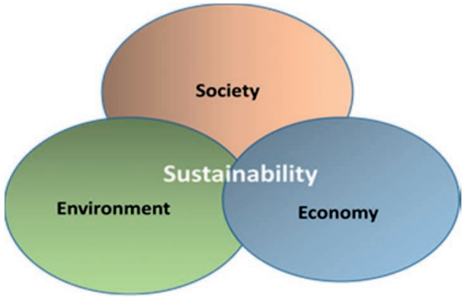
An interdisciplinary framework for assessing the socio-economic impact of MUOPs

In this chapter, we describe the methodology for integrated socio-economic assessment of the viability and sustainability of different designs of MUOPs. This methodology allows us to identify, valuate, and assess the potential range of impacts of different feasible designs of MUOP investments, and the responses of those impacted by the investment project.

This methodology integrates the socio-economic and environmental impacts and also considers the issues of equity and environmental sustainability focusing therefore on both the spatial and temporal dimensions of the interventions. In this context, the suggested methodology, focusing on marine sustainable management, extends the standard process of financial analysis into an interdisciplinary assessment that incorporates societal and environmental parameters.

Sustainability requires the simultaneous satisfaction of the following conditions:

- Dynamic and spatial economic efficiency and sustainability
- Dynamic and spatial social equity and sustainability
- Dynamic and spatial environmental and ecological sustainability



Sustainable development

By: Stichting Dienst Landbouwkundig Onderzoek - DLO

Under this framework, we performed a holistic approach in each of the selected MERMAID sites. First, we conducted the socio-economic characterization of each of each case study with regards to future economic activities, including wind and/or wave production, aquaculture and transport maritime services. Next we examined the production and demand functions of the MUOPs, identifying and quantifying the marketed costs and benefits (financial analysis) as well as the non-marketed costs and benefits (economic analysis). Our aim was to capture both private and socio-economic impacts. Hence, financial analysis considers also social and ecological parameters related not only to private organizations, firms and individuals but also to the society as a whole as well as the environment.

We incorporated into the analysis the impacts on the environment following the ecosystem services approach. The ecosystem services approach includes the identification of the ecosystem services of the marine area, links them with human welfare and elicits their value. At the final stage, policy recommendations are based on a Social Cost-Benefit Analysis (SCBA) economic tool, followed by a risk analysis in each site.

Interdisciplinary tool for applying socio-economic assessment

For the web visualization of the methodology we constructed an assessment tool, which is a web-based tool developed entirely in open source technologies, available through General Public License.

The sites as defined in the Mermaid project (Mediterranean, North, Baltic, Atlantic) comprise the first case studies for socio-economic assessment. Each site implies different area characteristics, which leads to different legal, technological, environmental, socio-economic, and financial concerns. Hence, the user chooses one of the four predefined sites and proceeds to the socio-economic assessment for that site.

The assessment tool takes into account MUOPs' technical feasibility, legal feasibility and the economic and social impact of the designed platform along with its accompanied activities. These elements are integrated in this assessment tool which consists of four parts.

Technical and legal feasibility

The first part corresponds to the technical and legal feasibility of the platform, based on identified legal and technical constraints (see table 1). The user selects the appropriate answer which is then quantified accordingly as input into the tool. The first questions are the main aspects that need to be taken into account for the legal and technical feasibility. The tool quantifies the answers and feeds them into an algorithm that will display a message of whether the user may continue with the rest of the process, or, a message will be shown that he cannot go on with the rest of the assessment tool according to unmet technical or legal constraints, hence if the answers to the last questions are negative. If the placement of the selected MUOP is not possible, then the tool indicates which functions (aquaculture, energy extraction, transport) can be included in the platform and which cannot.

Environmental impact assessment

The second part takes into account the environmental effects produced by the implementation of the selected platform design and corresponds to the Environmental Impact Assessment (EIA) applied in the case studies. The answers of the users are quantified for the tool, which displays an appropriate message if the placement is not environmentally possible, along with a brief summary of the negative answers (see table 2).

The user will then choose the location of the MUOP and the expected CO2 emissions change and the tool will use predetermined economic values for each effect to be included in the Social Cost Benefit Analysis.

Economic and financial assessment

The third part includes the economic and financial data collected for each case study. The user can upload a csv (comma-separated value)-formatted file, a format that can be easily exported from all common spreadsheet software such as Microsoft Excel. Alternatively, the user can manually input the requested values in the appropriate input boxes (see table 3).

Social cost benefit analysis

The tool runs a social cost benefit analysis based on the data received as inputs and concludes with a risk analysis, simulating different scenarios to define sensitive values and the overall risk of the selected infrastructure.

- First scenario: Deterministic model

The tool uses a number of potentially sensitive variables according to user selection over a predefined list, and calculates net present value for the user specified time horizon. The user chooses the extreme range for each of the variables. The tool performs sensitivity analysis based on these inputs and produces visualizations so that the user can observe the behavior of these variables.

- Second scenario: Stochastic models with one variable fixed.

While one of the potentially sensitive variables of the model (e.g. interest or growth rate) is fixed at the user input value, the tool models the others as randomly distributed according to a predefined distribution. With these parameters, the tool runs a Monte Carlo simulation so as to obtain a distribution for the total cost. The results are presented as a summary table with basic statistical values for the distribution of the total cost, and graphic visualizations.

Applying the methodology in the four case studies: Atlantic, Baltic, Mediterranean, and North

Economic welfare includes the net benefit earned by a private company, as well as the total benefit /cost to the national economy. If we want to

Table 1. Technical and legal feasibility

Please Select the appropriate answer	WIND	WIND	WAVE	WAVE
	Yes	No	Yes	No
Do you have approximations to production parameters (capital costs, O&M costs, administration costs and revenues)				
Do you have a definition of project time horizon?				
Are there any possibilities of combined use?				
Is there any possibility for technological upgrades?				
Is there uncertainty about the reliability of technique?				
Is there any uncertainty about estimates of costs and revenues?				
Are there correlated risks between functions that can cause impact diffusion?				
Is there political uncertainty?				
Is there unclear definition of property rights?				
Legal considerations: Is the placement feasible?				
Technically Considerations: Is the placement feasible?				

Table 2. Environmental impact assessment

Please Select the appropriate answer	**Yes**	**No**
Are there any negative environmental impacts (local, regional, global)?		
Are there any positive environmental impacts (local, regional, global)?		
Is there EIA available for similar project in the region?		
Is there uncertainty about Climate Change and other environmental parameters?		
Are there non linear environmental effects and is the threshold identified?		
Is it possible for the MUOP to produce irreversible environmental effects?		
Environmental considerations: Is the placement feasible?		

Table 3. Economic and financial assessment

Year	1	2	3	4	5	6
Investment						
Offshore wind turbine						
Equipment						
Construction						
Labor						
Other						
Operation						
Energy						
Energy-Output						
Energy-Price						
Energy-Revenue						
Energy-Labor						
Energy-Raw Material						
Energy-Energy						
Energy-Other						
Energy-Maintenance						
Energy Operating Costs						

Overview of the impact pathway of policy change (Defra 2007)

capture the total economic value of a project such as the implementation of an MUOP, we need to consider socio-economic and possible environmental impacts to the ecosystem.

Socio-economic impacts can be characterized as “direct” and “indirect”. This distinction is with regards to the level of effect on those who are involved in the MUOPs, meaning that particular economic sectors and people can be affected directly and/or indirectly by the use and operation on MUOPs. Direct impacts correspond to the earning capacity and costs of aquaculture, energy and maritime business, concerning for example the employees and their families, as well as the suppliers of aquaculture, energy, and maritime businesses. Indirect impacts on the other hand are related to impacts on consumers and the broader economy.

Based on the analysis produced under each MUOP design for each site and stakeholder views, MUOPs will create new employment opportunities and have strong economic impact in the community. Enterprises will benefit by the development of new technologies that will improve the technical capacities for energy production and aquaculture. In addition, MUOPs have the potential to increase research and development regarding technological advances and to boost educational aspects.

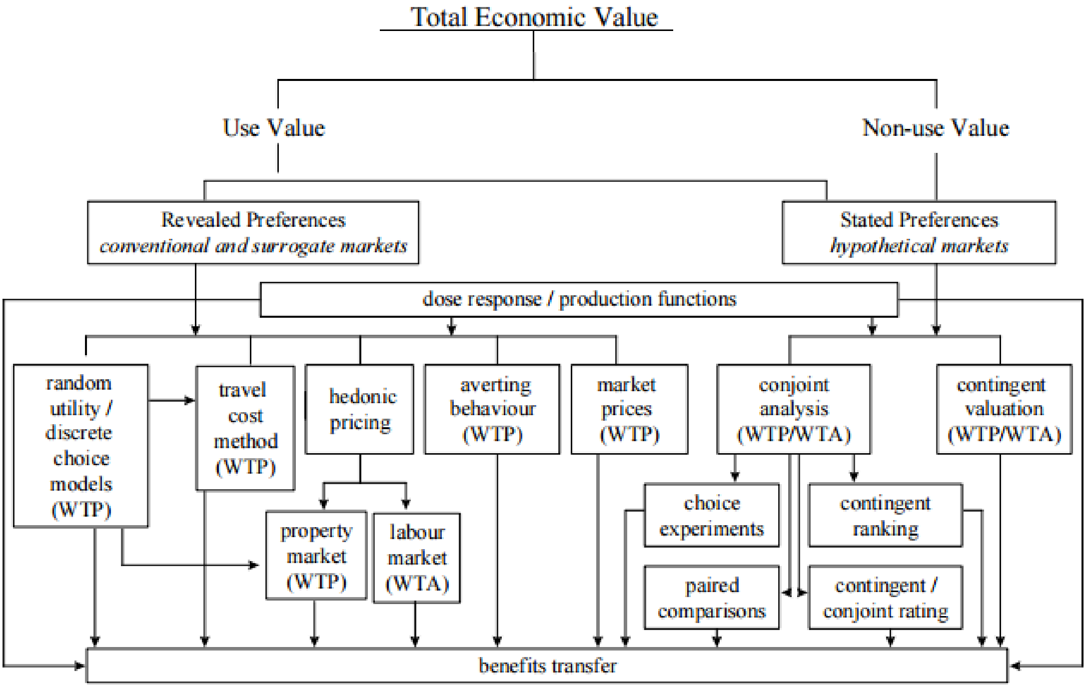
Accordingly, implementing an MUOP would affect the environment and the ecosystem services. Ecosystem services are defined as services provided by the natural environment that benefit people (Defra 2007). Individuals place values on the environmental resources and their ecosystem services for given changes in their quality and/or quantity, which are expressed in relative terms based on individuals’ preferences. Following the ecosystem services approach for the MERMAID project, we identified the ecosystem services of the marine area, linked them with human welfare, and elicit their value using economic theory.

The Total Economic Value (TEV) for any given product or resource is the sum of use (direct, indirect, option value) and non-use values (altruistic, bequest, existence value). Environmental impacts are generally on resources and their services that are not traded in markets. As a result, no market price is available to reflect their economic value. Hence, expressing these impacts in monetary terms using non-market methods is required. More explicitly, preferences are measured in terms of individuals’ willingness to pay to avoid an environmental loss or to secure a gain, and their willingness to accept compensation to tolerate an environmental loss or to forgo a gain. The figure shows the TEV framework and the economic techniques used in economic valuation of benefits derived from the ecosystem services.

Preliminary valuation can be done using either stated preferences or revealed preferences techniques. For the MERMAID Project, we used the Benefit Transfer method instead of applying preliminary research, taking estimates from similar case studies which can be used as a monetary indicator of the impacts of the MERMAID study sites.

In addition, based on the Life Cycle Assessment (LCA), we compared each platform’s CO2 emissions to those that would have been produced via traditional (not renewable) energy sources as the result of producing same amount of electricity and aquaculture products. For this case, we used the social cost of carbon (SCC) to estimate the benefits produced from this comparison.

After the identification and quantification of the environmental and socio-economic benefits, we included financial costs and revenues from energy extraction and aquaculture production to the analysis.



Techniques for monetary valuation of non-market services (Pearce & Howarth 2001)

Social cost benefit analysis and risk analysis

In order to assess the monetary social costs and benefits of each MUOP's construction and operation over a 22-year period in comparison with single-use offshore platforms, we applied a Social Cost Benefit Analysis (SCBA). In this framework, the estimated economic values accrued by the involved stakeholder groups are aggregated over their relevant populations and added to capture the total economic value generated by each MUOP. The aim of SCBA is to have the benefits of each MUOP contrasted with their associated financial and economic costs.

For the Baltic site, the MUOP (wind-fish-seaweed farm) 10 per cent efficiency gains are expected from the combined use. More explicitly, the construction of the offshore wind-farm costs 1.5 million euros in addition to 0.2 billion euros for grid connection. Salmonid farming costs 40 million euros per year for operation and maintenance. Seaweed farming is a future option that requires future testing and market analysis. Additional administrative costs of 0.1 billion euros are also included in the social cost benefit analysis. The expected financial revenues are 0.28 billion per year.

The North site is quite similar to the Baltic site. The MUOP (wind-mussel-seaweed farm) 10 per cent efficiency gains are also expected from the combined use. Based on market analysis and literature references, for the offshore wind farm 2800 million euros will be invested for the first year and 1800 million euros in year 16, while 60-140 million euros per year operation and maintenance costs are foreseen. For mussel farming 7-11 million euros will be required to be invested every 5 years and 8.5-57 million euros per year as operation and maintenance costs. In the case of seaweed farming 21-400 million euros every 10 years will be needed in addition to 47-68 million euros per year for operation and maintenance costs. Revenues for each function are expected to be 442, 45 and 17-48 million euros per year respectively. In year 16, when subsidies to wind farming cease, revenues from wind farming decrease and become 112 million euros per year.

The Mediterranean site's MUOP (wind-fish farm) requires 44 million euros and it is expected to produce 1 million euros per year for 20GWh per year for the energy extraction. On the other hand costs for fish farming are estimated to be 3.7 million euros and revenues are expected to be 19,9 million euros. Synergies are not possible without extra cost. Finally, for the Atlantic site MUOP (wind-oscillates water column farm) total manufacturing cost is estimated to be 364,591,964 euros whereas total capital expenses reach 1,973 million euros (3.20 mill€/MW).

For the Social Cost Benefit Analysis, we included the economic values produced given the change in CO2 emissions and the changes in the ecosystems services (marine research and education - Atlantic, harmful algal blooms appearance - Mediterranean, clean water due to mussel production - North, artificial reef effect - Baltic) as well. These values represent costs and revenues for each site and together with the financial costs and revenues were discounted using the Net Present Value method.

Additionally, a risk analysis was also applied for the site. The results were subjected to rigorous uncertainty/sensitivity analysis, since uncertainty is present at all stages of the assessment process

Recommendations for sustainable spatial marine management

The methodology provides decision-makers with the information and tools needed to decide on the implementation of an MUOP project regarding the change in the overall social welfare and hence decide if such project should be undertaken. In addition this methodology plays an important role in facilitating the implementation of the Marine Strategy Framework Directive.

During the project, many obstacles regarding the legal, institutional, and social European framework were identified. All these showed the importance of following a consistent methodology that takes into account different socio-economic and environmental aspects.

These aspects are diffused across the economy at local, regional or national level but they are not taken into account since the corresponding benefits or costs do not influence private net benefits directly. Hence, an investment in an MUOP may not be efficient under the scope of a private firm, but it may be efficient at the level of the national economy, and vice versa.

MERMAID indicated that combining offshore energy production with aquaculture for each site involves different legal, societal, economic, and environmental aspects while data unavailability delayed the social cost benefit analysis. A strong sufficient institutional framework that allows such synergies is required and can be socially accepted in case of applying an interdisciplinary analysis that takes into account not just financial gains, but also social gains and considerations.

The results for the Atlantic and North Sites suggested that construction and operation of the multi-use platforms is feasible and sustainable given the mitigation of negative environmental effects produced by the platforms. In contrast for the Mediterranean site, in the short term, going offshore is not feasible. However, in the long-run, coastal and marine spaces might become more limited, and then going offshore will become more important and efficient.

Nevertheless, the opportunity cost of using ocean space should be considered for future multi-use platform development. We need to be able to understand and measure the opportunity cost of using them and the benefits from efficient use of its space. Viable planning of marine space would increase the overall efficiency of the use of marine space. Hence, following an interdisciplinary, holistic approach with regards to future sustainability is required to support the implementation of multi-use platforms.

Facts on the MERMAID project

Photo: DHI

Factsheet on the MERMAID project

Funded by	European Union, Seventh Framework Programme for research, technological delvelopment and demonstation - Theme [OCEAN.2011-1]
Full title	Innovative Multi-purpose off-shore platforms: planning, design and operation
Short name	MERMAID
Grant Agreement no.	288710
Start date of project	01 Jan 2012 - Duration: 48 month
Budget	7,4 million euro.
Funded	The European Union has granted a financial contribution of 5,5 million euro.
Partners	29 partners: 11 universities, 8 research institutions, 6 industries and 4 SME's
Results and available material	http://www.mermaidproject.eu/sharepoint/Documents/Deliverables of the project/
Films about the project on YouTube	https://www.youtube.com/channel/UCRkGGo-oqJYbbqnspbjimSg A full movie of 14:52 minutes or a short version of 3:25 minutes can be watched.

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Work packages (WP) and work package leaders (WPL) in the project

WP1: Project management

Coordinator and WPL
Erik Damgaard Christensen
DTU Mechanical Engineering

Deliverables

D1.1 Inception report
D1.2 Quality plan

WP2: Assessment of policy, planning and management strategies

WPL Marian Stuiver
Wageningen University and Research Centre; Stichting Dienst Landbouwkundig Onderzoek (DLO)

Deliverables

D2.1 Inventory, legislation and policies
D2.2 Stake holder views
D2.3 Report on stakeholder views
D2.4 Platform solutions
D2.4 Platform solutions
D2.5 Guidelines
D2.6 Report on integrated sustainable planning
D2.7 Policy recommendation

WP3: Development of renewable energy conversion from wind and waves

WPL Inigo Losada and
Raul Guanche Garcia
Faculty of Engineering of the University of Cantabria

Deliverables

D3.1 Energy resources
D3.2 Offhore Technology
D3.3 Report on energy converters
D3.4 Integration into MUP
D3.5 EIA of energy converters

WP4: Systems for sustainable aquaculture and ecologically based design

WPL Flemming Møhlenberg and
Nick Ahrensberg
DHI

Deliverables

D4.1 Physical test of offshore cage reported
D4.2 Sites for seaweed
D4.3 Test of seaweed farm
D4.4 IMTA offshore
D4.5 Fish farming opportunities
D4.6 In and offshore fish farming
D4.7 Ecology

WP5: Interaction of platform with hydrodynamic conditions and seabed

WPL Jan-Joost Schouten
Stichting Deltares

Deliverables

D5.1 Metocean conditions
D5.2 Numerical tools
D5.3 Interaction between currents, wave, structure and subsoil
D5.4 Guidelines for seabed support structure interaction

WP6: Transport and optimization of installation, operation, and maintenance

WPL Wei He
Statoil Petroleum AS

Deliverables

D6.1 Operators tool-box
D6.2 MUP business case
D6.3 Report on Synergies in MUP’s
D6.4 DSS

WP7: Innovative platform plan and design

WPL Barbara Zanuttigh
University of Bologna

Deliverables

D7.1 Site specific conditions
D7.2 Site specific impact of policies
D7.3 Site specific design conditions

WP8: Economical, technical and environmental feasibility of multi-use Platforms

WPL Phoebe Koundouri
Athens University of Economics and Business

Deliverables

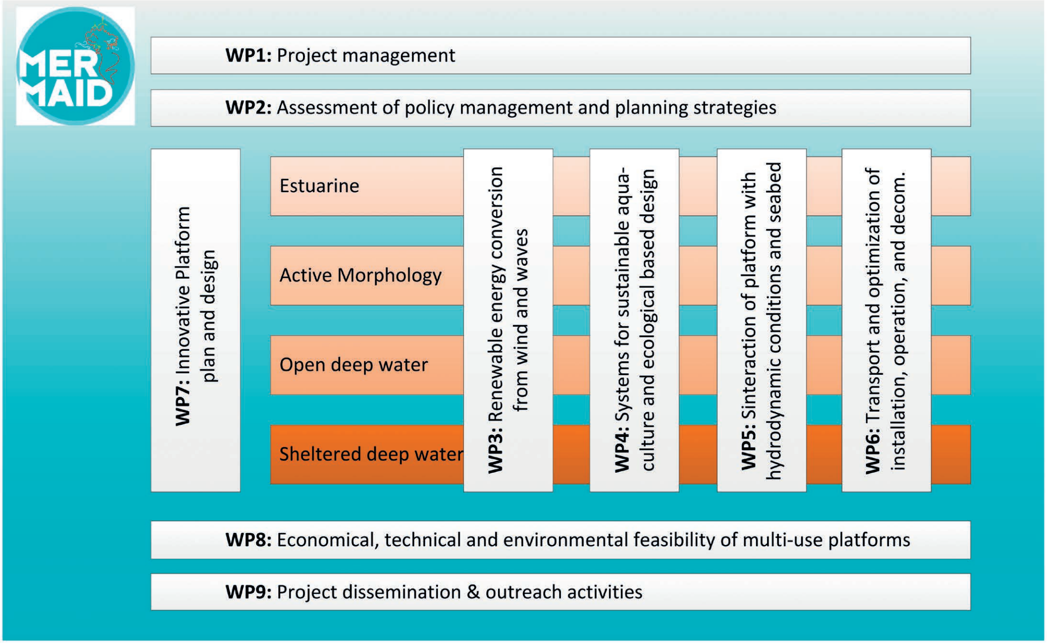
D8.1 Method statement ISEA
D8.2 Socio-economics, Baltic
D8.3 Socio-economics, North Sea
D8.4 Socio-economics, Atlantic
D8.5 Socio-economics, Mediterranean
D8.6 Risk assessment for the four sites

WP9: Project dissemination & outreach activities

WPL Simon Claus
Vlaams Instituut voor de Zee

Deliverables

D9.1 Inception report with a exploitation plan
D9.2 DVD – Films on youtube
D9.3 Mid-term dissemination report
D9.4 Website and booklet
D9.5 Final dissemination report on publications and net-working
D9.6 End user conference



Overview of the nine MERMAID work packages and their interaction. The technical WP's WP3-WP6 are delivering to WP7, WP2 and WP8.

References, Endnote and Contributors

References

Bandura 1971
Bandura, A., 1971. Social Learning Theory. General Learning Corporation. Retrieved 25 December 2013.

Corbetta et al 2015
Corbetta, G., Mbistrova, A., Ho, A., Guillet, J., Pineda, I., Wilkes, J., 2015. EWEA: The European offshore wind industry - key trends and statistics 2014.

DEFRA 2007
DEFRA (Department of Environment, Food and Rural Affairs), 2007.An introductory guide to valuing ecosystem services. Product code PB12852.

Ehler & Douvere 2009
Ehler, C., Douvere, F., 2009. Marine Spatial Planing: a step-by-step approach toward ecosystem-based management. Intergovernmental Oceanographic Commission and Man and the Biosphere Programme. IOC Manual and Guides No. 53, ICAM Dossier No. 6. UNESCO, Paris.

Falcão 2010
A. F. de O. Falcão 2010, Wave energy utilization: A review of the technologies, Renewable and Sustainable Energy Reviews, Volume 14, Issue 3, April 2010, Pages 899-918, ISSN 1364-0321, http://dx.doi.org/10.1016/j.rser.2009.11.003.
(http://www.sciencedirect.com/science/article/pii/S1364032109002652).

Franzén 2012
Franzén, F., 2012. Creating pathways for stakeholder participation in water management. Lic thesis 2063. KTH, Land and Water Resources Management, Stockholm.

Gibbons et al 1994
Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., Trow, M., 1994. The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies. SAGE, London.

He et al 2015
He, W., Yttervik, R., Olsen, G.P., Ostvik, I., Jimenez, C., Schouten, J. EWEA Offshore 2015, PO. 054,
A case study of multi-use platform: Aquaculture in offshore wind farms, 10-12 March 2015.

Jentoft & Knol 2014
Jentoft, S., Knol, M., 2014. Marine spatial planning: risk or opportunity for fisheries in the North Sea? Marit.
Stud. doi: 10.1186/2212-9790-13-1.

Nelson & Winter 1977
Nelson, R. and S. Winter 1977. In search for a useful theory of innovation. Research policy 6:36-76.

Pearce & Howard 2001
Pearce, D. W., & Howarth, A. 2001. Technical report on methodology: cost benefit analysis and policy responses.

Pearce & Howarth 2014
Pearce, D. W., & Howarth, A. 2001. Technical report on methodology: cost benefit analysis and policy responses.

Rasenberg et al 2013
Rasenberg, M., Stuiver, M., Van den Burg, S., Veenstra, F., Norrman, J., Söderqvist, T., 2013, Stakeholder Views; Deliverable D2.2, MERMAID project.

Reed 2008
Reed, M., 2008. Stakeholder participation for environmental management: A literature review. Biological Conservation, 141, pp 2417-2431.

Rip 2000
Rip, A., 2000. Fashions, lock-ins and the heterogeneity of knowledge production. In: Jacob, M., Hellstrom, T. (Eds.), The Future of Knowledge Production in the Academy. SRHE and Open University press, Buckingham, pp. 28–39.

Schot & Rip 1997
Schot, J.W. and A. Rip, 1997. The Past and the Future of Constructive Technology Assessment. Technological forecasting and social change 54 (2-3) 251-268.

Smits 2016
Smits, R., 2006. Developing a stimulating environment for innovation in the Dutch agro-sector. Zoetermeer: TransForum Agro en Groen.

Wenger 1999
Wenger, E., 1999. Communities of practice, learning, meaning and identity. Cambridge: Cambridge University Press.

Endnote

1 http://www.eea.europa.eu/data-and-maps/indicators/aquaculture-production-3/assessment#toc-1

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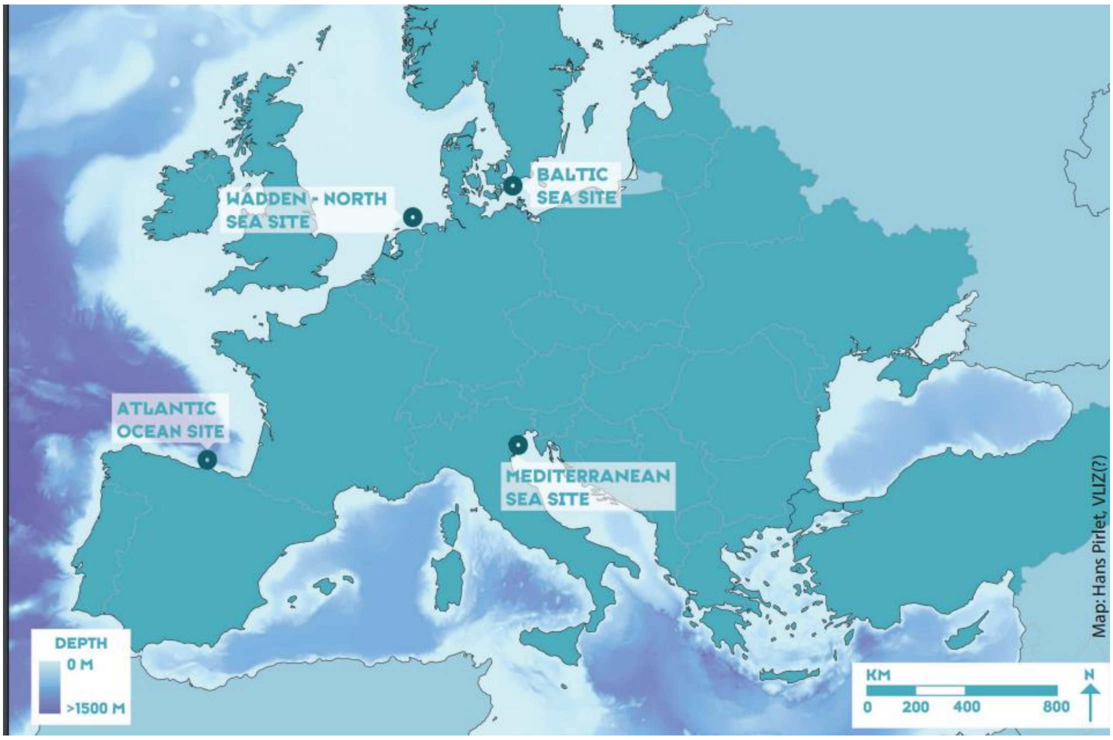
Go offshore - Combining food and energy production

PUBLISHER: DTU Mechanical Engineering,Technical University of Denmark, Nils Koppels Allé, Bldg. 404, 2800 Kgs. Lyngby, Denmark •
EDITING: Lena K.C.arlberg, Erik Damgaard Christensen• **GRAPHIC DESIGN:** Vivi Jessen • **COVER PHOTO**: Simulation developed by Flanders Marine Institute (VLIZ) •
PRINT: GraphicCo. • November 2015 • **ISBN:** 978-87-7475-424-4

3 Introduction – The four study sites

In order to contribute to real design concepts and industrial application, four pilot study sites with different environmental characteristics have been identified.

1. Baltic Sea site - Krigers Flak, Estuarine site
2. North Sea site - Wadden Sea, Gemini site
3. Atlantic Ocean site - Ubiarco and Santoña, Cantabria Offshore Site - Far offshore area
4. Mediterranean Sea site - Area offshore Venice



Map: Hans Pirlet, VLIZ(?)

Figure 3-1 Map of Europe - The four study sites

The sites represent specific challenges in relation to environmental, social, and economic conditions (as shown in the table) as well as the availability of data and the opportunity to link directly to local research teams, stakeholders, policy managers, SMEs, and industrial networks.

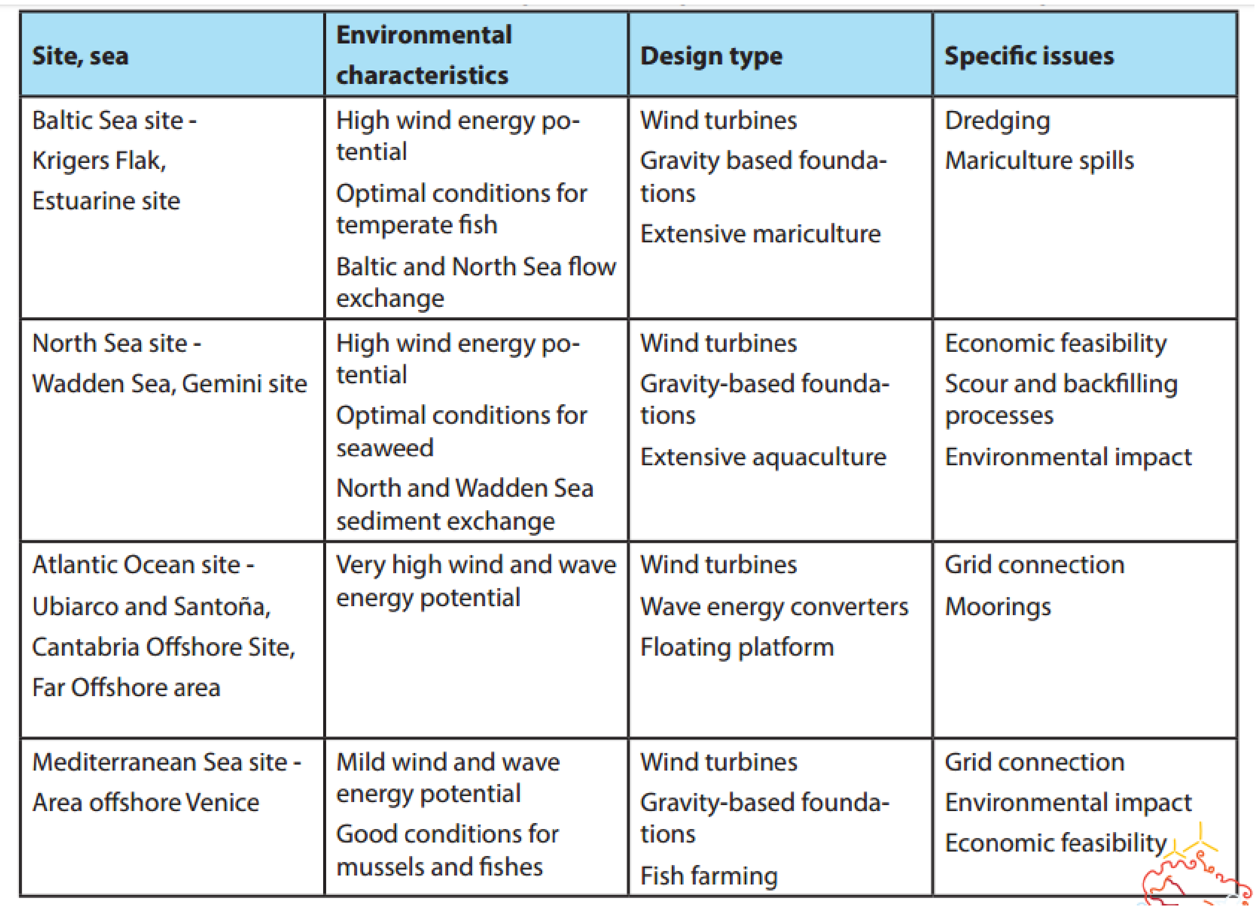
A series of possible design options and industrial interaction were scoped and conceptually designed on a site-by-site basis. The selected conceptual design of the multi-use platform (MUOP) was an iterative participatory process with stakeholders.

The participatory process depended on the existence and/or flexibility of policies and socioeconomic and environmental management schemes or constraints.

For the design and the planning, the following were included

- Assessment of the site conditions and requirements (stakeholders requirements; local demand for energy, food; spatial study of the resources)
- Preliminary design of MUOPs (technical evaluation; energy and food production performance; construction, installation, operation, servicing, maintenance)
- Evaluation of MUOP designs (environmental impact assessment, economic evaluation, benchmark to single-use solutions)

- Selection of the preferred design based on a multi-criteria analysis aiming to assure sustainable development of the area;
- Evaluation of possible consequences on policies, and specifically on marine spatial planning.



Site, sea	**Environmental characteristics**	**Design type**	**Specific issues**
Baltic Sea site - Krigers Flak, Estuarine site	High wind energy potential Optimal conditions for temperate fish Baltic and North Sea flow exchange	Wind turbines Gravity based foundations Extensive mariculture	Dredging Mariculture spills
North Sea site - Wadden Sea, Gemini site	High wind energy potential Optimal conditions for seaweed North and Wadden Sea sediment exchange	Wind turbines Gravity-based foundations Extensive aquaculture	Economic feasibility Scour and backfilling processes Environmental impact
Atlantic Ocean site - Ubiarco and Santoña, Cantabria Offshore Site, Far Offshore area	Very high wind and wave energy potential	Wind turbines Wave energy converters Floating platform	Grid connection Moorings
Mediterranean Sea site - Area offshore Venice	Mild wind and wave energy potential Good conditions for mussels and fishes	Wind turbines Gravity-based foundations Fish farming	Grid connection Environmental impact Economic feasibility

Table 3-1 Environmental characteristics, design type and specific issues

4 Perspectives learned from the four sites

Extensive investigations and investment in marine renewable energy utilization worldwide and large progresses have been achieved over the last years.

However, there are still some technological barriers to overcome such as:

- the production of energy in ordinary conditions while devices should withstand extremes;
- the need for harvesting energy in deeper areas and with low environmental impact, while the design of moorings has often proved insufficiently reliable;
- financial feasibility due to the lack of innovative and highly efficient technology for energy conversion;
- the huge energy losses and costs related to energy transfer to shore;
- the immature technologies for local energy storage.

The use of resource diversity can develop promising technical synergies, reduce the variability of renewable power, and lower system integration costs. The integration of marine renewable devices with aquaculture and transportation can lead to shared infrastructures and greener solutions, such as the design of stand-alone MUOPs where the energy produced is used to support the different MUOP functions.

The design and construction of MUOPs is a multi-expert, multi-stakeholder participatory process. While the technological knowledge and the selection and planning methodologies are transferrable, the use of the methods has to accommodate site-specific conditions. The application of the technical methodologies are strongly dependent on the social component (public perception) and on the legislation framework (licensing regulations).

A significant challenge is the lack of the definition of standards and standard procedures. This is a challenge not only for the design, but also for the assessment of (environmental) impacts, for the identification of the optimal site location (taking into account the conflict with other applications), and for the selection of the MUOP scheme that is better suited to a given site. MUOP design

The selection of the MUOP design at the sites was a complex process based on expert assessment of selected criteria including:

- maturity of technology in terms of reliability, performance, and technological innovations;
- environmental impact, accounting for the use of marine space, the impact on native species, and maintenance requirements;
- induced risks, including geotechnical failure, hazard for maritime activities, pollution, power take-off failures, and structure modularity;
- costs as a function of installation depth, power take off, mechanical complexity of the overall system, and maintenance.

While the methodology depends on assessments of experts with different backgrounds, it offers the possibility to combine these assessments in a systematic and transferable procedure. It can be therefore adopted to elicit a participatory design approach to identify the most suitable MUOP for the given offshore site.

The viability level of MUOPs in the different sites also depends on:

- the national level of power grid development (is the grid ready for receiving local and variable inputs?),
- the national technical skills of the managers (who need interdisciplinary skills, besides technical ones, to understand the projects before approval),
- the sensitivity of the population to environmental issues (in both terms of potential environmental impacts produced by the installation and of preference towards greener solutions rather than traditional fuels).

5 The Baltic Site

5.1 Site description

The Kriegers Flak is a large sandy shoal with a sand layer thickness of up to 8 m located in the Western Baltic Sea between Denmark, Sweden and Germany (Figure 5-1 Location of Kriegers Flak depicting territorial and EEZ of Denmark, Sweden and Germany. Star symbol show location of monitoring station for water quality.). The name Flak actually refers to a wide shallow shoal in Danish. The central plain is located at 18-20 m depth gently sloping to more than 40 m to the N, E and S. The major part of the sandy plain is located within the Danish Economic Zone. In the shallow parts (18-23 m) the seabed consist of medium sand with a varying median grain size between 0.2 and 0.4 mm with some content of gravel and coarser fractions. Organic content (loss on ignition, LOI) is low at 0.1-0.15 % of sediment dry weight at the plain but increased to 3-5% at 40 m. Dedicated areas (about 20 km^2) within the Danish part are extensively used for sand extraction.

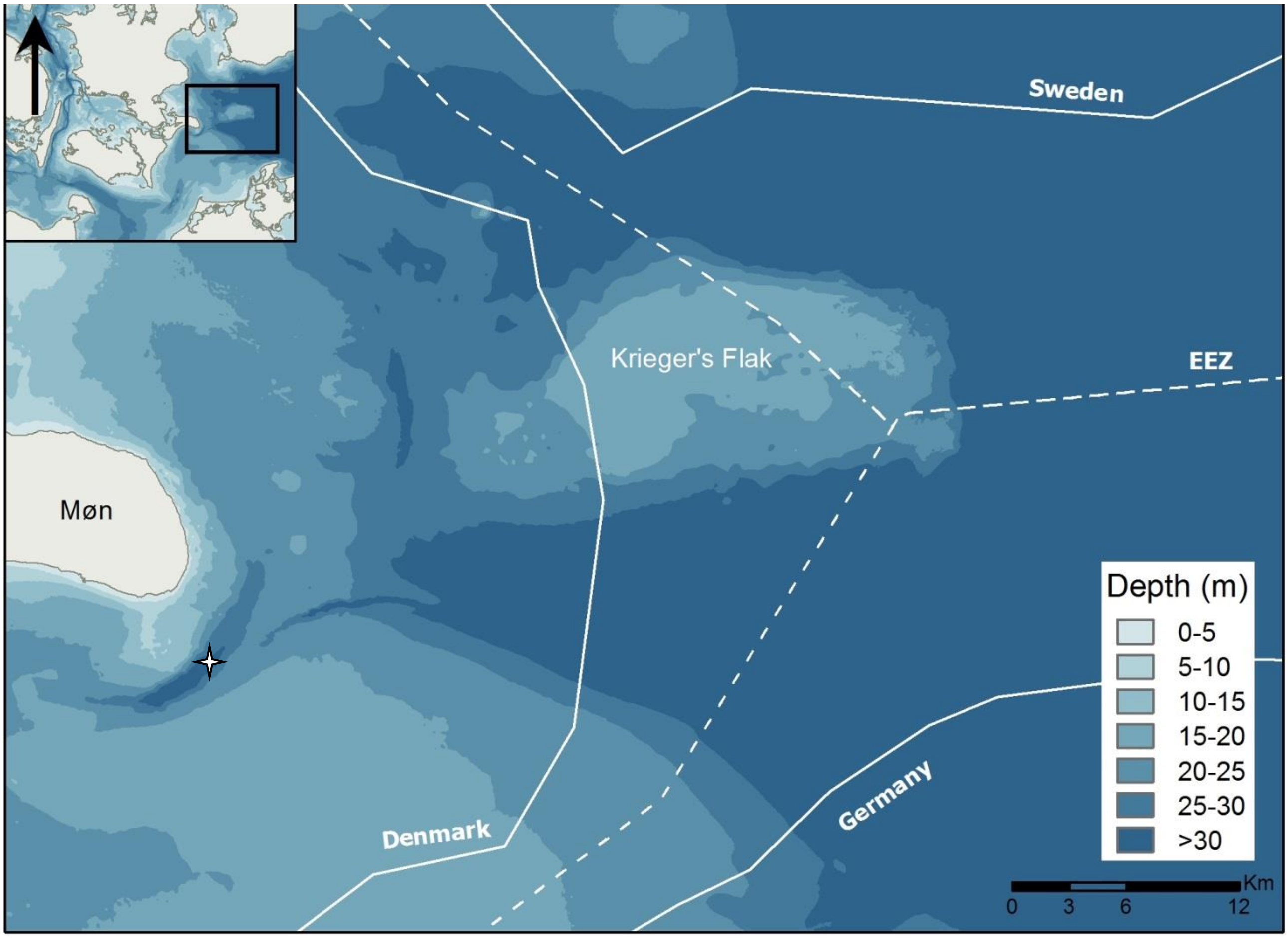


Figure 5-1 Location of Kriegers Flak depicting territorial and EEZ of Denmark, Sweden and Germany. Star symbol show location of monitoring station for water quality.

5.1.1 Met-ocean conditions and databases

Wind conditions

Wind speed in the following is based on analysis of Envisat ASAR satellite data providing speeds at 10 m above sea level. The mean wind speed is shown in Figure 5-2.

Wind statistics as a wind rose and Weibull distribution is shown in Figure 5-3. Winds are predominantly westerly during summer. Easterly winds are common during winter.

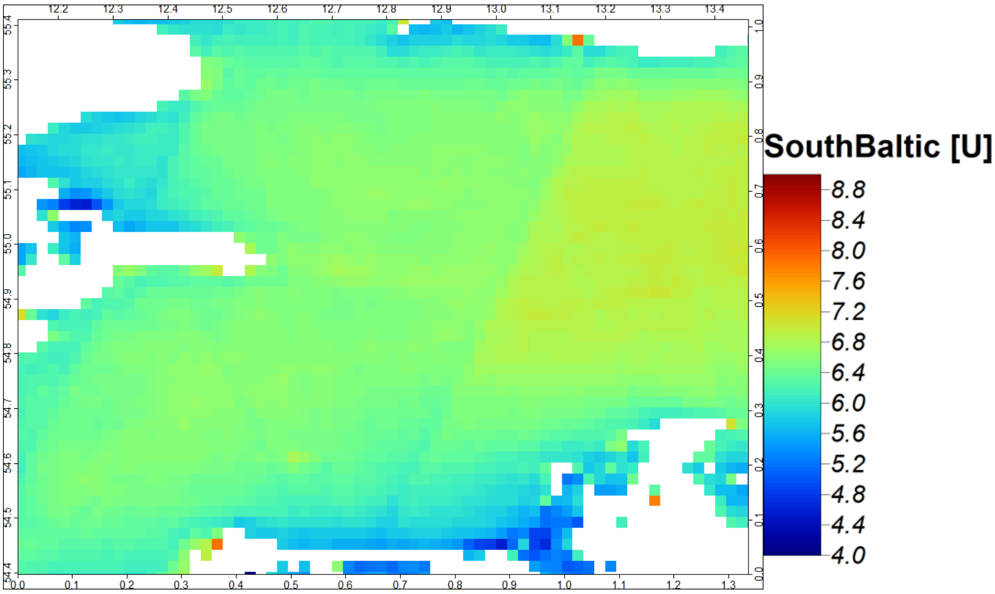


Figure 5-2 Map of mean wind speed from Kriegers Flak based on Envisat ASAR wind fields.

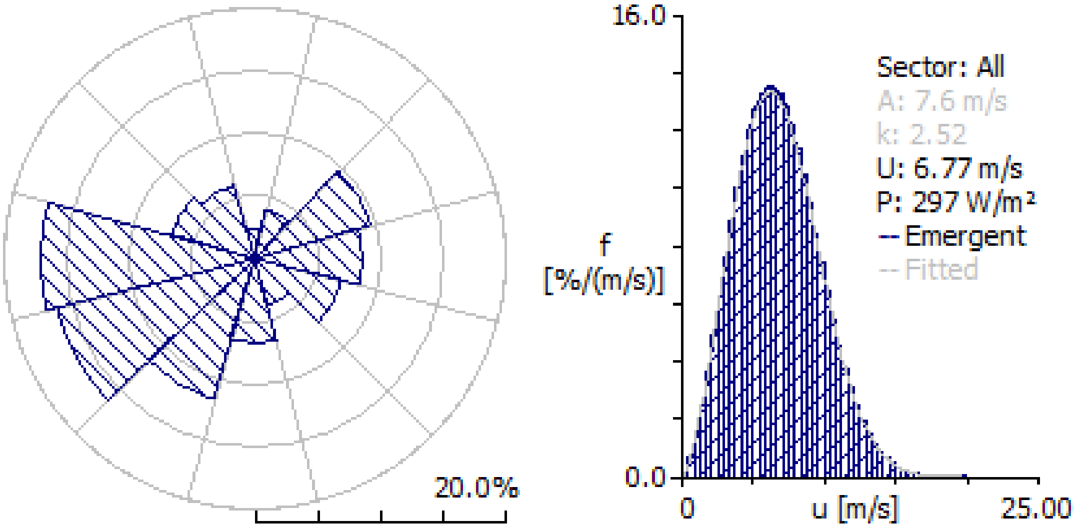


Figure 5-3 Wind rose and Weibull distribution at 10 m at 55.00°N 13.08°E in the South Baltic Sea observed from Envisat ASAR.

Hydromorphological analysis

Currents are very variable and driven by wind, horizontal density gradients and differences in sea level. Freshwater surplus in the Baltic Sea catchment gives rise to westerly annual mean currents of 2-5 cm/s in the Kriegers Flak area. Being located at the main entrance to the Baltic Sea there are ae dense bottom currents flowing easterly direction north and south of the shoal. Combined with the strong meteorologically induced variability, this gives rise to rapid salinity fluctuations within a range from 8 PSU to 30 PSU. The inflow currents are of the order 20-30 cm/s. In general currents on the shoal are modest below 1 m/s.

The Southern Baltic Sea is basically tideless, but may experience storm surges up to about 1 m, in extreme cases 3.3 m during adverse meteorological conditions, where passing low pressure systems may induce a combined pumping of North Sea water into the Baltic and "sloshing" in the Baltic Basin (BSH, 2005)

Waves conditions are generally modest, but rough seas (waves larger than 2-3 m) are common in November-December (see Figure 5-4, Figure 5-5, Figure 5-6). During May through August calm sea (< 0.5 m) are common. Swells are uncommon at Kriegers Flak. Significant wave heights are on long term average about 0.9 m. In extreme situations preliminary estimates of the significant wave heights are about 4.5 m (10 year return period), 5.2 m (50 year return period) and 5.5m (100 year return period) (Hanson and Larson, 2009. Estimated mean wave periods at KF are about 3.5 sec with peak periods up to 4.5 sec (Soomere and Räämet, 2011).

The seabed at Kriegers Flak in the area planned for the Danish offshore wind farm consist of medium to fine sand from Littorina deposits with median grain size between 0.2 and 0.4 mm and very low content of fines but some content of pebbles and stones. The seabed is relatively level with slopes below 0.3 %. The thicknesses of the sand shoal are typically 8 m.

Geologically the Kriegars Flak is considered stable, with very little erosion and active sediment transport (Energinet.dk, 2012)

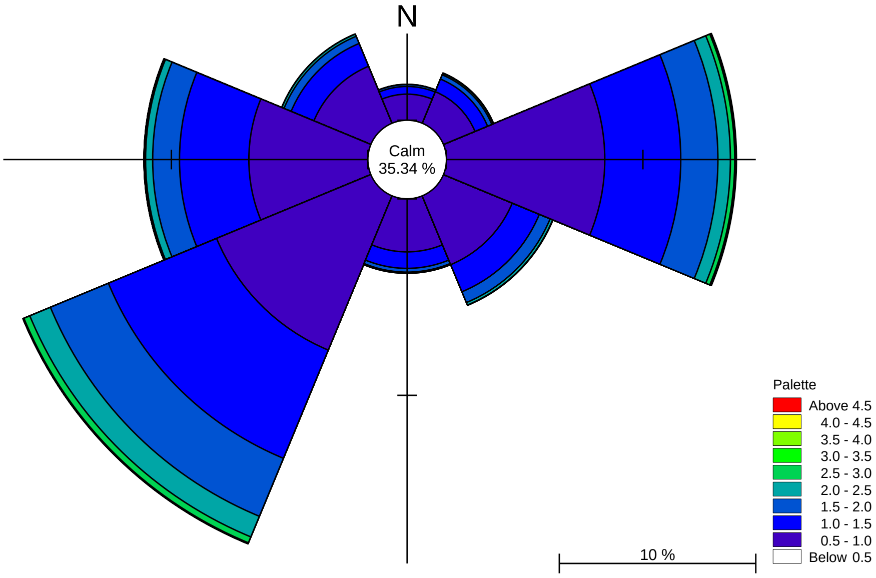


Figure 5-4 Example of wave rose from Kriegers Flak

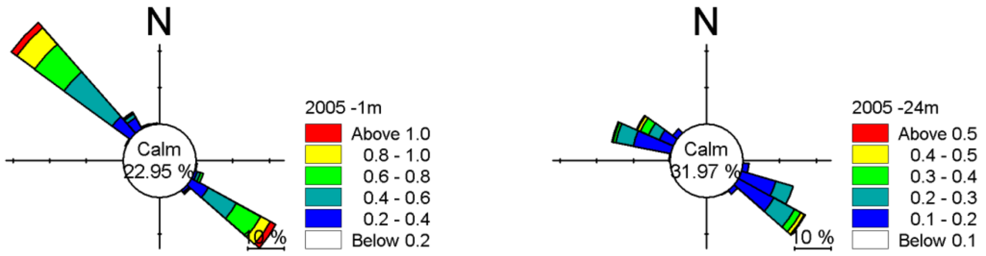


Figure 5-5 Example of current Rose, surface and bottom.

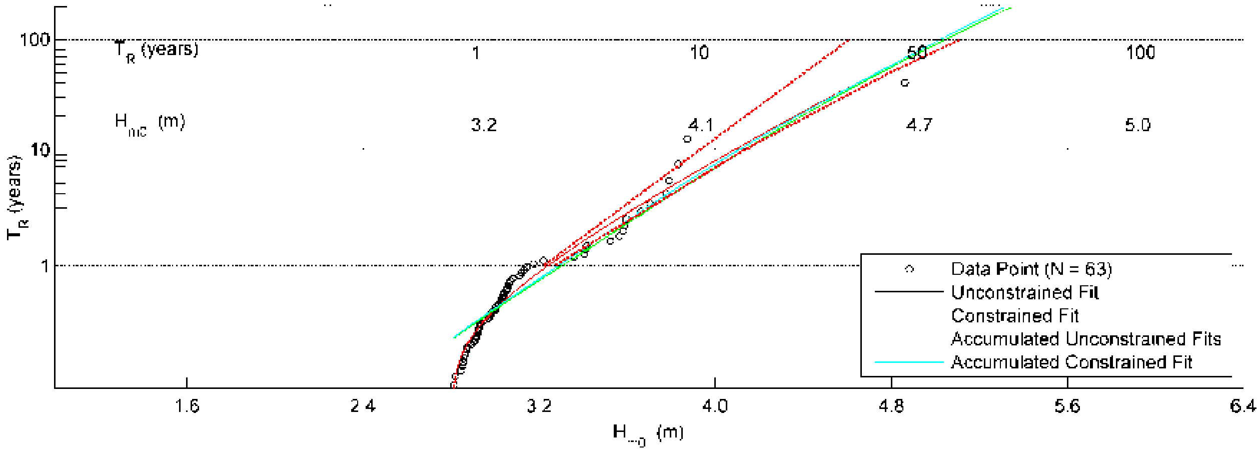


Figure 5-6 Example of extreme wave statistics.

Environmental characterization

Hydrographic and water quality data are available from a near-coastal station east of Møn sampled monthly during 1990-1997 under Danish Monitoring Programme (MADS) and recently (2009-2010) during an EIA study (DHI 2013). Additional data were collected in the Swedish sector of Kriegers Flak in 2002 and 2003 in connections with an Environmental Impact Assessment for a Wind Farm (SoW AB 2004).

Throughout the year salinity is stable at 7-9 PSU in the upper 15-18 m part of the water column. Density stratification occurs regularly during calm periods in summer and is reinforced by thermoclines located between 10 and 15 m. Surface water temperature varies seasonally between 0 and 20 °C. During summer and early autumn bottom water oxygen becomes under-saturated, if stable density stratification is established but concentration rarely decreases to below 2-3 mg/l. During winter, spring and early summer concentration of dissolved oxygen in bottom water is saturated.

At the monitoring station (see **Error! Reference source not found.**) concentration of total nitrogen varies between 16–24 µmol/l with no consistent trends through the water column and year (2009-2010). Total phosphorus varies between 0.5 and 1 µmol/l with the lowest values during summer. Spring bloom occurs in March to early April with peak chlorophyll a concentrations reaching 6-8 µg/l, but on a yearly basis chlorophyll a is low at 1.5 µg/l. Cyano-bacteria blooms that common in the central Baltic Sea rarely affects the Kriegers Flak.

Seabed flora and fauna

Benthic vegetation is rare on Kriegers Flak due to depth and the associated low light intensity and, lack of hard substrate (e.g. boulders) for macroalgae. Single fonts of *Saccharina latissima* have been observed.

The benthic fauna on the shallow plain is species-poor (average 6-8 species per 0.1 m^2 sample) and characteristic for shallow, low saline areas in the western Baltic Sea (DHI 2003, DHI 2005, SoWAB 2004). Abundance (200-4000 ind. m^{-2}) and biomass (average 2-6 g ash-free DW m^{-2}) are dominated by a few species of polychaetes (*Pygospio elegans, Marenzelleria viridis (invasive), Hediste diversicolor*) and bivalves (*Mytilus edulis, Mya arenaria, Macoma balthica*). On the slopes species richness and abundance increases with depth averaging to 20 species per 0.1 m^2 sample at 40-42 m with dominance of polychaetes in the organic richer sediments. In the Danish sector red-listed species are not present.

Fish Aquaculture

Apart from wave exposure the environmental conditions are excellent for growth-out of salmonids, especially rainbow trout and salmon due to the following environmental conditions:

- Salinity is stable at 7 psu and almost equal to the osmolality of fish plasma meaning that energy expenditure to osmoregulation in fish will be low - and accordingly, that growth efficiency can be high. A low environmental salinity will also prevent infections by sea lice.
- The instantaneous dilution is high at 4000-6000 (**Error! Reference source not found.**) implying that the well-being and growth of fish on the one hand side and the pelagic environment on the other hand will not be affected by excretes from the fish including ammonia, CO_2, medicines and release of antifouling agents such as Cu.
- On the shallow plain of Kriegers Flak more or less regular high waves and currents will erode deposits from the fish cages accumulated on the seabed as evidenced by the median grain size and low organic content under the present conditions. Therefore, permanent accumulation of organic matter in sediments below fish farm established on the shallow plains and the connected impacts on sediment chemistry and fauna will not be likely
- Summer blooms of cyanobacteria occur regularly in the Baltic proper but are rare in the western Baltic Sea. The dominating species *Nodularia spumigena* produce toxin that can be lethal to zooplankton but except in laboratory lethal or sub-lethal effects on adult fish has not been described. Lethal spring blooms of *Chattonella* and *Chrysochromulina* have not been documented for the western Baltic Sea.

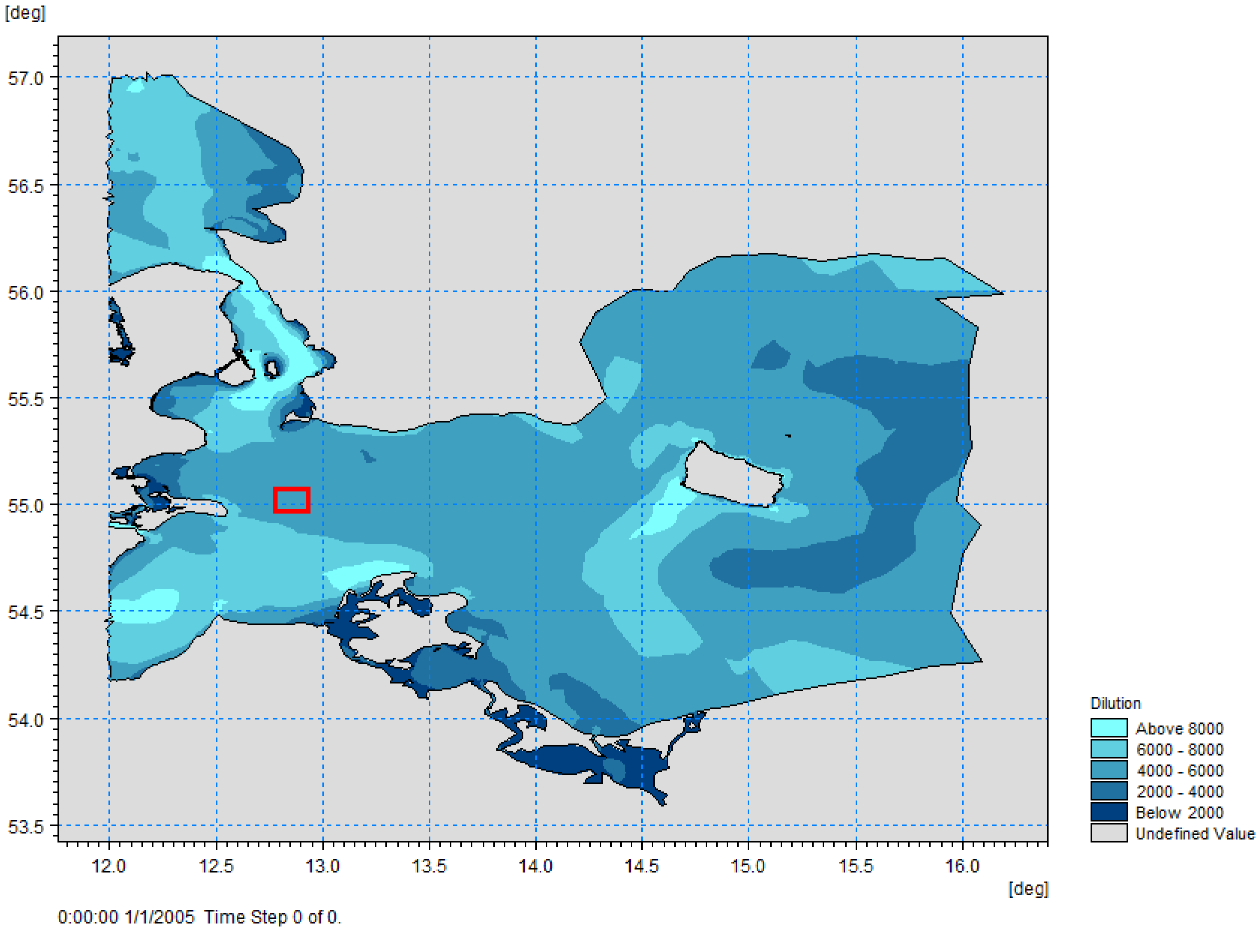


Figure 5-7 Dilution rate quantified using a calibrated 2-D hydrodynamic model (MIKE 21 HD).
Kriegers Flak indicated by red rectangle. The model was executed for 2005 and forced by meteorology, run-off, and water level, salinity and temperature at the boundaries. For every model cell and at every stored time step (1 h) dilution rate was estimated as a near-field study by adding a tracer in fixed concentration and calculate tracer concentration 1000 m downstream of the release point (e.g. a fish farm) assuming default values of momentum dispersion coefficients. In order to take account of the underestimated currents speeds at larger depths we assumed that tracer concentration in surface waters (0-10 m) was representative of the real dilution. Yearly values of dilution were subsequently calculated for each model cell as medians.

5.2 Participatory design process

The selected data has been based mainly on information gathered by the so-called site managers during the participatory design process within the MERMAID project. Each site had a site manager: a key expert and process facilitator for that particular site. The participatory design process aimed to co-develop MUPS by a group of relevant stakeholders for each site. It was organized through three steps:

1. Collection of the views and needs of selected stakeholders in the first round (Rasenberg et al, 2013)
2. Reviewing the preliminary MUPS design in the second round (Rasenberg et al, 2014)
3. Evaluating the final design in the third round (Röckmann et al, 2015)

Within the different sites, the site managers invited different stakeholder groups: such as policy makers, businesses, sector representatives, NGO's, local citizens and research institutes (Röckmann et al, 2015).

This combination of offshore wind energy and aquaculture is interesting given the large-scale development of offshore wind – with subsequent spatial claims and the critical attitude towards nearshore aquaculture. Stakeholders involved are businesses that expressed interest in the development of a MUPS, policy makers and shipping authorities. Furthermore, NGO's and scientists participated.

There is a political goal in Denmark to be completely independent of fossil fuels by the year 2050. Thus, there is a lot of focus on renewable energy sources, where off-shore wind farms are of high interest, especially since land based windfarms increasingly are perceived as negative.

Further, with regard to aquaculture, there is a political vision to increase the production, but at the moment there is public scepticism against consumption of farmed fish due to e.g. medicine residues in the fish, environmental impact of fish farming, and farming conditions (Solgaard et al, 2011), as well as rather strong regulation.

Cooperation between and learning among stakeholders have been observed in research projects (MERMAID, TROPOS and H2OCEAN), which have contributed also to learning. The stakeholders have gotten much more realistic about synergies and costs. Also spontaneous initiatives to develop MUPS have been observed among stakeholders who took part in research projects (e.g. SUBMARINER), such as smaller initiatives to look for the possibility to grow mussels in combination with wind farms.

Also several transnational network initiatives around MSP in the Baltic Sea Region (Zaucha et al, 2015), such as around ocean based energy production in Sweden (e.g. VINNOVA, Offshore Vast). They have carried out a pre-study on establishing a test-bed for ocean based energy production of the west coast of Sweden. In this pre-study they are acknowledging the possibility of the combination of off shore wind and wave energy (Ingemarsson et al, 2013).

After the first stakeholder meeting a number of environmental and ecological obstacles were stated (Röckmann et al, 2015). Parts of the sea bed area will be occupied by the foundations of the wind turbines and parts of the sea by the fish cages. This will have an effect on the habitats and their living environment. The foundation and scour protection of wind turbines have proved to become an artificial reef in which algae and invertebrates appear to do well and the fish cages should be positioned such that those artificial reefs and their habitats are not disturbed.

5.3 Final design description

5.3.1 Single and multi-purpose design concept

The Kriegers Flak KF offshore wind farm is already scheduled to be in operation in 2020 (site location in Figure 5-8). To this end, obvious additional activities and commercial use of platform is aquaculture of fish (rainbow trout and/or Atlantic salmon) and production of seaweed in specific Furcellaria lumbricalis that can be cultured at the low salinities characteristic for the KF area.

Table 5-1 Summary of design for MUP at the Baltic Site

Fish farm:
• Two sections with 12-14 round cages with a diameter of 45 m and a feeding barge • Project time horizon: 5-10 years. • Decommissioning: Removed and transported to shore yearly after harvest
Seaweed farm:
• Area: Future option – in best case the production potential is 6 tons dryweight/ha/y • Project time horizon: 10-15 years. • Decommissioning: removed and transported to shore
Wind farm:
• Area: 180 km2 • Gravity or monopile based foundations • Project time horizon: Construction will finish 2021. Operational for ~25 years. • Decommissioning removed from bed level to upwards and transported to shore

Structural support and design

Two different preliminary designs of wind farms have been suggested, one consisting of 200 3-MW-turbines and another based on 8 MW turbines (Figure 5-8). In either case there is ample of “empty” space between turbines or in the non-occupied area between the two groups of turbines to establish a large aquaculture facility combining salmonid production and seaweed production arranged in a manner to dampen waves.

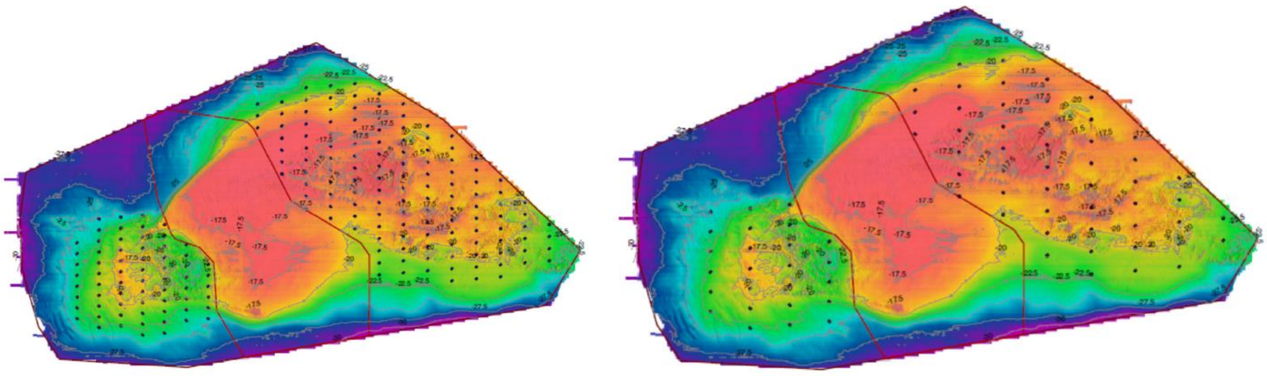


Figure 5-8 Two preliminary layouts of wind farm to be established at Kriegers Flak; left: based on 3 MW turbines; right: based on 8 MW turbines. (from “Dokument nr. 37007/13, sag 12/497”)

Off-shore energy storage and/or transmission systems

Kriegers Flak is located 30 km off shore in the centre of the Baltic, thus grid connections to shore are a key part of the project. In addition to the onshore transport of energy, the central location also opens the possibility for establishing a connection between the grids in DK and DE via Kriegers Flak. The grids in DK and DE are nor synchronized thus it may be beneficial to use HVDC lines, connected to onshore substations with conversion to the local grids. This may require local DC conversion using an off shore substation at Kriegers Flak. Offshore energy storage may be relevant to the extent that the aquaculture farming is supplied directly from the wind turbine production. However the consumption of the farms may not be significant, thus it may be a more optimal solution to use only one net.

Figure 5-9 Pre-assembled turbine parts in the harbour.

Use of the platform

The multi-use platform at Kriegers Flak will be used for combined energy production from wind turbines and aquaculture of salmonids, possibly also with aquafarming of seaweed.

Off-shore energy storage and/or transmission systems

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Transport and logistical analyses

Transportation and installation of offshore wind turbines are related to various specific factors. Factors that must be identified to improve the installation performance according to different special conditions.

Parameters like wind and sea always limit and narrow the time window for a safe installation. The time window is so important and must be calculated accurately to avoid risky situations that can occur on the way and at the site.

The distance from the shore to site or from the port to site increases the travel time. In this case this parameter will be at least 30 km, but that might also increase to several hundred kilometres in worst case, depending on the nearest load out harbour. This factor creates the need of higher service speeds and larger cargo capacity for the installation vessels.

Different options for installing the wind turbines offshore exist. Different installation vessels, different turbine models etc., and in this case we do not know what type of turbines that will be installed. It might be 3,6 MW turbines, but if the installation first will be made in 2020 6 MW or higher might be the preferred turbine size. Offshore turbine installations require lifting of heavy pieces and placing them at certain heights. In order to safely install these heavy turbine components, most installation vessels rise on their jack up legs to create a stable working platform. These installation vessels are mainly specified in two groups: "Self-propelled installation vessels", and "Jack up barges" (Fig. 3.2.6).

The self-propelled unit that for the most recent builds specially designed according to offshore wind industry's demands. These self-propelled installation vessels have jack up legs and cranes with high lifting capacities. Their service speeds are also normally higher than the other installation units.

Gaining access to an off-shore wind-farm for routine servicing and emergency maintenance is difficult, or even impossible in harsh weather conditions due to wave heights, wind speeds and poor visibility. The traditional and obvious method for transporting personnel and equipment is by boat, which is limited to wave heights below 2 meter (dependent on site- and vessel characteristics).

Since the beginning of offshore wind farm development, suggested methods for gaining safe access includes helicopters and crew accommodation platforms. This was used for the first time at the Horns Rev 1 (2003) wind farm (helicopters), and off-shore platforms for the crew at Horns Rev 2 (2009). An alternative to the accommodation platform is to use a hotel ship during the yearly service period.

5.4 Operation and maintenance

Today the global installed capacity of wind turbines has reached almost 200 GW spread across the world. Onshore wind power is now considered the most mature renewable technology and operators have obtained significant experience in operation and maintenance (O&M) of wind farms. The most common approach for large onshore wind farms is a combination of scheduled maintenance, typically one to two visits per year and reactive maintenance, restoring components after failure. This approach has been deemed to be cost effective for operators and has allowed onshore availabilities of over 97% to be achieved.

Uncertainty exists around the costs of O&M with estimates ranging from 20 – 33% of overall project cost seen over the lifetime of the project (Valpy, 2010).

5.5 Technical assessment and risks

The combined wind-turbine and aquaculture will pose an increased risk due to complex navigation. The fish cages are floating structures that may break the moorings during severe conditions and potentially damage neighbouring turbines or cages.

5.6 Environmental assessment and risks

Comprising both fixed and floating structures, the environmental impact assessment (EIA) will address both impacts on the seabed during installation and during operations. The EIA of the turbines will follow modern standard procedures for EIA, addressing impacts both during installation, such as noise, sediment spills and other spills and possible impacts on habitats. During operation EIA will address effects of scour around the structures, impacts on birds and wildlife among other things. The aquaculture part will have some direct physical effects from anchoring and mooring lines, but the impact from the production on water quality and habitats may be the most significant. For both activities impacts from the decommissioning will have to be addressed.

Impacts include the effects of noise on marine mammals and fish, disturbance and loss of habitats, bird collisions and visual intrusion. Offshore structures can also interfere with other uses of the sea – causing hazards to shipping and the servicing of the offshore industry, and displacing fishing activities and recreational boating. The grid connections will need separate investigations along the cable routes, addressing impacts on conservation issues, noise or impacts on habitats.

5.7 Financial assessment and risks

For the Baltic site, the MUOP (wind-fish farm) efficiency gains for maintenance, salaries and mortality are expected to be 3%, 2% and 1%, respectively, from the combined use (i.e. 4% total efficiency gains). The total price of the wind farm is expected to be between 2.0-2.7 billion euros, whereof the grid connection is budgeted at 0.47 billion euros. With regards to salmon farming, in existing 3000 tons farms, production costs are 2,85 euros per kg and it is expected to have slightly lower production costs in a larger farm, but also slightly higher cost of insurance. Salmon farming costs cover operation, maintenance and depreciation of freshwater and marine activities and the expected revenues for salmon farming are 36 million euros per year. Seaweed farming is a future option that requires future testing and market analysis. However, since no explicit data for the fish farming were available the produced social cost benefit analysis was applied only for the wind energy function of the MUOP, as well as the environmental effects derived from this function.

The risk analysis indicated that we can conclude with a high degree of confidence that the project passes the CBA test at a 4% discount rate comparing with ENTSO-E energy production. Similar conclusions we have when comparing with coal energy production.

Table 5-2 Annual Equivalent Operating Cost

	AOC (3%)	**AOC (4%)**
Single-use: Wind function operation compared to coal energy production	102.0	90.53
Single-use: Wind function operation compared to ENTSO-E energy production	84.39	73.18

All values in million euros.

5.8 References

Rasenberg, M.;Stuiver, M.; Van den Burg, S.; Norrman, J.; Söderqvist, T.Stakeholder Views 2; Deliverable D2.3, MERMAID project,2014.

Rasenberg, M.; Stuiver, M.; Van den Burg, S.;Veenstra, F.;Norrman, J.;Söderqvist, T.Stakeholder Views; Deliverable D2.2, MERMAID project, 2013.

Röckmann, C.; Stuiver, M.; van den Burg, S.; Zanuttigh, B.; Zagonari, F.; Airoldi, L.; Angelelli, E; Suffredini, R.; Franceschi, G.; Bellotti, G.; Schouten, J.J.; Söderqvist, T.; Garção, R.; Guanche Garcia, R.; Sarmiento Martínez, J.; Svenstrup Petersen, O.; Aarup Ahrensberg, N. Platform Solutions; Deliverable 2.4, MERMAID project, 2015.

Solgaard, H.S.;Yang, Y. Consumers' perception of farmed fish and willingness to pay for fish welfare. British Food Journal.2011, 113(8), 997-1010, doi: 10.1108/00070701111153751.

Valpy, B. B. A. 2010. How to Improve the Cost of Energy from Offshore Wind - Technology Perspectives, in "RenewableUK" 2010, Glasgow, UK, 2010.

Zaucha, J. The key to governing the fragile Baltic Sea.MSP in the Baltic Sea region and way forward. VASAB Secretariat, Riga, Latvia, 2014. Available online: http://www.vasab.org/index.php/documents/cat_view/7-documents/15-msp-and-iczm (accessed on 25 Nov 2015).

Ingemarsson, P.;Johansson, F.;Lindqvist, H. Förstudie – Havsbaserat testområde för el- produktion. SP Technical Research Institute of Sweden. SP Arbetsrapport: 2013:12. Borås, Sweden, 2013. Available online: http://media.maritimaklustret.se/2014/02/1312_Forstudie_Havsbaserat_testomrade_elproduktion_SP.pdf (accessed on 25 Nov 2015).

BSH (Bundesamt für Seeshifffahrt un Hydrographie) (2005), Storm surges in the southern Baltic sea (Western and Central parts). Sztobryn, M. et al. Berichte des BSH, Nr. 35.

Soomere, T. and Räämet, A. (2011) Long nterm spatial variations in the Balt5ic Sea wave conditions. Ocean Science, 7, p 141-150.

Hanson, H. and Larson, M. 2009, Implications of extreme waves and water levels in the southern Baltic Sea. J. Hydraul. Res, 46, 292–302.

Energinet.dk (2012), Kriegers Flak Review Study, Report.

DHI 2003 Baggrundsundersøgelse af bundfauna i et sandindvindings område på Kriegers Flak. Report to Amager Strandpark I/S

Sweden Offshore Wind AB, 2004: Vindkraftspark – Kriegers Flak, Miljökonsekvensbeskrivning Zettler ML, Röhner M, Frankowski J, Becher H & I Glockzin (2003) F+E-Vorhaben „Benthologischer Arbeiten zur ökologischen Bewertung von Windenergie-Anlagen-Eignungsgebieten in der Ostsee“; FKZ: 802 85 210, Endbericht für die Areale Kriegers Flak (KF) und Westlicher Adlergrund (WAG) February 2003, Sweden Offshore Wind AB; contractor IfAÖ, Germany (2004): Evertebrater och makrofyter.

DHI 2005 Bundfauna på Kriegers Flak i 2005 efter sandindvinding i område A Report to Amager Strandpark I/S .

6 North Sea Site

6.1 Gemini offshore wind farm site

The North Sea is characterized by relative shallow waters and excellent wind conditions, which are ideal conditions for offshore wind developments. Therefore the largest installed capacity of offshore wind in the world is found in this area. Even larger offshore wind farm developments are proposed for the coming decades, significantly increasing spatial claims of already one of the busiest seas in the world. Furthermore, the North Sea water contains relatively high values of nutrients calling for the combination of different types of aquaculture with offshore wind farms as a promising multi-use concept. Within MERMAID the focus was on the Gemini offshore wind farm, being developed during the course of the project.

The MERMAID project focused specifically on the study area located 55 km north of the Wadden Sea Islands in the North of the Netherlands, called the Gemini site, see also Figure 6-1. This site consists of 3 permits, from which 2 sites with 300MW of capacity installed is under construction during the MERMAID project, enabling broad involvement of stakeholders.

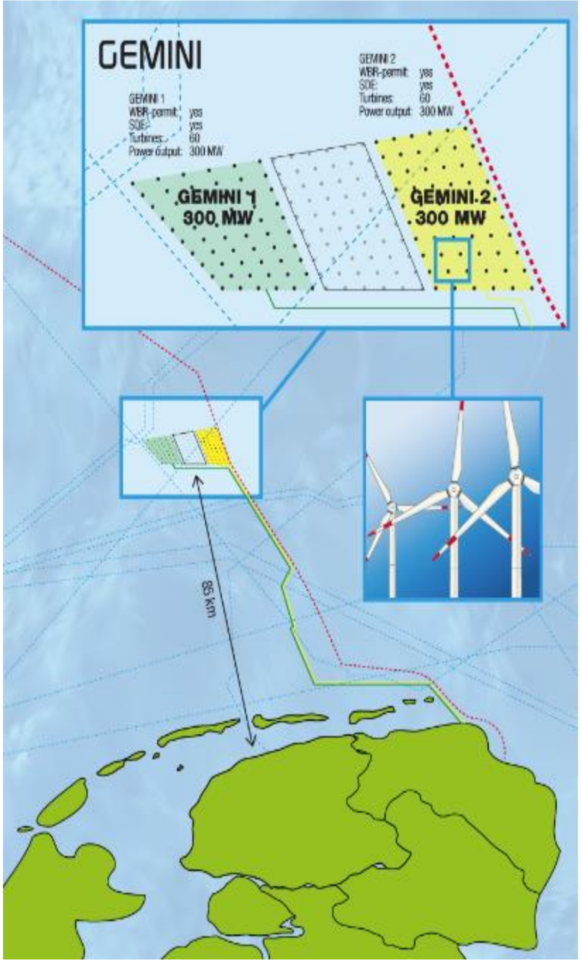

Figure 6-1 Location of the Gemini offshore wind farm in the North Sea (source: www.4Coffshore.com)

The wind farm consists of two areas with a total of hundred and fifty 4MW Siemens turbines and will be fully operational in 2017. The seabed conditions are excellent and monopiles are selected as type of foundations. In addition to the turbines, two 220 kV substations and two necessary submarine cables to the onshore connection at Eemshaven are developed.

6.1.1 Met-ocean conditions at the North Sea Site

Wind conditions

Wind speed in the following is based on analysis of Envisat ASAR satellite data providing speeds at 10 m above sea level. The mean wind speed is shown in Figure 6-2. Wind statistics as a wind rose and Weibull distribution is shown in Figure 6-3. Winds are predominantly (south) westerly.

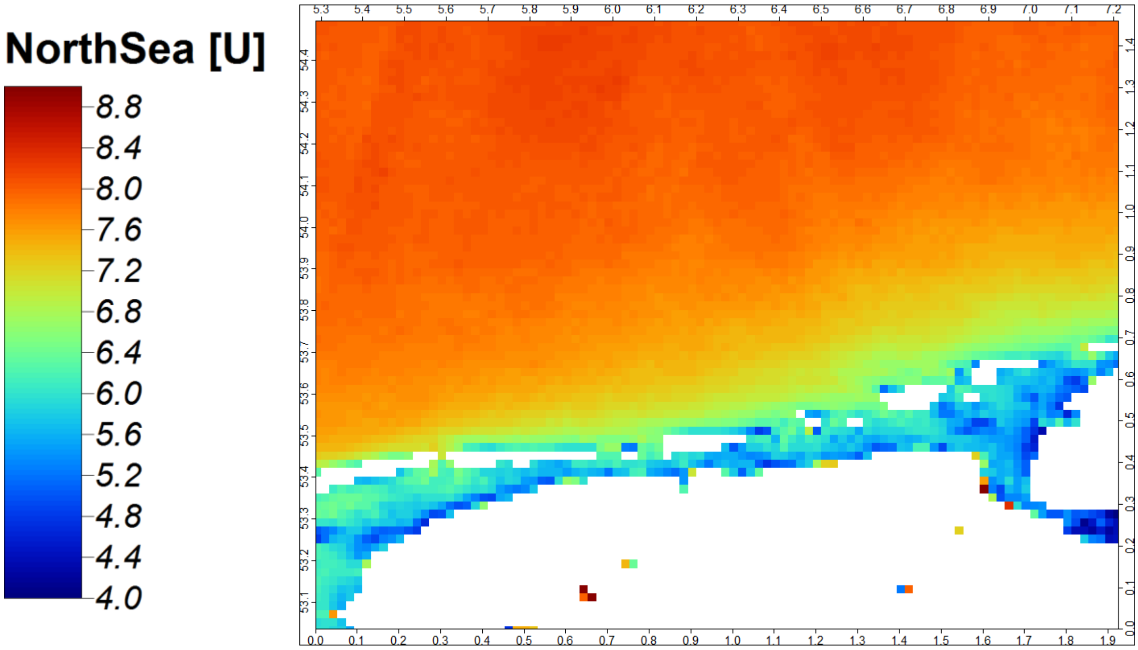

Figure 6-2 Map of mean wind speed from Gemini based on Envisat ASAR wind fields

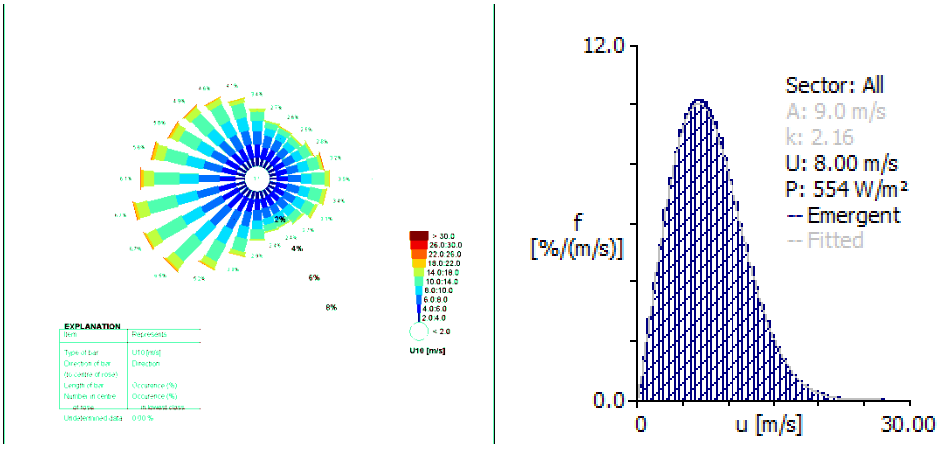

Figure 6-3 Wind rose and Weibull distribution at 10 m at 54.04°N 5.96°E in the Southern North Sea observed from Envisat ASAR and Coastdat.

Hydrodynamic metocean conditions

Tidal levels

The German **Helmholtz-Zentrum Geesthacht** has recently carried out long-term and high resolution hindcasts of waves, wind, currents, water levels, seawater salinity and temperature for the North Sea. The hindcasts were placed in a database named CoastDat. The hindcasts were done using atmospheric wind and pressure fields obtained from a dynamic downscaling of the NCEP/NCAR reanalysis. The water level and current hindcast was carried out with the TELEMAC2D model with water level data measured at Aberdeen used as boundary condition. See Weisse and Plüß (2006), Weisse and Günther (2007) and Feser et al. (2001) and references therein for a detailed description of the flow, wave and atmosphere hindcasts, respectively. In this study the water level from CoastDat database we applied. The estimated astronomical tide estimates are shown in Table 6-1.

Astronomical tidal level	Level [m, MSL]
Highest Astronomical Tide	0.95
Mean High Water Spring	0.65
Mean High Water Neap	0.45
Mean Sea Level	0.00
Mean Low Water Neap	-0.45
Mean Low Water Spring	-0.75
Lowest Astronomical Tide	-1.00

Table 6-1: Astronomical tidal levels

Extreme water levels

Table 6-2 shows the low and high return value estimates.

Return period	Extreme high water level [mMSL]	Extreme low water level [mMSL]
1/1 y	1.72 (1.67, 1.78)	-1.51 (-1.56, -1.47)
1/50 y	2.58 (2.28, 2.96)	-2.31 (-2.67, -2.11)

Table 6-2: Water level low and high return values

Current conditions

Maximum values of tidal currents at North Sea study site reached during spring tides are around 0.7 m/s. The strongest currents are found during September spring tides, following the database, see also Figure 6-4. The distribution function shows that the 50% of the magnitudes are below 0.35 m/s while only the 5% of the values exceed 0.6 m/s. Figure 6-5 shows that the prevailing tidal currents are from ESE. West, WNW and East directions are also frequent. These are also the directions of the strongest currents.

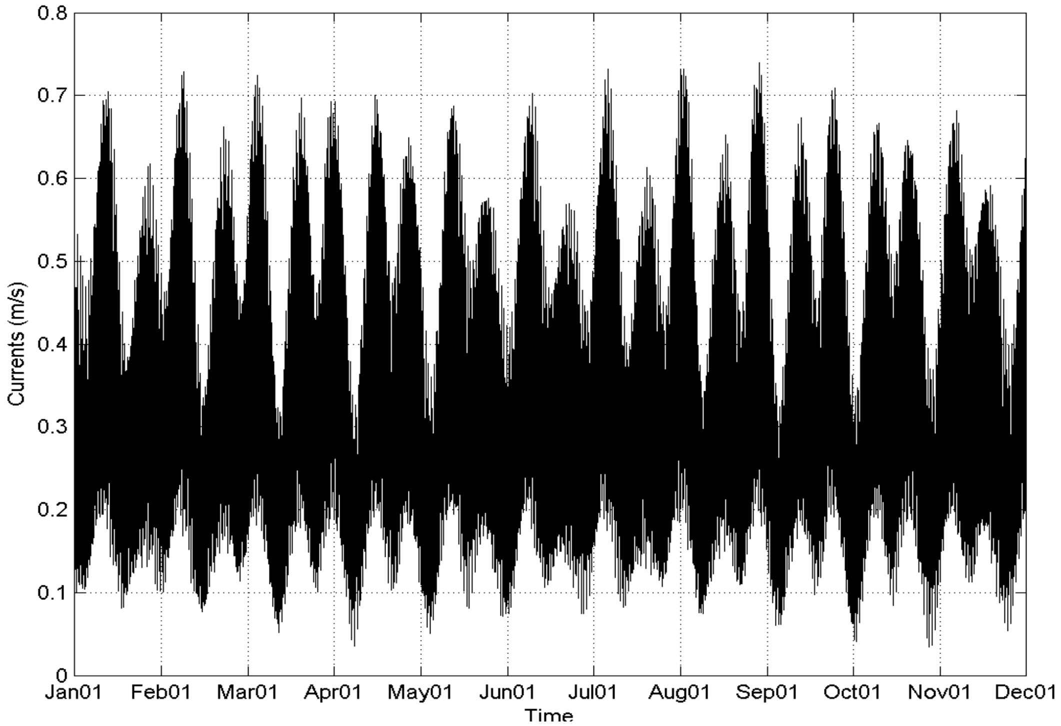

Figure 6-4 Tidal current time series at North Sea study site

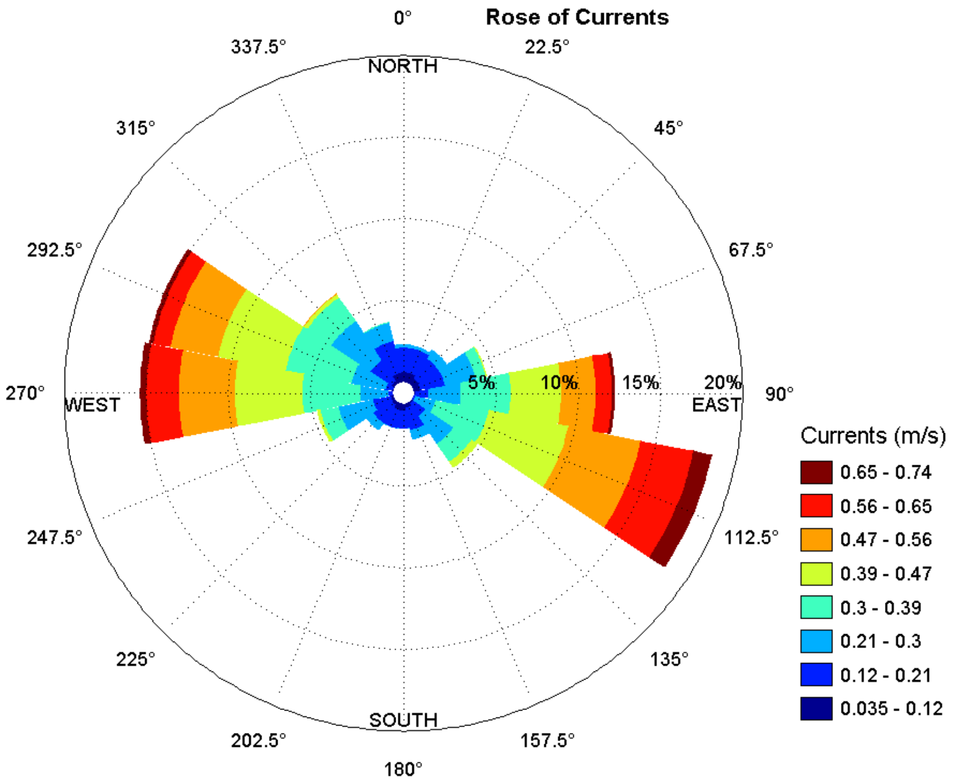

Figure 6-5 Tidal current rose for the North Sea study site

Wave conditions

Figure 6-6 shows the rose of the significant wave height *H_s*, and mean wave direction, MWD, for the entire dataset, based on the CoastDat database[1].

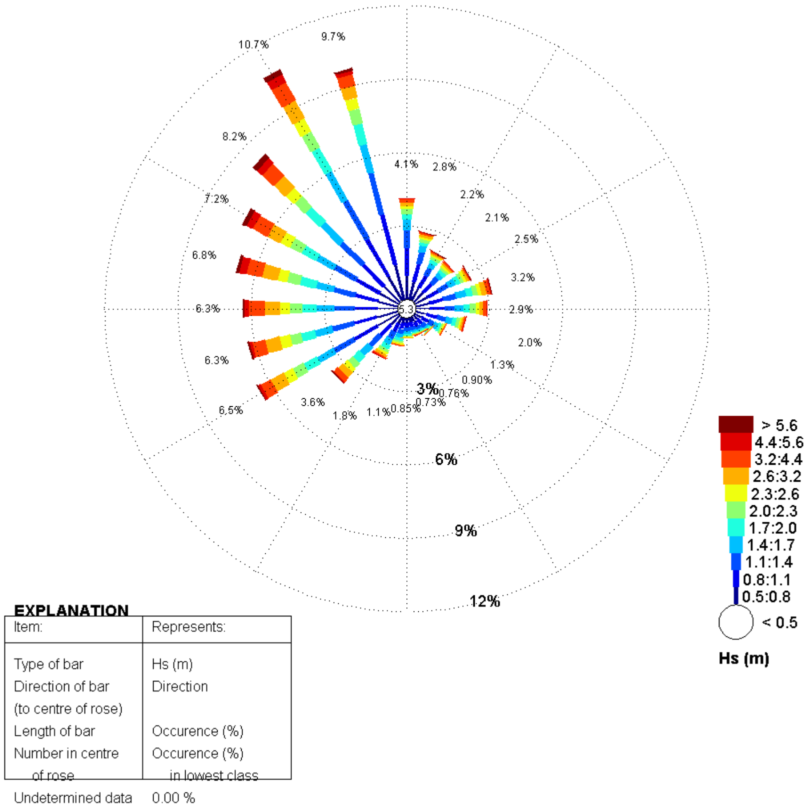

Figure 6-6 Wave rose of the Gemini Site

Figure 6-6 shows that the wave climate is characterized by waves predominantly from Northwest, which is also the sector from which the higher and longer waves come. Waves from the Dutch, German and Danish coasts (from south, southeast, east and northeast) are generally less frequent, which can be explained by the shorter fetches for those directions. The significant wave height is generally lower than 2.1 m. The peak period varies generally between 2 s and 10 s. The highest significant wave height in the entire dataset is 10.99 m (February 17, 1962).

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[1] The German **Helmholtz-Zentrum Geesthacht** has recently carried out long-term and high resolution hindcasts of waves, wind, currents, water levels, seawater salinity and temperature for the North Sea. The hindcasts were placed in a database named CoastDat. The hindcasts were done using atmospheric wind and pressure fields obtained from a dynamic downscaling of the NCEP/NCAR reanalysis. The water level and current hindcast was carried out with the TELEMAC2D model with water level data measured at Aberdeen used as boundary condition. See Weisse and Plüß (2006), Weisse and Günther (2007) and Feser et al. (2001) and references therein for a detailed description of the flow, wave and atmosphere hindcasts, respectively.

Extreme wave conditions

Significant wave height return values were estimated using extreme value analysis. Table 3 shows that the 1/1 yr H_s return value is 7.86 m and the associated peak period 12.99 s. The 1/50 yr H_s return value is 11.15 m and the associated peak period 16.78 s.

Table 6-3 also shows estimates of maximal wave height, *Hmax*, which is defined as *H0.1%* (largest wave height in 1000 waves during a certain sea state). The return values estimates of *Hs* are also associated with the parameters peak period (*Tp* (s)), and the wind speed at 10 m height (*Wind10m* (m/s)). These are presented in the table below. The table also includes the estimates for the extreme crest height of the maximal wave height. Please note that in the figures and tables the point estimates are given as the value before the brackets. Besides that, the 95%-confidence intervals are provided (the values between the brackets).

Return period	H_s [m]	T_p [s]	H_{max} [m]	Extreme crest height [m]	$Wind_{10m}$ [m/s]
1/1 yr	7.86 (7.61, 8.09)	12.99 (12.74 15.12)	13.21 (12.94 15.05)	8.73	21.90 (21.57 24.63)
1/50 yr	11.15 (10.15 12.51)	16.00 (13.21 17.15)	16.78 (15.65 23.27)	12.42	25.73 (22.18 27.13)

Table 6-3: Significant wave height return values

Environmental characterization

For the present study, measurement data from platform FINO 1 [2](located relatively close to the study site) were purchased. Amongst others, air and sea water temperature at different heights/depths are available for the period 2004 up until 2013 (with some gaps that differ per variable).

Salinity

The salinity mainly varies between 32.5 and 35 ppt. In summer the salinity is lower than in winter (the average difference is in the order of 1 ppt). The relatively low salinity values in the month February can be explained by the fact that for some years, data is missing in the month February, which introduced a biased outcome. The statistical box plots show no substantial difference

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[2] The German Government supports the harnessing of offshore wind power as part of its energy policy, which is aimed at increasing the share of renewable energies in total energy production as a contribution to climate protection and energy supply security. To support technological developments and improve the knowledge of the impacts of offshore wind energy technology on the marine flora and fauna, the research project FINO (research platforms in the North and Baltic Seas) was started in 2002. The project is funded by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) represented by the Jülich Research Centre (Project Management Organization Jülich, PTJ). The database contains the results of comprehensive meteorological and oceanographic measurements made at the three research platforms and in the offshore test field, as far as they have become operational. For the meteorological and oceanographic measurements, the German Wind Energy Institute (DEWI) and the Federal Maritime and Hydrographic Agency (BSH) have been commissioned to participate.

between the different vertical layers, indicating that the salinity is well mixed over the water column.

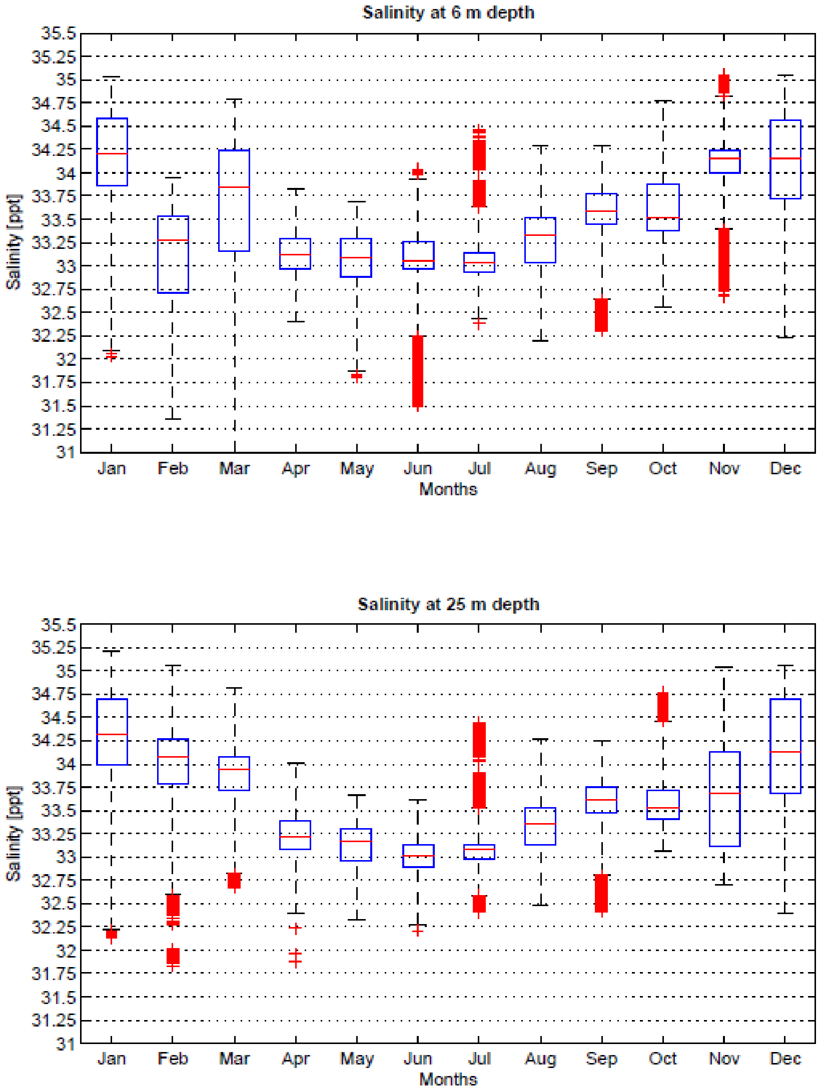


Figure 6-7 Sea water salinity at Fino 1, based on the Fino1 database.

Sea temperature

The sea temperature varies between 2 °C and 20 °C. The lowest sea temperature occurs in the months February and March (on average between 3 °C and 5 °C). The highest sea temperature occurs in August (on average between 17 °C and 19 °C). There is no substantial difference between the different vertical layers, indicating that the temperature is well mixed over the water column, as is the case for salinity.

6.1.2 Seabed flora and fauna

This subsection describes flora, fauna, habitats and species colonizing the area, protected or exotic/invasive species, water characteristic parameters useful for aqua-farming (salinity, temperature, nutrients, etc.), pollution problems, etc.

The North Sea is a biologically rich and productive region. The densely populated, highly industrialized countries bordering the North Sea conduct major fishing activities, carry out oil and gas offshore activities, extract sand and gravel, use it for dumping dredged material and for pipelines and cables. The North Sea is one of the most frequently traversed sea areas of the world and two of the world's largest ports are situated on the North Sea coast. In addition, the coastal zone is used intensively for recreation. Regular assessment and monitoring of the North Sea have been carried out for years. The Quality Status Report 2010 for the Greater North Sea (OSPAR 2010) comprises the latest comprehensive assessment.

The North Sea is made up of a mosaic of different habitats that are important for the ecological functioning of the North Sea. A general conservation strategy is to protect the quality and quantity of habitats to protect the organisms living in and contributing to the habitats, and to preserve the ecosystem structure and functioning. The North Sea is very productive, due in part to large inputs of nutrients leading to high primary production, the basis for all food chains. The intricate webbing of the food chains in the North Sea makes the ecosystem durable, yet vulnerable to major alterations such as overexploitation of single species, which can be deleterious (OSPAR 2010).

6.1.3 Social perception and constraints

The granted wind farm concession and permits for this North Sea site are only for single use activities. The MUP possibilities are just conceptually based and fully under discussion. Since a year there are meetings with three Dutch focus groups, not only for this site but also for two more concessions for large scale offshore wind farms, the IJmuiden site and Borssele site. During the yearly North Sea meetings researchers and stakeholders are discussing nowadays some social and environmental MUPS. For the Dutch North Sea area there aren't yet comparable on-going pilots, however right from the start of the single use pilot wind farms the environmental impacts have been monitored. There are such positive impacts that e.g. NGO's are strongly in favour not to extend these single-use activities in multi-use business with possibly a detrimental impact. Even one is in favour of declaring the single use wind farms as a nature protective area.

For the North Sea site the following stakeholders are becoming increasingly involved: Dutch offshore wind energy the Dutch offshore wind industry is already active in this field for 40 years, however in operating near-shore wind farms only in the past 6 years. Around 150 companies in the Netherlands are active in offshore wind throughout the entire supply chain, ranging from blade production and hydrography up to foundation constructions and heavy logistics. It is well known that the Netherlands excels in foundations, installation work and logistics. Since a few years more companies are becoming active in the more far offshore large wind farms developments of which the Gemini project is the first one to be built in due time. The other two sites are still concessions off the coast of IJmuiden (2800MW; middle Netherlands) and Borssele (1400 MW; south Netherlands). By the year 2023 the Dutch Government aims to have installed 6000 MW of offshore wind energy capacity to reach its renewable energy goals. Only approximately 2000-3000 MW can be installed within 50-60 km distance from the shore, the remaining capacity will have to be installed further away, far offshore with water depths of more than 30 meters with larger challenges, installation and operation/maintenance of a wind farm.

6.1.4 Dutch offshore aquaculture (fish cages, shellfish, seaweed)

On the contrary with the Dutch offshore wind, this sector is at the beginning of a new development. For example the shellfish companies are in a transition phase, from inshore blue mussel cultures to more offshore cultures. Because of the shallow waters off the coast of the Netherlands no companies are interested yet in fish cage cultures. Regarding seaweed large volumes are already being imported by Dutch companies from Asia and France for a very competitive price. And only on a very small pilot scale some experiments are being conducted by research institutes and universities, see Table 6-4. Once a large scale North Sea seaweed business case has been drafted, then maybe some companies are interested as well. Although North Sea proven installations have still to be designed and offshore tested in the coming years before one can ever think of any multi-use activities in/near wind farms. An expected timeframe is 5 – 10 years.

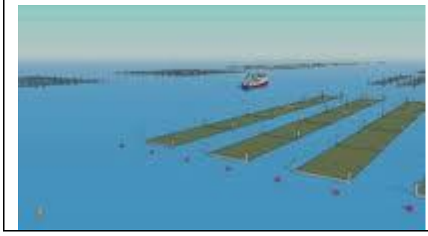
Dutch offshore aquaculture	**status**
Fish cages 	Dutch continental shelf too shallow (abt 30 m)
Bluemussel cultures 	Start in 2013 with pilot mussel seed collectors near-shore (Voor-Delta) (6 x 25 ha)
Seaweed 	Small-scale research pilot off the coast of Texel and in the Easter Scheldt Estuary

Table 6-4: Several initiatives of offshore aquaculture in The Netherlands

Fisheries

Already from the start of the planning and building of the two Dutch wind farms out in the sea, the Egmond aan Zee Offshore wind Farm (108 MW, NUON, shell, 2006) and Princes Amalia wind farm (120 MW; Eneco, 2008) and fishermen (organizations) are discussing either compensation fees for loss of their fishing grounds and/or additional employment for their fishing vessels, e.g. fishing with static gears and sailing with tourists in/around the farms. Also the Dutch North Sea fisheries are in a transition phase to more sustainability. Through the Masterplan Sustainable Fisheries new fishing boat designs have been drafted with multipurpose possibilities for service and maintenance work in wind farms. Since 2011 these MUP discussions have been further structured under the umbrella of some fishermen organizations with governmental and offshore wind parties.

Mussel and seaweed aquaculture

Although only offshore wind farms have licenses for single use, more stakeholders in the Netherlands are starting to discuss multi-use possibilities, such as regional fishermen and entrepreneurs for aquaculture and tourism. In collaboration with the stakeholders - identified and subsequently involved during the MERMAID project (MERMAID D2.4), offshore wind farms combined with seaweed and mussel aquaculture was identified as the most promising conceptual MUOP design. Seaweed will increasingly gain importance as a raw material and the most relevant benefit of local cultivation is the possibility to offer wet seaweed on the local market. In addition, the shellfish industry is looking for additional fishing grounds for mussel seed collectors and cultivation of mussels on long-lines. The market demand for the blue mussel is twice the current Dutch production.

Multi-use and economics

From 2012 onwards, offshore wind is no longer eligible for subsidy under the SDE$^+$ program. It is argued that offshore wind is too expensive – compared to other production methods – and focus should first be on innovation, reducing cost price. This is one of the reasons that the single users are becoming interested in sharing infrastructures decreasing the Operation and maintenance costs (O&M).

Besides there is no common framework to discuss and assess the risks associated with third-party access. This increases uncertainty. It also explains recurring discussions on the insurance of MUPs. Current practice of regulators is to forbid third-party access to the offshore wind parks. Differing insights between policy-makers and regulators can be an obstacle to further development.

Multi-use and Social considerations

In Dutch policies, multi-use platforms are mentioned as a promising way to make the most out of scarce available space (Ministries of V&W, VROM en LNV, 2009). Till 2012 there was no“demand” for multi-use platforms, there are no companies who want to construct them yet. Energy companies have and will build various small scale offshore wind parks but integration with other functions is not desired. The offshore aquaculture sector is small – focusing only on mussels. Consequently, policy-makers and regulators have not been challenged to handle request for permits and a regulatory framework for MUPs is missing. Also, in the spatial plans for the North Sea, there is no area designated for aquaculture. However in the Dutch annotation Beleidsnota Noordzee 2009-2015, it is explicitly mentioned that co-use offshore wind energy parks, for example for recreation, fisheries and aquaculture, should be allowed as much as possible and needs to be discussed with the involved parties as the policy is implemented.

Multi-use and environmental considerations

In 2011 Rijkswaterstaat stated that smart uses of space could be a solution to the shortage of space on the North Sea (Verhaeghe et al, 2011). Aquaculture inside off shore windmill platforms was mentioned as a possible smart use of space, which leads to chances for clever entrepreneurship. However in the Integral Management plan for the North Sea (Integraal Beheerplan Noordzee, 2006) there is no space indicated for offshore aquaculture for the Dutch part of the North Sea. This means that aquaculture activities in wind energy platforms need to get exemption, to be applied for trough permits. This framework exists of five tests:

1. Defining spatial claim,
2. Precaution,
3. Usefulness and need,
4. Location choice and spatial use and
5. Reducing the effect and compensation.

For new activities this means that developers have to reduce or prevent negative effects on the environment, which is tested using precautionary test. They have to address why it is important that this activity takes place in the North Sea using a social cost-benefit analyses. The space needed for the activity must be carefully chosen and sufficiently used and when the activity compromises important natural values these need to be compensated in another area.

Marine protein production in open water systems per definition interacts with the surrounding aquatic ecosystem. Whether and to what degree this affects ecological sustainability depends on the type of culture and the extent of integration between different culture types and other activities. Multi-Use Platforms at sea (MUPs) aim at optimal integration of activities, and each activity is thereby placed in a wider ecosystem context. The aim is to manage all activities in such way that it contributes to the sustainable development and equity of the whole. The foreseen MUPS production system combines a set of different production functions/chains, probably with mutual interactions between the individual functions.

6.2 Participatory design process

The selected data has been based mainly on information gathered by the so-called site managers during the participatory design process within the MERMAID project. Each site had a site manager: a key expert and process facilitator for that particular site. The participatory design process aimed to co-develop MUPS by a group of relevant stakeholders for each site. It was organized through three steps:

1. Collection of the views and needs of selected stakeholders in the first round (Rasenberg et al, 2013)
2. Reviewing the preliminary MUPS design in the second round (Rasenberg et al, 2014)

3. Evaluating the final design in the third round (Röckmann et al, 2015)

Within the different sites, the site managers invited different stakeholder groups: such as policy makers, businesses, sector representatives, NGO's, local citizens and research institutes (Röckmann et al, 2015).

This combination of offshore wind energy and aquaculture is interesting given the large-scale development of offshore wind – with subsequent spatial claims and the critical attitude towards nearshore aquaculture. Stakeholders involved are businesses that expressed interest in the development of a MUPS, policy makers and shipping authorities. Furthermore, NGO's and scientists participated.

There is a political goal in The Netherlands to be completely independent of fossil fuels by the year 2050. Therefore, there is a lot of focus on renewable energy sources, where offshore wind farms are of high interest, especially since land based windfarms increasingly are perceived as negative. The MERMAID North Sea case study turned out to be a purely Dutch case study. The Netherlands are famous for their "poldering tradition", meaning that stakeholders want to be involved, and is the only way to make a project succeed. Moreover, parallel to the MERMAID project, several other projects/ activities have been ongoing about the feasibility of MUPs, and there was lively interaction between all of these initiatives.

The North Sea case study focused on the future wind park location Gemini. Relevant stakeholders had already been identified. Step one of the MERMAID participatory approach consisted of interviews with the most relevant stakeholders (i.e. including the mussel sector). Similar to the Baltic case study, this rather "narrow" first step of stakeholder involvement was considered very useful and efficient. However, from then on, the crucial new MUP stakeholder (i.e., the mussel sector) was and has been missing. One could speculate that this might have been a strategic decision to avoid being overruled by the mussel sector because of the "polder model". Nonetheless, MERMAID still considers offshore mussel farming in the proposed North Sea MUP design, mainly because model results suggest that offshore locations in the North Sea do offer the potential for mussel farming (Terradellas Vilella 2014). Furthermore, mussels excrete particles as well as diluted nutrients and these nutrients are food for seaweed. Hence, there is some potential for integrated multi-trophic aquaculture (IMTA).

There is now increased enthusiasm and optimism about MUPs; the various stakeholders are more aware about potential business synergies and opportunities, in particular concerning potential cost reductions. Still, comments from stakeholders indicate that those synergies and opportunities have to be shown in more detail and for cases in which multi-use can be developed in an integrated way already at the planning stage. This is important in particular for the more mature offshore wind sector. In order to promote the opportunities of MUPs, increased MUP awareness of governmental ministries is particularly important, because regulatory/legislative government incentives are urgently needed. For example, the wind energy sector should be obliged to consider multi use options in the planning phase. The relatively less experienced offshore aquaculture sector needs to be supported to carry out single-use pilot studies offshore. For example, mussel farming in the North Sea has traditionally been carried out in coastal areas, and the sector is hesitant to go offshore. Incentives are needed to encourage mussel farming further offshore. In particular, single-use offshore mussel farming pilot studies will help to make the sector more mature. Additionally, the seaweed sector has become interested in MUP. In contrast to the mussel sector, seaweed farming is still in its infancy in the North Sea, and actually in most parts of Europe. This sector could thus directly start offshore and thereby avoid competition for near-shore space with the already existing mussel farming areas. However, since single-use mussel or seaweed farming might not be feasible due to exploding costs. If costs can be reduced by synergies such as in operation and maintenance, multi-use might be the solution to make it feasible.

6.3 Final design description

Although these offshore wind farms only have licenses for single use, more stakeholders in the Netherlands are starting to discuss multi-use possibilities, such as regional fishermen and entrepreneurs for aquaculture and tourism. The selected wind turbines for the Gemini offshore wind farm are the Siemens SWT 4.0 (which is an upgrade of the 3.6MW design).

In collaboration with the identified stakeholders, offshore wind farms combined with seaweed and mussel aquaculture was identified as the most promising conceptual multi-use design. Seaweed will increasingly gain importance as a raw material and the most relevant benefit of local cultivation is the possibility to offer wet seaweed on the local market. The optional support structure of seaweed aquaculture is presented in the figure below.

For the seaweed cultivation three types of seaweed are considered:

- **L. digitata**, very flexible, leaf tears easily in broad or small strokes, dependent on their exposure. This specie can cope with heavy wave forces, but also fully moves along with the waves. Therefore all forces are being avoided due to the flexibility of the plant. And only limited force is being transferred to the holdfast (A holdfast is a root-like structure that anchors seaweed to the substrate).
- **L. hyperborea**, flexible, with a thick rigid stem. And goes a bit deeper in the water and therefore has more interaction with the flow compared to L. dig. The Specie can eventually also be cultivated on an artificial string. It is expected that this kind could results in most wave attenuation. Grows slowly.
- **Saccharina**: long leaf, grows naturally outside the zone where waves are active, but can handle flow (currents). As long as the plants are not to large they can be cultivated in areas with waves ~ 1-2 m. It is expected that if the waves are more severe problems will occur with the attachment of the holdfast. If the thallus becomes larger in combination with heavy wave forces this will tear off. They have less capability to adjust to more heavy circumstances and therefore they could have a larger effect on wave attenuation (when considering relative small waves).

All 3 species could be used together, but they should be cultivated in a row: A front with L. dig, then L. hyp and behind a large field of Sacch. This could also be applied this vertically: Upper 1 meter L. dig, below the L. hyp and underneath 3-4 m Sacch. In this way the specific characteristics (like flexibility, resistance to wave energy, etc.) of each type of seaweed is applied in its optimal form.

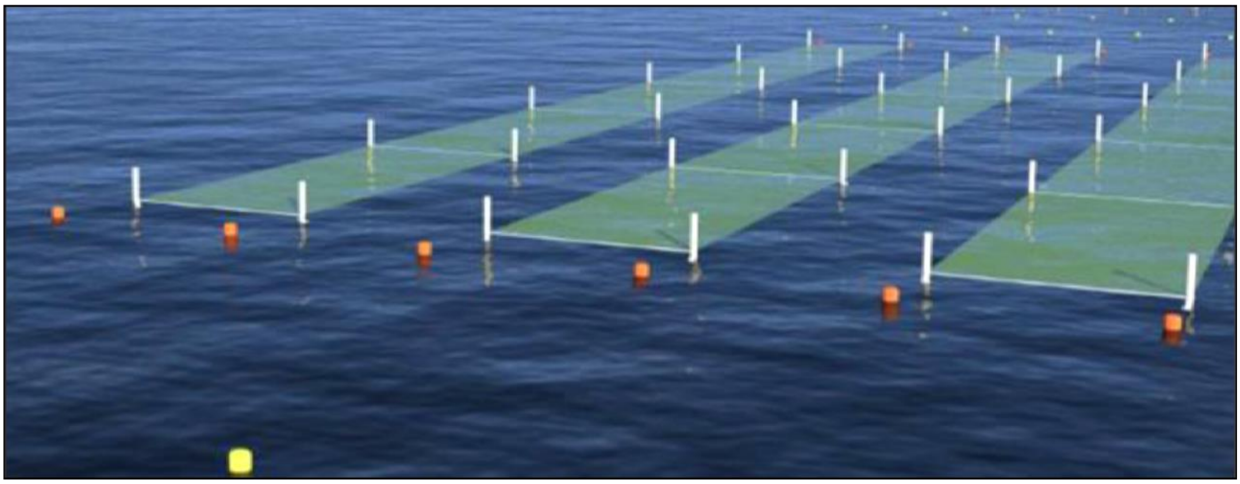


Figure 6-8 support structure for offshore seaweed aquaculture.

The shellfish industry is looking for additional fishing grounds for mussel seed collectors and cultivation of mussels on long lines, see Figure 6-9. The market demand for the blue mussel is twice the current Dutch production.

Figure 6-9 mussel cultivation on long lines

Fish aquaculture was excluded from the design due to relatively high water temperature peaks during the summer. Currently no native species are expected to survive under these circumstances while being in a relatively shallow cultivated environment in the North Sea. Wave energy convertors were initially considered, however due to the low efficiency in combination with limited availability of wave energy in the North Sea it was concluded that this function is currently not feasible.

Figure 6-10 present the conceptual design. Here, green diamonds illustrates seaweed, round circles are the offshore wind turbines and black and white diamonds are the areas with mussel aquaculture.

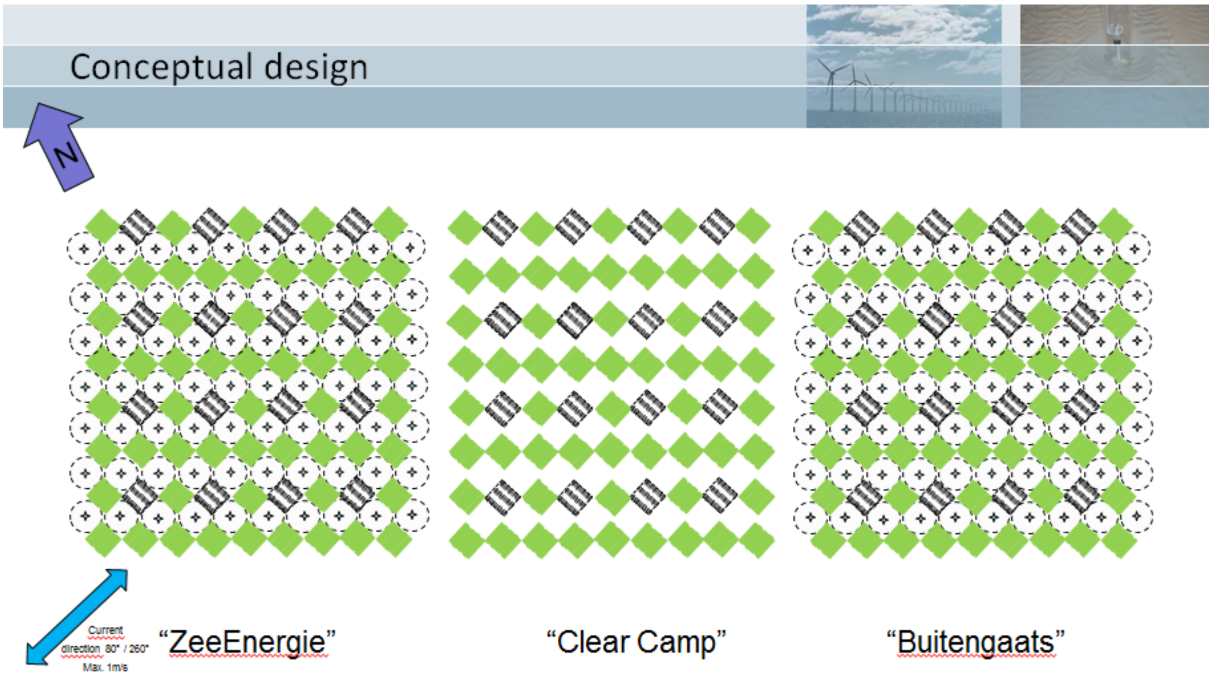


Figure 6-10 Conceptual design of the multi use offshore wind farm at the North Sea site

Based on the technical feasibility analyses followed by the (socio-) economic analyses the capacity and production per function is estimated as follows:

Function	Capacity	Production
Wind energy	600MW	2,600 GWh
Mussels	3 kg WW/m^2	48 kton WW
Seaweed	10 kg WW/m^2	480 kton WW

Table 6-5: capacity and production per function (use) of the conceptual design

Figure 6-11 below shows the artist impression of the conceptual design.

Figure 6-11 Artist impression of the conceptual design of the multi use offshore wind farm at the North Sea site.

6.4 Transport and logistical analyses

Transportation and installation of offshore wind turbines are related to various specific factors. These factors must be identified to improve the installation performance according to different special conditions. Parameters like wind and sea always limit and narrow the time window for a safe installation. The time window is so important and must be calculated accurately to avoid risky situations that can occur on the way and at the site. The distance from the shore to site or from the port to site increases the travel time. In this case this parameter will be at least 85 km, but that might also increase to several hundred kilometres in worst case, depending on the nearest load out harbour. This factor creates the need of higher service speeds and larger cargo capacity for the installation vessels.

Different options for installing the wind turbines offshore exist. Different installation vessels, different turbine models etc. Offshore turbine installations require lifting of heavy pieces and placing them at certain heights. In order to safely install these heavy turbine components, most installation vessels rise on their jack up legs to create a stable working platform. These installation vessels are mainly specified in two groups: “Self-propelled installation vessels”, and “Jack up barges”. The self-propelled units that for the most recent build, specially designed according to offshore wind industry’s demands. These self-propelled installation vessels have jack-up legs and cranes with high lifting capacities. Their service speeds are also normally higher than the other installation units.

Gaining access to an off-shore wind-farm for routine servicing and emergency maintenance is difficult, or even impossible in harsh weather conditions due to wave heights, wind speeds and poor visibility. The traditional and obvious method for transporting personnel and equipment is by boat, which is limited to wave heights below 2 meter (dependent on site- and vessel characteristics). Since the beginning of offshore wind farm development, suggested methods for gaining safe access includes helicopters and crew accommodation platforms. An alternative to the accommodation platform is to use a hotel ship during the yearly service period. This hotel ship will be utilised for the Gemini offshore wind farm, also during the operation and maintenance phase, see section below.

6.5 Operation and maintenance

The operation and maintenance of floating devices is a key point that is being investigated currently to reduce the potential costs and improve future strategies. In the case of floating MUPs, some advantages can be highlighted with respect to fixed platforms. The most important one is that floating devices can be transported completely operative from shore to their final location, reducing the investment in transport equipment. In the following, the principal vessels needed for the operation and maintenance of a MUP farm are presented:

- Personal transfer vessel (PTV) – Transport equipment and technicians from the harbour to the MUP to be maintained.
- Tug vessel – O&M transport of the MUP.
- Helicopter – O&M when it is not possible to use a boat because of the bad weather conditions.

Several ways and techniques of harvesting are described in the rapport (NetAlgae, 2012), which is one of the results of the EU project NetAlgae, see figure below.

Figure 6-12: Examples of Mechanical harvesting (NetAlgae, 2012)

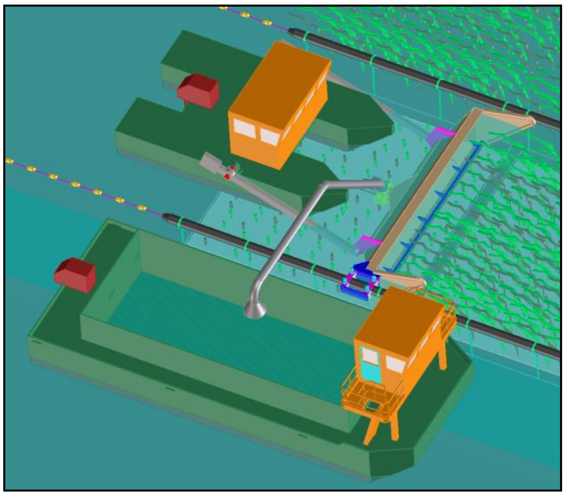


Figure 6-13 large scale harvesters (Lenstra et al. 2010)

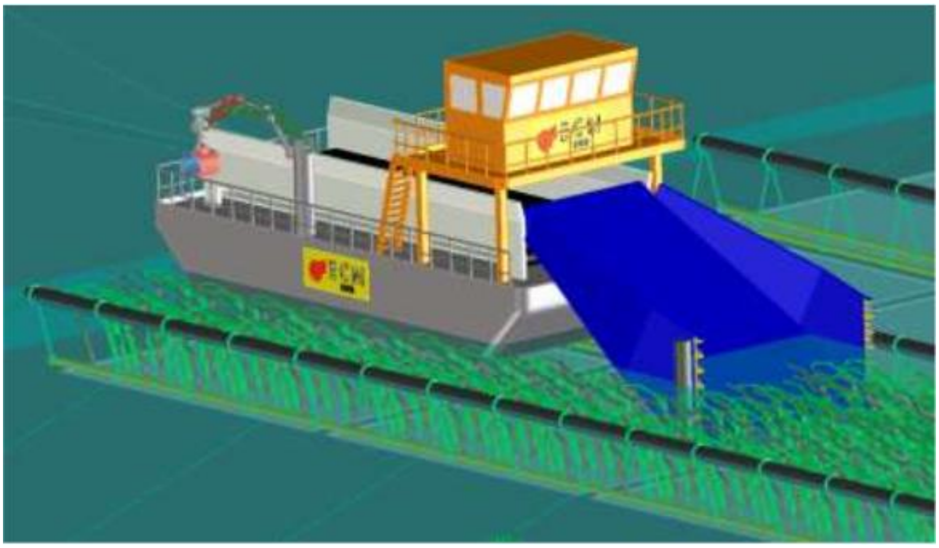


Figure 6-14 harvesters (Lenstra et al. 2010)

6.6 Technical assessment and risks

The combined wind-turbine and aquaculture will pose an increased risk due to complex navigation. The mussel and seaweed cages are floating structures that may break the moorings during severe conditions and potentially damage neighbouring turbines or cages. Another risk could be that the people conducting O&M at the offshore aquaculture damage the offshore wind farm (for instance cables).

The possible synergies which are identified for combining offshore wind with seaweed and mussel aquaculture are as following:

- Logistics
- Operation and maintenance costs
- Wave attenuation: optimise design due to less fatigue loads
- Improve longevity of material

- Less waves inside the OWF, enhances O&M
- Mussel and seaweed cultivation cleans the seawater.

6.7 Environmental assessment and risks

Comprising both fixed and floating structures, the environmental impact assessment (EIA) will address both impacts on the seabed during installation and during operations. The EIA of the turbines will follow modern standard procedures for EIA, addressing impacts both during installation, such as noise, sediment spills and other spills and possible impacts on habitats. During operation EIA will address effects of scour around the structures, impacts on birds and wildlife among other things. The aquaculture part will have some direct physical effects from anchoring and mooring lines, but the impact from the production on water quality and habitats may be the most significant. For both activities impacts from the decommissioning will have to be addressed.

Impacts include the effects of noise on marine mammals and fish, disturbance and loss of habitats, bird collisions and visual intrusion. Offshore structures can also interfere with other uses of the sea – causing hazards to shipping and the servicing of the offshore industry, and displacing fishing activities and recreational boating. The grid connections will need separate investigations along the cable routes, addressing impacts on conservation issues, noise or impacts on habitats.

The environmental restrictions that have to be considered in the area are related with:

- Wind turbine impacts on birds
- Soil effect due to interconnections
- Electrical interaction with local fauna
- Natural mobility disruption

Table 6-7 below presents the questions posed to experts and researchers, including the set of risks to be identified.

Please Select the appropriate answer	**Yes**	**No**
Are there any significant negative environmental impacts (local, regional, global)?	X	
Are there any positive environmental impacts (local, regional, global)?	X	
Is there EIA available for similar project in the region?	X	
Is there uncertainty about Climate Change and other environmental parameters?	X	
Are there non linear environmental effects and is the threshold identified?		X
Is it possible for the MUOP to produce irreversible environmental effects?		X
Environmental considerations: Is the location feasible?	**X**	

Table 6-6: Environmental Impacts Assessment and Significant Risks

The proposed concept of offshore aquaculture is based on a floating technology. Therefore, the seabed will be only affected by the anchors or mooring systems and, up to some extent, by the mooring lines. Both impacts can be catalogued as low environmental impacts.

In terms of noise influence and birds impacts, specific studies must be carried out in order to identify the critical points.

6.8 Financial assessment and risks

The financial and economic assessment of the MUOP at the North Sea site benefited from data available about the ongoing Gemini offshore wind farm project (see Section 3), and from some specific research developed for the North Sea, focused on mussels and seaweed (Bartelings et al, 2014; Buck et al., 2010; Burg et al., 2013). Additionally, seaweed farming assessment received valuable contributions from Schipper (2015).

Based on specific data from the Gemini Offshore Wind Farm, market analysis and literature references, for the offshore wind farm 2800 million euros will be invested for the first year, while an additional investment of 1800 million euros will be required to replace the wind turbines that are expected to have a design life time of 15 years. Different values within the range of 60-140 million euros per year for operation and maintenance (O&M) costs are obtained based on several references related to hypothetic or real sites. Different O&M costs per energy produced yearly in MWh (Bartelings et al., 2014; Næss-Schmidt, H. S. and Møller, U., 2011; IEA, 2013; DECC, 2013), or per capacity installed in MW (DECC, 2013 and 2011) are suggested. The range mentioned already excludes sites from the literature considered as not representative for the North Sea site, e.g. whenever they are much closer to the coastline than the Gemini site, located around 85 km from the nearest port, which affects significantly transport costs. It should be noted that the O&M cost interval might be an overestimation, since the details of the investment agreement are not fully known; at least some O&M costs might be included in the investment costs. It is assumed that at least all costs of an offshore hotel and support centre at the Gemini site are already considered under the investment cost of the offshore wind farm and its O&M costs. On the revenues side, for the offshore wind farm 442 million euros per year are estimated for the first 15 years. Later on, the estimated revenues decrease to 112 million euros per year, as the project is only entitled to be subsidized during the first 15 years. That is, the subsidies are estimated to amount to 330 million euros per year during 15 years. These revenues were calculated considering a production of 2,600,000 MWh per year and a price of 170 euros or 43 euros per MWh, respectively for the first 15 years when subsidies are included, and after that. That is, it is assumed that the subsidy during the first 15 years adds 127 euros per MWh to an energy price of 43 euros per MWh.

For mussel farming 7-11 million euros are assumed to be required to invest every 5 years, which is based on assumptions and on unitary costs of components in a mussel plot (Buck et al., 2010) applied to the proposed design of the North Sea site. The higher value of the range takes into account eventual need of investing in a new vessel (Buck et al., 2010). The range of 8.5-57 million euros per year of O&M costs is based, respectively, on annual sub-costs per area and on annual sub-costs per area for a specific production installed, as suggested by Bartelings et al. (2014), and is probably an underestimation of the total O&M costs. Revenues of 45 million euros per year consider a mussel production of 48,000 ton WW (Wet Weight) per year and a price of 940 euros per ton WW.

In the case of seaweed farming 21-400 million euros are required as initial investment. According to Schipper (2015), the investment of 21 million euros for the production capacity installed is succeeded by reinvestments of around 10 million euros every 5 years. Much higher values of 40 million euros (based on Burg et al., 2013) and of 400 million euros (based on Burg et al., 2013, and on Bartelings et al, 2014) are estimated both as initial investment and as investment every 10 years. The first is obtained if considering unitary costs per production capacity installed (Burg et al., 2013), and the second if taking into account unitary costs per area for a specific production installed (Burg et al., 2013; Bartelings et al, 2014). In addition, a range of values within the interval of 47-68 million euros per year for operation and maintenance costs is obtained, based on unitary costs and sub-costs per area for a specific production capacity (Schipper, 2015; Bartelings et al, 2014). On the other hand, revenues for seaweed farming are expected to be within the range of 17-40 million euros, depending on estimated prices of 210 euros per ton DM (Dry Matter) (Bartelings et al., 2014) or of 600 euros per ton DM (Schipper, 2015), which at this stage is very uncertain. A production of 80,000 ton DM of seaweed, corresponding approximately to 480.000 ton WW of seaweed, is used in the calculations (Bridoux, 2008).

The values presented before have a large uncertainty as some data is missing - not made available or unknown -, and therefore existing data was completed by using not site specific data and expert judgement, which allowed providing an estimation. It was not possible to estimate costs for the different cost sub-categories as intended initially, which is necessary to estimate efficiency gains by having multi-use platforms instead of single use platforms. Nevertheless, and based on Bartelings et al. (2014), 10% efficiency gains 3are expected from the combined use of wind-mussel-seaweed farm.

The Table 6-7 below provides a summary of the financial characteristics for the North Sea Site, as previously described. Note that future revenues/costs are at this stage of the analysis not discounted for the computation of annual figures.

	Offshore wind	**Mussel farming**	**Seaweed farming**
Investment costs	2800 M€ (year 1); 1800 M€ (year 16)	7-11 M€ (every 5 years)	21 - 400 M€ (year 1) 10 (every 5 years) - 400 M€ (every 10 years)
O&M costs	60 – 140 M€ / year	8.5 – 57 M€ /year	47 – 68 M€ /year
Revenues	442 M€ / year (first 15 years); 112 M€ / year (15th year and followings)	45 M€ / year	17 – 48 M€ / year
Financial profitability	Yes, as long as there are subsidies.	Yes, probably	Very uncertain. Depends very much on the development of the market price of seaweed products.

Table 6-7: Summary of the financial characteristics for the North Sea site

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[3] Please note that this is an estimate of efficiency gains that is not really used so far in the analysis. It is uncertain.

6.9 Socio-economic assessment and risks

A thorough examination of the current political and social conditions in the North Sea site revealed that in terms of final MUOP design, which includes mussels and seaweed production (see Section 1), the most vulnerable groups and those impacted more are fishermen, persons involved on activities related to tourism, recreational boating and shipping. With regards to wind power production, fishermen consider that there will be reduction in the area available for fishing. The energy sector concerns are dealing mostly with difficulties to reach agreements with the fishing communities since they often do not adhere to rules and regulations. With regards to aquaculture, the wind energy industry considers the introduction of such multi-uses as a barrier and additional risks. The introduction of multi-use may also make transport maritime services more complex, but on the other hand there are potential synergies. To counterbalance the negative impacts, fishermen were exploring the possibility of compensation fees for lost fishing ground and/or additional employment for their fishing vessels, e.g. through fishing with static gears and sailing with tourists in and around the farms. New fishing vessel designs have been drafted in the Master plan Sustainable Fisheries projects taking into account adaptations for service and maintenance work in wind farms.

Specific employment impacts of aquaculture are is scarcely available. Operation and maintenance for mussel farming: 18 full employed people and 18 seasonal positions (based on Buck et al, 2010). Operation and maintenance for seaweed farming: 20 people (based on Burg et al, 2013).

With regards to wind-power production, it is expected that the Gemini wind-power park will create around 500 full time jobs during the construction and installation phase and another 120 full time jobs during the operational phase. Local tourist industry might also benefit from sightseeing trips to wind farms. The employment impacts of the transport maritime services are mainly concentrated on the redesign of fishing vessels towards multipurpose vessels, which may give fishermen the opportunity to carry out maintenance works, logistic and transport activities.

Main stakeholder groups in wind power production and transport maritime services include competent authorities, energy companies, construction companies, investment and development companies, consultancies, fisheries, shipping and NGOs. For the case study site, those stakeholders include Ministry of Economic Affairs, Ministry of Infrastructure and Environment, Province of Groningen, Energy Valley (authorities), NUON Vattenfall, ENECO (energy companies), Van Oord, Ballast-Nedam, Siemens (construction and development companies), Typhoon Offshore (investment and development company) Fair Wind (consultancy), Visafslag Lauwersoog, VisNed, Vissersbond (fisheries), Groningen Seaports (shipping), and The North Sea Foundation (NGO). For aquaculture, also aquaculture companies are main stakeholders. For the case study site, they include POMossel, Machinefabriek Bakker and, Hortimare.

6.10 Conclusions and discussion

In collaboration with the identified stakeholders, offshore wind farms combined with seaweed and mussel aquaculture was identified as the most promising conceptual multi-use design for the North Sea site. Seaweed will increasingly gain importance as a raw material and the most relevant benefit of local cultivation is the possibility to offer wet seaweed on the local market. This conceptual design was further elaborated under the MERMAID project.

Conclusions should point to the value of externalities (and energy prices) reaching a certain threshold before wind energy would become viable. This notwithstanding that investments and research is conducted in order to attempt to produce more energy in a low-carbon manner. From the current social cost benefit analysis nothing can be concluded on this. The only conclusion is that mussels are economically viable both from a financial as a socio-economic perspective, although sites nearer to shore would improve both financial as a socio-economic performance. Seaweed under current technical (investments and O&M costs) and economic (market prices) conditions is not an economic viable undertaking. As for wind the financial viability can improve when there would be subsidies available for ‘start-ups’ for off-shore production of mussels and seaweed, although for seaweed production subsidies required would be significant.

Furthermore, there are a number of governance issues to be resolved, like permitting and the possibility to obtain insurance in case of a MUOP.

As yet little insight is gained on the contribution of external costs and benefits in the SCBA and the possibility for efficiency gains in combining different uses in a MUOP. This could improve (or worsen) the case for any of the options.

The analyses on **monetization of environmental externalities** included CO_2 emissions, whereas ecosystem services such as provision of food and raw materials, among others, did not become part of the quantitative assessment, as requirements for using the benefit transfer approach were not fulfilled. Consequently the results of the monetization of environmental externalities are “deviated”, although not clear in which direction.

On the other hand, the **financial and economic assessment** was mainly supported by data from literature review and expert judgment, as limited site-specific data was available. Consequently, there is the risk for inconsistencies because of different sources and different assumptions, and considerable uncertainties associated with estimated values (large intervals). Additionally, the lack of site-specific data on sub-categories of costs makes it difficult to estimate efficiency gains from combined use.

This raises significant limitations when formulating conclusions for the **Social Cost Benefit Analysis**. The assessment performed concluded that the societal profitability, positive or negative, varies depending on the use, if wind, mussel or seaweed farming, and depending if a single use or a combined use in multi-use is considered. For single use, seaweed is the one performing the worst. Wind farming, if not entitled to subsidies, can also result in a negative societal profitability. Combined uses that result in a negative NPV include multi-use of mussel and seaweed farming. One should take into account that additional information available, for instance, wider monetization of environmental externalities, could eventually change some of the conclusions, namely, that after all there is an interest to include seaweed as part of a multi-use platform.

In such a study as the one described in the present deliverable, it can be controversial how to balance / what to prefer: if having some more data and results though with high uncertainty (more what was done in the financial and economic assessment), or to only gather accurate data and obtain accurate results, even if few (more what was done when trying to monetize non-market items), therefore also limiting conclusions to be taken.

Aspects such as data availability (lack of data), focus of the research and time availability conducted the **research in a certain direction, with the presented outcomes**. Other outputs could result of different or complementary inputs and approaches, such as: 1) different design of the site (capacity installed, size of the site), 2) comparison of the NPV of seaweed farming standing in a offshore MUP, an offshore SUP, an onshore seaweed farming close to the North Sea or seaweed farming in the conventional markets (e.g. Asia), 3) what if we are comparing the profitability of introducing offshore mussel farming instead of more near-shore mussel farming, 4) when comparing near shore with offshore, the assessment of the externalities would be of particular relevance as much environmental pressure is already taken place in coastal areas.

Literature suggests 10% of **cost reduction due to synergies** when combining uses. The little experience with offshore seaweed, the lack of data and high uncertainty, as well as no monetization of externalities for the different uses, make seaweed farming appear as a not promising business. It was shown that seaweed as a single use has a negative NPV, and that decreases significantly the NPV of MUP when being incorporated as part of a multi-use. However, precaution should be taken to not exclude (completely) seaweed farming as a possible and eventual profitable use in a future MUP, as knowledge gaps in the assessment are significant.

On the other hand, it is important to have in mind that even the offshore wind farming itself (without subsidies) can have, a negative NPV, though other reasons justify providing subsidies for this use.

When it comes to answer questions such as “Are the benefits for the society due to MUOP good enough to justify subsidizing future MUOP?” and “In which conditions should the projects be subsidized?” the following should probably be taken into account.

Significant uncertainties last, namely when it comes to quantify both synergies and risks, as well as costs and revenues. On the other hand, some certainties are that these different uses have different time horizons and costs being the wind farming the one with components with the highest lifetime and costs. Moreover, wind farming is already benefiting from subsidies.

According to the results and the assumptions considered, MUP can accommodate mussel farming. Complementary research about combined use with seaweed could be done for instance by incorporating this use as pilot installations in planned SUP or MUP, to increase the existing, even if limited, know-how and therefore decrease uncertainty about this use. On the other hand, subsidized projects of high investment like wind farming can (easily) accommodate what it comes to be a much lower investment (in fact, both mussel and seaweed might be, depending on the profitability scenario, “peanuts”).

The best would be the investor to benefit from the synergies, instead of benefiting from the existing subsidies. In the medium / long term, combined uses and resulting synergies should replace subsidies, or at least, make possible to provide lower subsidization.

6.11 References

Bartelings, H., D, Sander, B. van den, et al (2014). “Combining offshore wind energy and large-scale mussel farming: background & technical, ecological and economic considerations”. IMARES Wageningen UR - Institute for Marine Resources & Ecosystem Studies.

Buck, B., Ebeling, M., Michler-Cieluch, T. (2010). MUSSEL CULTIVATION AS A CO-USE IN OFFSHORE WIND FARMS. Potential and Economic Feasibility. [Online] Available at: find it at http://epic.awi.de/19760/1/Buc2008e.pdf.

Burg, S.v.d., Stuiver, M., Veenstra, F., Bikker, P., Contreras, A. L., Palstra, A., Broeze, J., Jansen, H., Jak, R., Gerritsen, A., Harmsen, P., Kals, J., Blanco, A., Brandenburg, W., Krimpen, M. v., Duijn, A.P. v., Mulder, W., Raamsgink, L.v. (2013) A Triple P review of the feasibility of sustainable offshore seaweed production in the North Sea.

DECC (2013) Electricity Generation Costs. [Online] Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/269888/131217_Electricity_Generation_costs_report_December_2013_Final.pdf.

Lenstra, J., Hans Reith, Jaap van Hal, 2010. Economic perspectives of seaweed Presented at the 4th International Algae Congress, December 2010, Amsterdam, The Netherlands doc. ECC-L-11-004

IEA (2013) Technology Roadmap. Wind energy. [Online] Available at: http://www.iea.org/publications/freepublications/publication/Wind_2013_Roadmap.pdf.

Feser, F., R. Weisse, and H. von Storch, 2001: Multi-decadal atmospheric modeling for Europe yields multi-purpose data. *Eos, Trans. Amer. Geophys. Union*, 82, 305.

Hasager, C. B., I. Losada, R. Guanche, Merete Badger, Ferhat Bingöl, Xiaoli Guo Larsén, (DTU Wind Energy) O. Svenstrup Petersen (DHI), W. Verbruggen (Deltares), D5.1 Metocean Conditions, MERMAID project, 2013.

Næss-Schmidt, H. S. and Møller, U. (2011). Havvindmøller på vej mod industrialisering: Implikationer for dansk tilgang. Copenhagen Economics, Copenhagen, Denmark.

NetAlgae. (2012). Seaweed industry in Europe .

Rasenberg, M.;Stuiver, M.; Van den Burg, S.; Norrman, J.; Söderqvist, T.Stakeholder Views 2; Deliverable D2.3, MERMAID project,2014.

Rasenberg, M.; Stuiver, M.; Van den Burg, S.;Veenstra, F.;Norrman, J.;Söderqvist, T.Stakeholder Views; Deliverable D2.2, MERMAID project, 2013.

Röckmann, C.; Stuiver, M.; van den Burg, S.; Zanuttigh, B.; Zagonari, F.; Airoldi, L.; Angelelli, E; Suffredini, R.; Franceschi, G.; Bellotti, G.; Schouten, J.J.; Söderqvist, T.; Garção, R.; Guanche Garcia, R.; Sarmiento Martínez, J.; Svenstrup Petersen, O.; Aarup Ahrensberg, N. Platform Solutions; Deliverable 2.4, MERMAID project, 2015.

Schipper, J., (June 2015). Oral communication by Job Schipper, CEO at Hortimare – Propagating seaweed for a sustainable future.

Weisse, R., and A. Plüß, 2006: Storm-related sea level variations along the North Sea coast as simulated by a high-resolution model 1958-2002. *Ocean Dynamics*, **56**, 16-25.

Weisse, R. and H. Günther, 2007: Wave climate and long-term changes for the Southern North Sea obtained from a high-resolution hindcast 1958-2002. *Ocean Dynamics*, doi:10.1007/s10236-0060094-x.

7 Atlantic Site

7.1 Site description

The Cantabrian Offshore Site (COS) represents an open deep water site in the Atlantic Ocean. It is located in the north coast of Spain, in the region of Cantabria (see Figure 7-1). Close to the capital city of the region, Santander. It is a medium size site; its surface is 100km2. It has a rectangular shape between 3 and 20 km far from the shore line (see Figure 7-2).

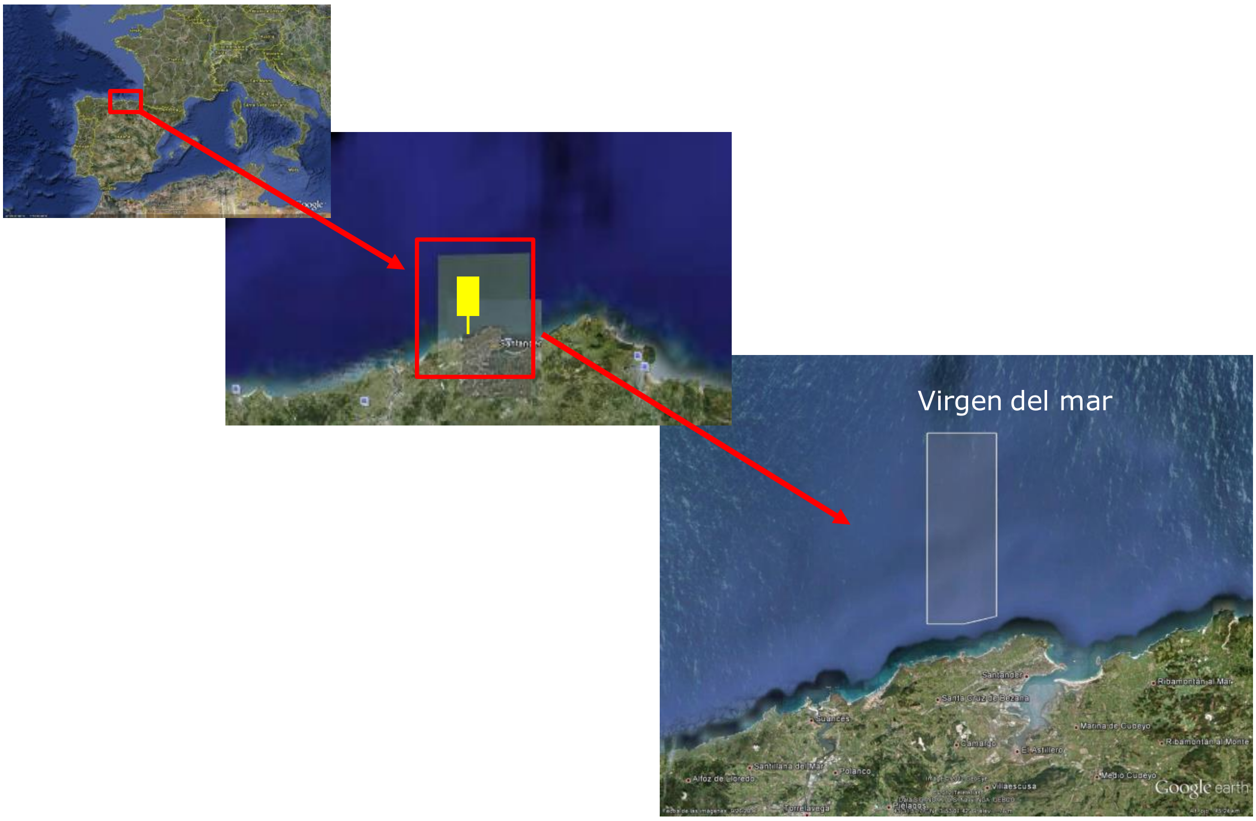


Figure 7-1 Location of Cantabrian Offshore site (The open deep water site, Atlantic Ocean

COS bathymetry varies between 50 and 250 m of water depth at 3km and 20km far from the shore line respectively. The bathymetry is in general smooth with some irregularities on the north-eastern part between 50 and 100m of water depth (see Figure 7-2).

Due to the local water depth range, in this test site only floating concepts will be considered. These concepts are especially relevant in some countries like Spain where the continental shelf is narrow.

The seabed observed in this area is a mix of sandy and rocky seabed, mostly limestone.

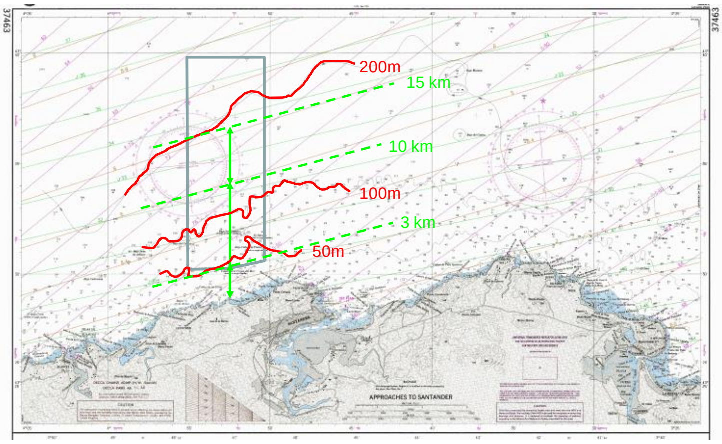


Figure 7-2 COS Bathymetry and key distances

The site is already monitored by private and public initiatives. The Government of Cantabria deployed on 2009 a measurement buoy (www.redvigia.es) at 40m of water depth which is located at hundreds of meters south of the southern limit of COS (see Figure 7-2). It measures waves, currents and wind, as well as other ocean parameters like temperature and contaminants. The IEO (Spanish Institute of Oceanography), deployed a wave buoy (http://www.boya_agl.st.ieo.es/boya_agl) on 2007. It is located, 35 km north from the shoreline and at very deep waters and focused on wave parameters.

On the other hand, there is a private initiative called Idermar (www.idermar.es), which is a regional company focused on the development of floating met mast. It has developed three different floating met mast prototypes, two of them are deployed on the COS (see Figure 7-3). Both devices are focused on wind measurements, the oldest one deployed on May 2009 measures wind up to 65m high. While the newest one has been deployed on October 2011 and it measures wind at five measuring point between 20 and 90m height (Figure 7-4). Idermar floating met masts are concepts already design and conceptualized in order to provide reliable data in deep and very deep waters. Those data are mainly focused on the offshore wind industry.

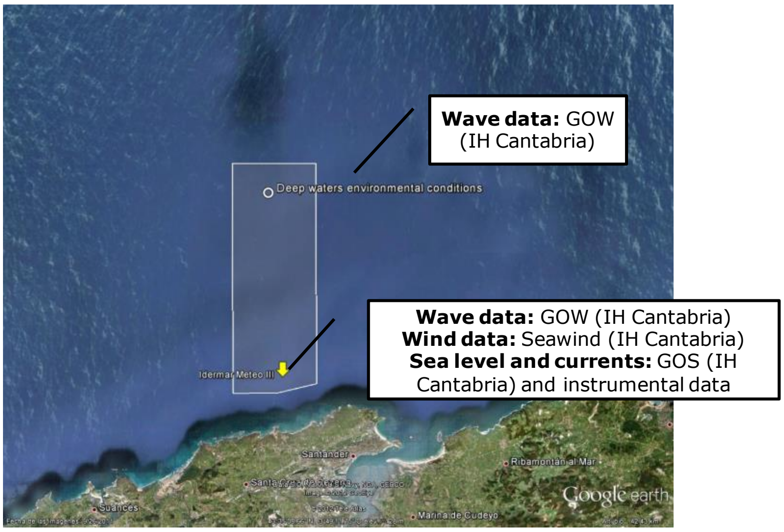


Figure 7-3 Cantabrian Offshore Site existing monitoring system

Figure 7-4 Idermar floating met mast at Cantabrian Offshore Site

7.1.1 Met-ocean conditions and databases

Firstly, the databases used to characterize the met-ocean variables at the site are presented. Afterwards, the met-ocean variables behaviour is described.

Databases

SEAWIND

SeaWind is a daily re-forecast for the Mediterranean and Euro-Atlantic region at 15 km resolution, providing wind-related variables with hourly frequency (Menéndez et al., 2013). This product is produced by a mesoscale limited-area atmospheric model (WRF, Skamarock (2008)) nested into ERA-Interim reanalysis data for the period 1989-2014. The focus is on the accurate representation of hourly variability and, thus, a scheme with daily restarts from global reanalysis data was adopted in order to keep the model as close to the observed marine win devolution as possible. The daily independent simulations also have the advantage of faster parallel computation, which was another requirement of the project, given the large domain simulated, the high resolution used and the long simulated period.

GOW – Global Offshore Wind

In this work, wave data were taken from Global Ocean Waves 1.0 (GOW 1.0), an hourly wave reanalysis database for the period 1948-2014, with a spatial of resolution of 1ºx1.5º, from IH Cantabria (Reguero et al., 2012). GOW 1.0 is generated using Wave Watch III model (WW3) and forced by winds from the NCEP/NCAR 40-year reanalysis project (Kalnay et al., 1995).

GOS – Global Ocean Surges

GOS (Global Ocean Surges) is a dataset of 66-year (1948-2014) storm surge. The historical reconstruction of storm surge in the European region (Cid et al. 2014; Abascal et al., 2012) has a spatial resolution of 1/8º (~30km). GOS has been performed using the Regional Ocean Model System (ROMS), developed by Rutgers University (Shchepetkin and McWilliams, 2003, 2005). ROMS is a three-dimensional, free-surface, terrain-following ocean model that solves the Reynolds-averaged Navier-Stokes equations using the hydrostatic vertical momentum balance and Boussinesq approximation.

Wind conditions

SeaWind databases have around 60 years of data. In Figure 7-5 (left panel), the intensity wind rose is shown. As it can be noticed, the most energetic wind directions are West, East and South. These directions are related to the storms or extreme events in the region. Moreover, it can be determined that 35% of time southerly winds are presented in the area, which means that wind flow is affected by coastal topography. In Figure 7-5 (right panel), the histogram of wind speed is shown. It can be determined that mean wind speed at the site is 6.12 m/s, and the standard deviation is 3.63 m/s.

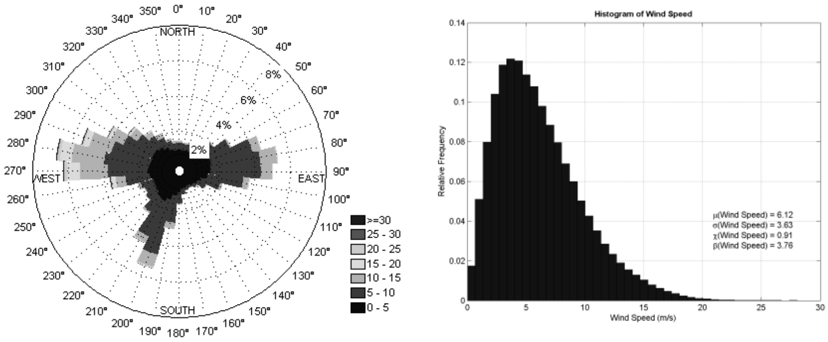


Figure 7-5 Wind intensity rose and probability distribution function.

Wave conditions

60 yrs of hourly sea state parameters (described in WP/Report 3.1) at the Cantabrian Sea study case have been analyzed to characterize the wave conditions and wave energy power.

Figure 7-6 shows the seasonal behavior of significant wave height, peak period and mean wave direction for the whole empirical distribution. The seasonal patterns of wave height and peak period show a clear winter-summer pattern and powered winter season. Lower wave heights and peak periods occur on June, July and August. Northwest is the dominant mean wave direction.

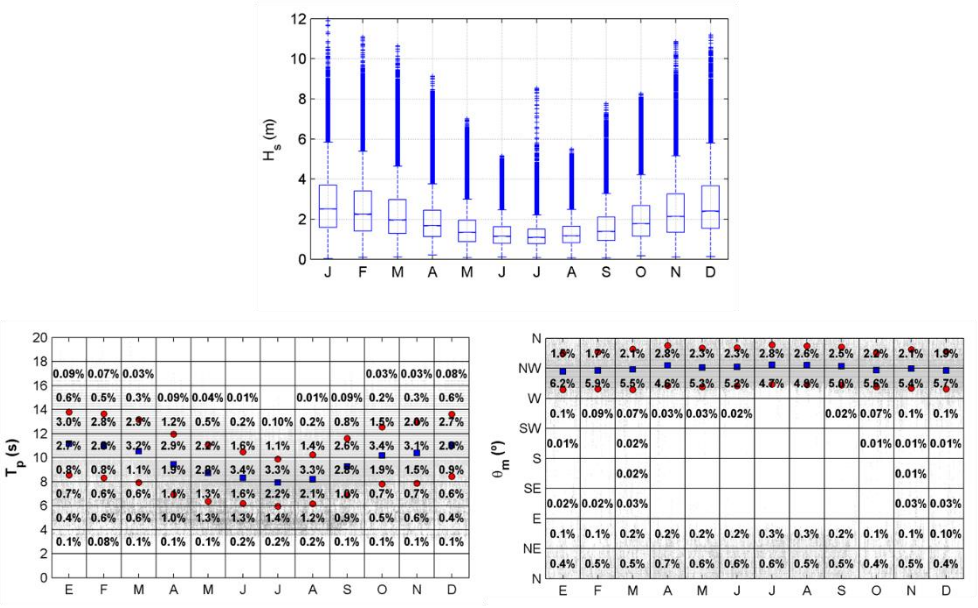


Figure 7-6 Seasonal behavior of significant wave height, peak period and mean wave direction at Cantabrian Offshore Site (■ μ ● μ ± σ)

Figure 7-7 shows directional and probability roses and polar quantile plot of significant wave height and peak period. Wave heights higher than 4 meters and peak periods higher than 12 s can be only detected from the Northwest dominant direction.

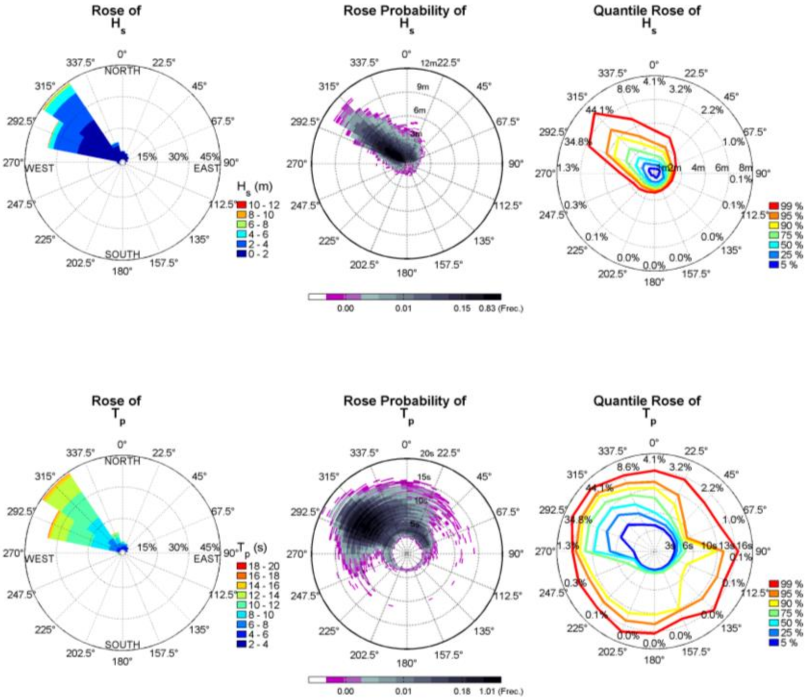


Figure 7-7 Directional and probability roses and polar quantile plot of significant wave height and peak period at Cantabrian Offshore Site.

The joint probability distributions of significant wave height vs. peak period and wave height vs. mean wave direction are shown in Figure 7-8. High probability corresponds to lower than 6 meters wave heights and peak periods between 4 and 14 s.

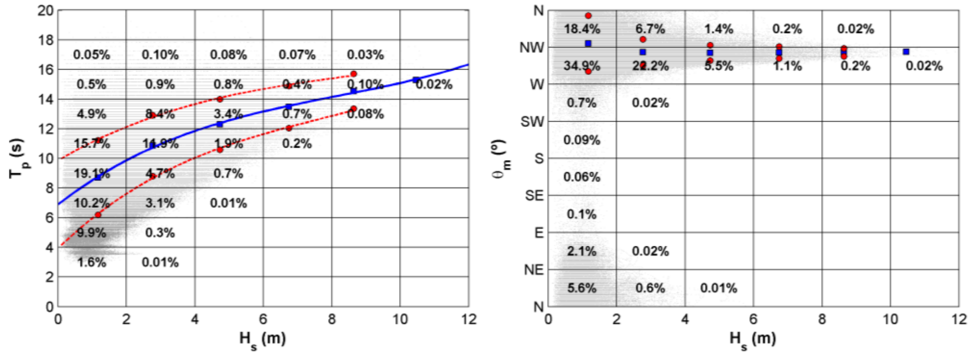


Figure 7-8 Joint probability distributions of significant wave height vs. peak period and wave height vs. mean wave direction.

Current conditions

Tidal currents time series at the Atlantic study site are shown inFigure 7-9. Maximum values almost reach 1.5 cm/s.

Figure 7.3.3.10 (left panel) indicates that the 50% of the data barely exceed 0.5 cm/s. magnitudes above 1 cm/s have an occurrence rate of 20%. Figure 7-10 (right panel) shows that there are only two main directions in the tidal propagation: WNW and ESE. Other directions have not only a low occurrence probability but also a small magnitude.

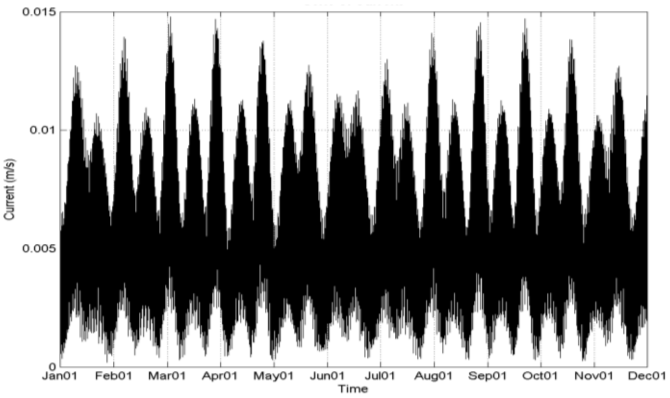


Figure 7-9 Tidal current time series at Atlantic study site.

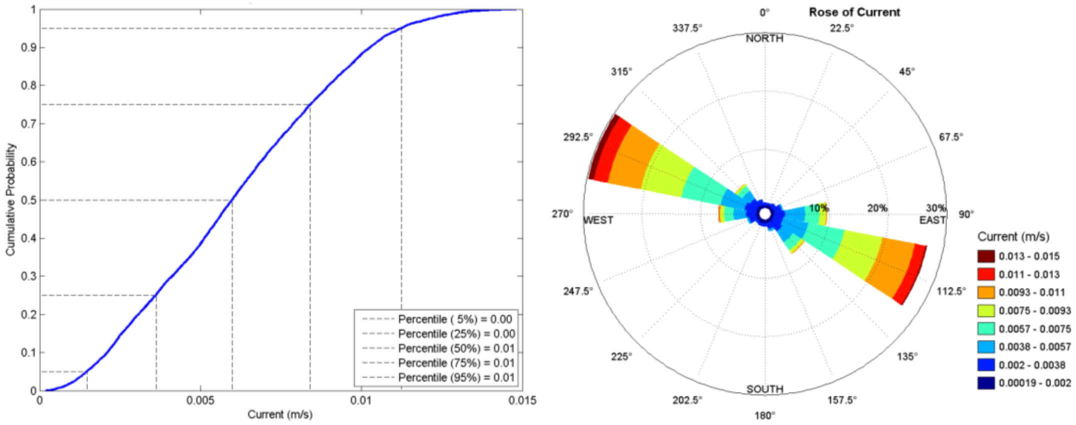


Figure 7-10 Tidal current PDF and Rose of tidal current for the Atlantic study site.

The general equation for power available from tidal currents is given by:

$$P_{cross-section} = \frac{1}{2} \rho \cdot U^3$$

ρ is the density of water (1027 kg/m3)

U is the instantaneous current velocity (m/s).

7.2 Participatory design process

There are three traditional activities in the Atlantic open ocean site: fishing, transport and leisure activities. However, new sectors, such as marine renewable energy and marine biotechnology are nowadays emerging as a new and highly promising economic sectors. In order to involve the already existing economic activities with the emerging ones, a participatory design process has been carried out.

The methodology was proposed in WP 2 and followed equally at every test site. Two meeting round with local stakeholders were carried out:

In the first stage of the design process, short meetings and interviews were carried out with the potential stakeholders in order to identify the different views from the ecological, economic and societal perspective. An additional objective was to identify the potential challenges and constraints that the future development MUPs may face. Based on the output of the first interview and considering the main site characteristics, designers proposed a set MUP draft. This set includes a wide variety of uses and technical approaches in order to open a later technical and non-technical discussion with different stakeholders.

On the second stakeholders meeting the set MUP designs proposed were compared and exanimated. From this meeting it has concluded that the respondents acknowledge that cooperation between stakeholders is the key for a correct and an accurate MUP design. Moreover, social acceptance issues have been pointed out. Some respondents provided examples to illustrate its importance: technically well-designed projects can still run into problems. Economic issues have been also identified as a way to integrate MUP farms in the local society: MUP development may lead to the creation of new jobs in the area.

The technical solutions exposed were also analysed. The ideas that emerged about the shape of MUP in this stage were:

1. Single wind turbines with aquaculture cages attached to them can be considered as a promising solution;
2. A floating platform on which various uses can be combined providing space for other uses.

Regarding to these ideas, a round table meeting with the main stakeholders involved was organized in order to discuss on the different MUP technical solutions.

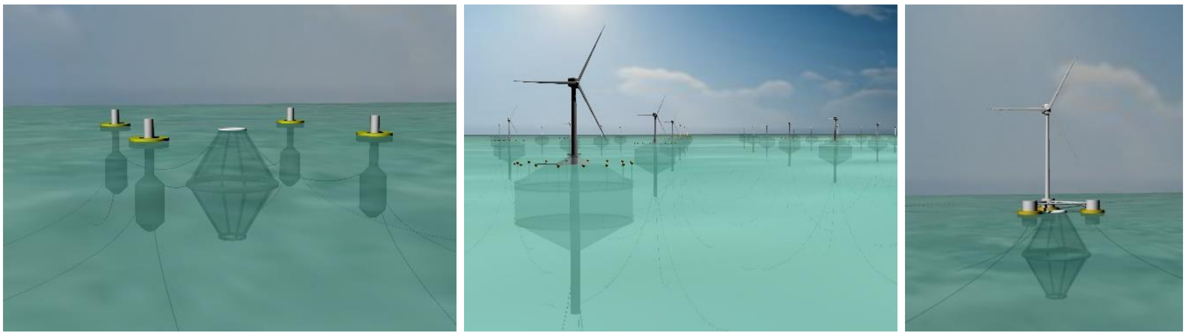


Figure 7-11 Different MUP solutions that combine aquaculture and wind and wave energy discussed at round table meeting

During the round table meeting the aquaculture sector showed much interest in the development of such MUPs, since they partially eliminate the economic obstacles of offshore aquaculture. However, after discussions with all the stakeholders, aquaculture was deemed very difficult technically.

The stakeholders also argued that it is important to select a good site where conflicts with other interests are minimal. In general, the stakeholders pointed out that the MUP should be sufficiently far away from the coast.

It was found important that a MUP should not cause negative impacts on the local fishing community, and that a MUP can provide revenues to both the local fishing community and local businesses.

All the stakeholders agree with the importance of including marine renewable energies at the MUP and the benefits of this sector in the area of Cantabria.

At the end, the final MUP design derived from the Mermaid project was the one presented in the next section where wave and wind energy is combined in the same floating platform.

7.3 Final design description

The final MUP design proposed for the Atlantic site combines the uses of wind and wave energy converters. This new design consists in a semi-submersible floating platform formed by three oscillating water column (OWC) wave energy converters and one horizontal wind turbine (Figure 7-12).

The semisubmersible includes a heave plate to support the different platform elements (even wave energy converters and wind turbine) and to give more hydrodynamic stability. Over the heave plate, four columns/floaters are placed to give to the platform the buoyancy required. Three of the four cylinders are located at the vertex of the base, while the other one is in the centre of the base. The four columns are connected between them by beams/braces with rectangular section.

The oscillating water columns (OWCs) converters are located around of the columns supported over the vertex of the heave plate, while the wind turbines is supported by the central column.

Furthermore, the MUP has available an active ballast system (water) in the columns to reduce the rotations due to thrust wind forces applied over the wind turbine.

The floating platform is anchored to the seabed by means of a mooring system formed by 4 catenary lines (weight 186 Kg/m and length 400 m).

The whole structure (full prototype) has been designed to be made in concrete.

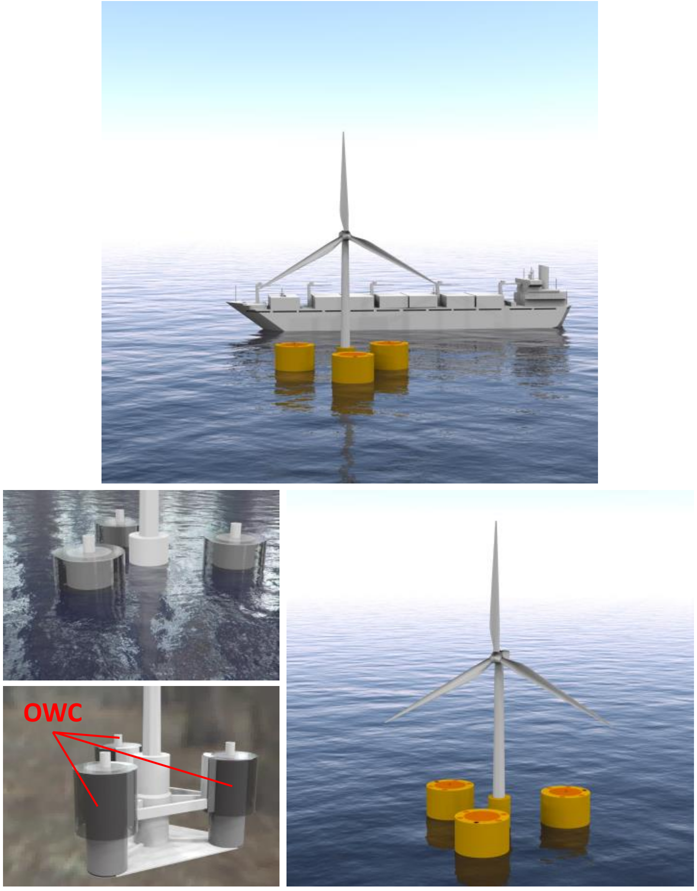


Figure 7-12 Atlantic site MUP: Final design.

The main characteristics of the floating MUP are summarized in Table 7-1. It can highlight the power capacity, which is around 8MW.

PaCOS Platform Cantabria Offshore Site		
Main characteristics	**Units**	**Dimension**
Platform Mass	Kg	8931262
Platform Draft	m	18
Diameter of Vertex floating Cylinder	m	11,97
Diameter of Central floating Cylinder	m	8,015
Side of heave plate (Equilateral Triangle)	m	65,905
Gravity Center from the base line	m	15,47
Wind Turbine	MW	NREL 5 MW
Capacity of each Oscillating Water Column	KW	1150 KW
External Diameter of OWC	m	17,99
Internal Diameter of OWC	m	11,97
Water Depth	m	105
Mooring System Weight	kg/m	186
Length of Mooring System	m	400
Number of Lines	m	4

Table 7-1 Main characteristics of the MUP proposed for Cantabria Offshore Site

In order to check the hydrodynamic behaviour of the multi use platform, numerical simulations have been performed to determine the hydrodynamic response of the platform under the actions of wave, currents and wind. Furthemore, to verify/certificate the numerical simulations results, physical model tests has been carried out at IH Cantabria facilities (CCOB).

7.3.1 Physical Model Tests

Physical model tests have been performed at IH Cantabria facilities (CCOB). The scale selected has been 1:35. In the physical model, the OWCs have also been simulated, as well as a specific wind turbine were also included in the final model (Figure 7-13).

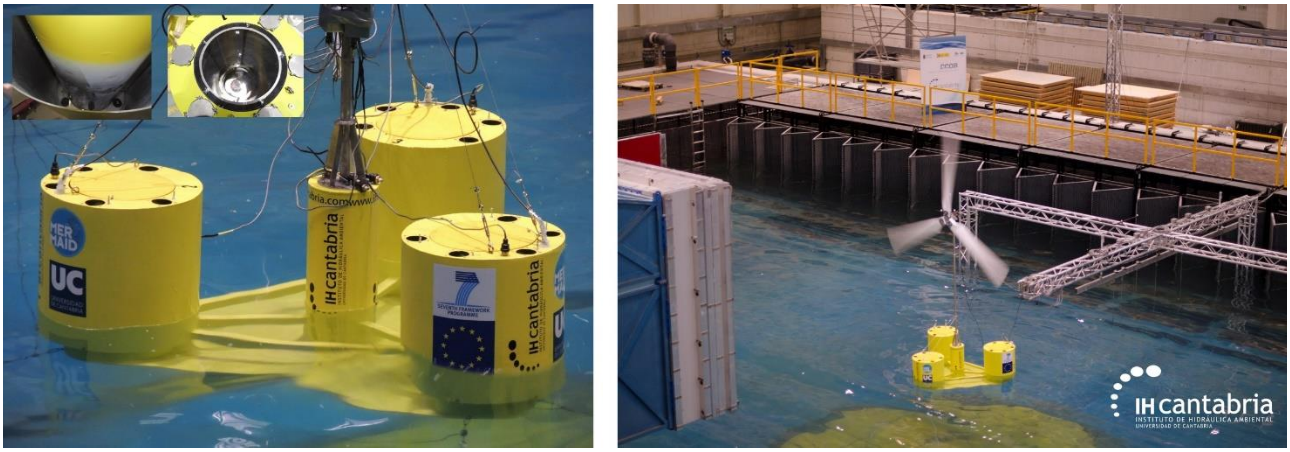


Figure 7-13 Physical model test. Left photo: OWCs. Right photo: general view of the platform.

The physical model tests have been carried out with waves, currents and wind. The floating platform has been tested under different load conditions:

1. Regular waves.
2. Regular waves and wind.
3. Operational sea states (irregular waves, irregular waves + wind, and irregular waves + wind + current).
4. Survival sea state (irregular waves + wind)

The selected sea states have been obtained from the met ocean conditions of the Atlantic site. Furthermore, to optimize the wave energy production, different chambers opening (from totally open to close) have been tested under the actions of different sea states. The test plan executed can be found in the deliverable 3.4 of the Mermaid project.

Following figures (Figure 7-14, Figure 7-15, Figure 7-16) show photos from physical model tests.

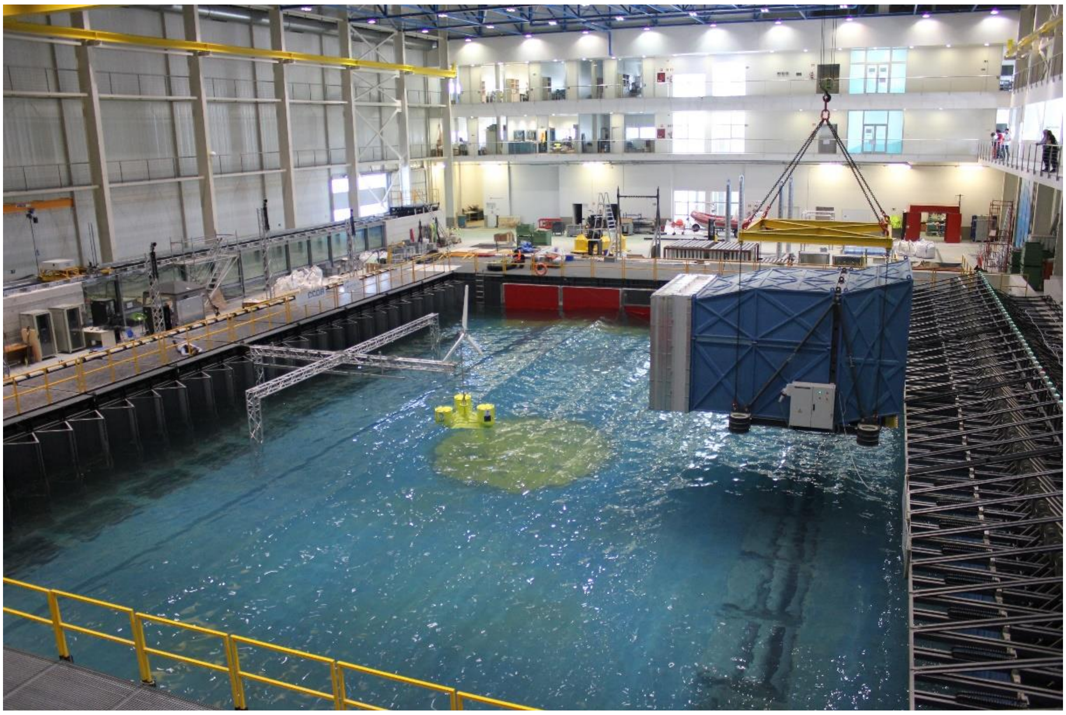


Figure 7-14 Physical model test. General view of the basin.

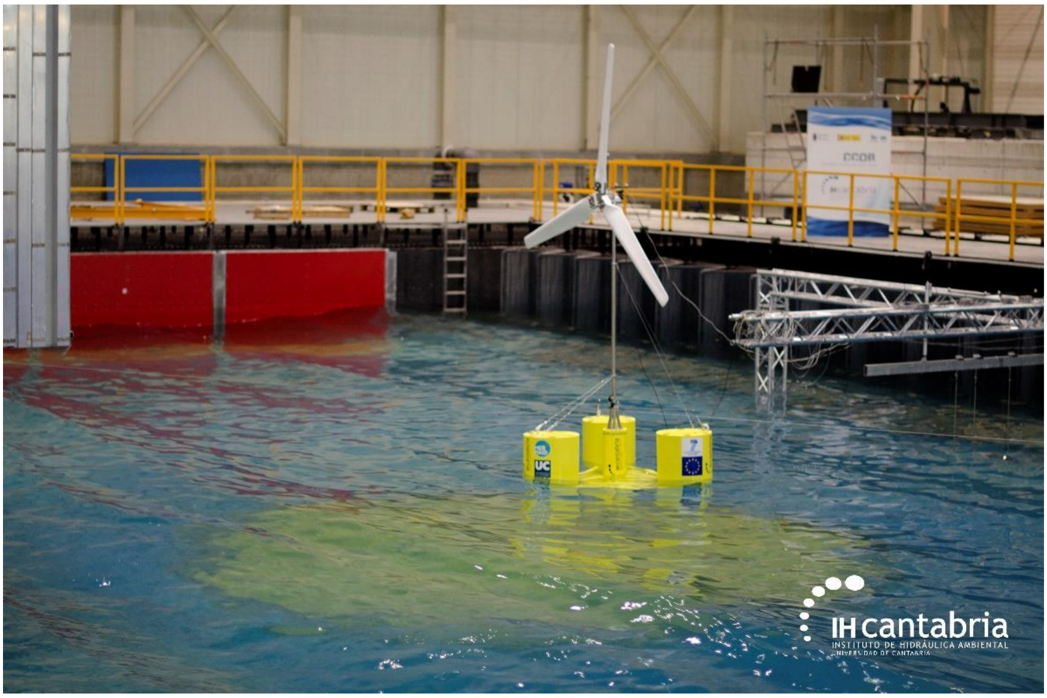


Figure 7-15 Physical model tests. General view of the MUP.

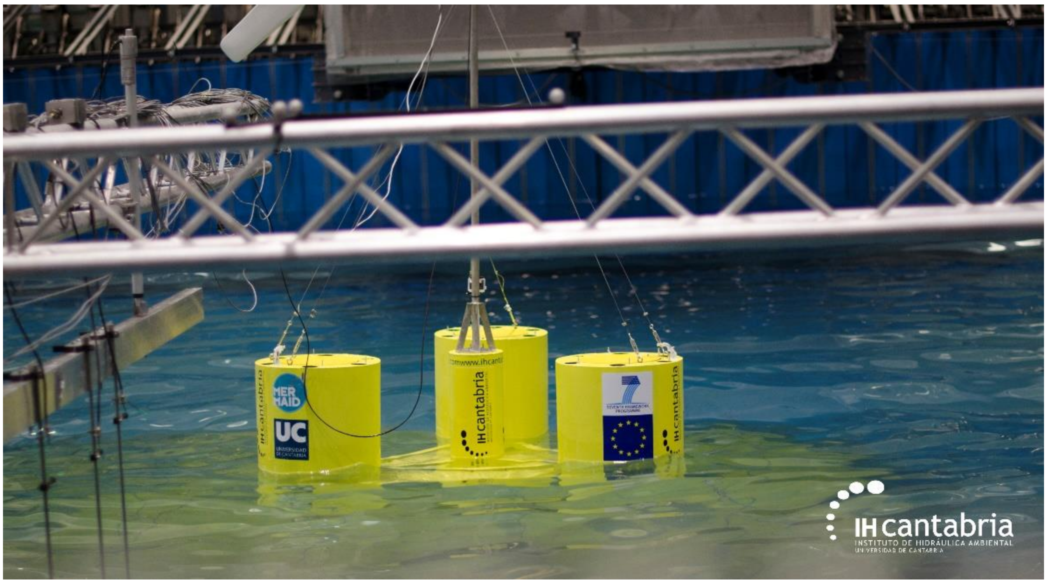


Figure 7-16 Physical model tests. General view of the platform base.

In order to measure the different parameters of interest, the following instrumentation were installed in the basin and inside the mockup:

- Incident wave (x6 Akamina gauges).
- Current (2 ADV sensors and 1 ADCP)
- Movement and acceleration of the platform (Qualysis system).
- Loads on the mooring system (x4 load cells, 1 in each the fairlead of the lines).
- Wind (Wind force has been recorded with an tri axial load cell placed below the nacelle)
- Free surface inside oscillating water columns to calculate wave energy production (x3 Akamina system)
- Pressure sensors in the oscillating water columns to calculate wave energy production (x3).

The main goals of physical model test were:

1. To characterize hydrodynamic of the floating platform. (Natural periods, metacentric weight, damping coefficients)
2. To determine experimentally the response amplitude operator.
3. To analyse the dynamic response of the structure under operating conditions combining wave, wind and current action over the floating platform.
4. To study the performance of the structure under extreme conditions (wave, wind and wind) with the turbine out of operation (parked).
5. To create a calibration data set for “in house model” to be able optimize the chamber opening of the OWC
6. To create a calibration/validation data set for calibration of “in-house model” (time domain model, *IH-wave to wire*, which included wave, current, wind, and also the effects of oscillating water columns).

Finally, the following figures (Figure 7-18, Figure 7-19, Figure 7-20) and **Error! Reference source not found.** show the most representative results obtained from the physical model test.

Mermaid- Atlantic Site Decay with mooring system: Open		
DOF	**Natural Period (s)**	**Damping (%)**
Surge	60,6	5
Sway	82,25	4
Heave	18,8	1,2
Roll	23,7	1,56
Pitch	23,6	1,15

Mermaid- Atlantic Site Decay with mooring system: Closed		
DOF	**Natural Period (s)**	**Damping (%)**
Surge	61,15	4
Sway	82,2	2,5
Heave	15,1	1,6
Roll	15,11	1,08
Pitch	15,05	1,1

Table 7-2 Physical model tests results. Decay tests with mooring system: Chambers open and closed.

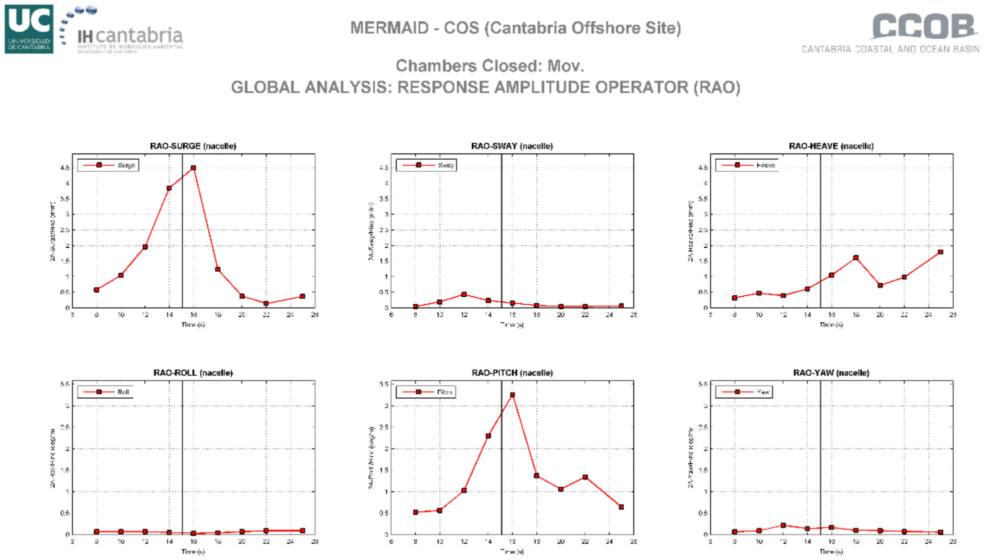


Figure 7-17 Physical model tests results. RAO functions from regular wave. OWCs Chamber Closed.

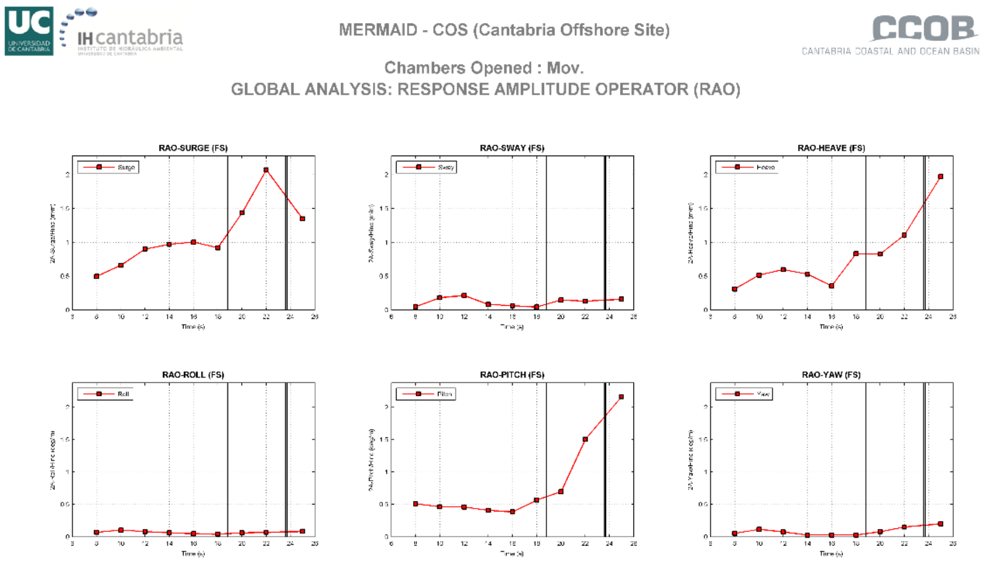


Figure 7-18 Physical model tests results. RAO functions from regular wave. OWCs Chambers Open.

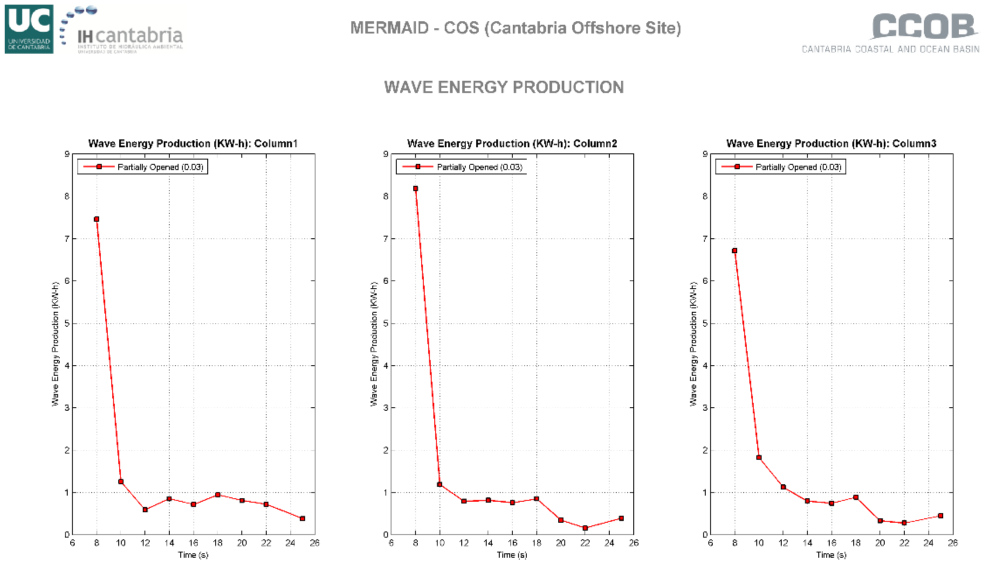


Figure 7-19 Physical model tests results. Wave energy production from regular wave. OWCs chambers partially open (0.033).

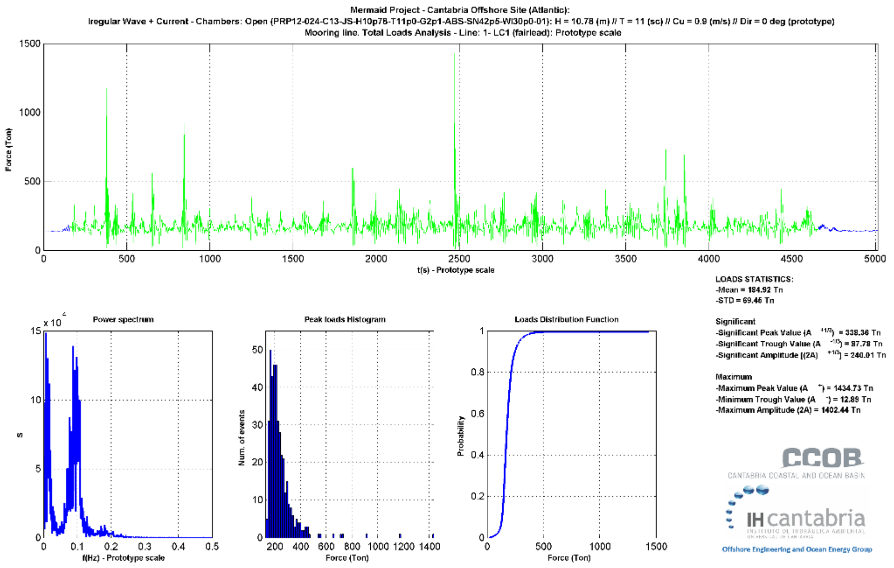


Figure 7-20 Physical model tests results. Survival sea states. Loads on the mooring system.

7.3.2 Numerical model simulations

Once the physical model tests have been finished, different numerical models have been calibrated to check the hydrodynamic response of the platform, as well as to optimize- calculate the chambers opening of the OWCs.

The methodology followed to take into account all coupled effects (platform movements + mooring system + OWCs effects + wind + current) in numerical simulations has been:

1. Coupled analysis of the hydrodynamic response of the platform and mooring system under the action of wave, currents and wind. The effects induced by OWC have not been taken into account in this stage (DeepC).

2. Study of the OWCs without to take into account the platform effects, movements and mooring system (in-house model).

3. Coupled analysis wave and wind energy converters as well as the mooring system (in-house model).

The following list summarizes the main characteristics and the results obtained with each numerical model used:

- ***Sesam (DNV-GL) – with DeepC module (time domain analysis, to evaluate the hydrodynamic response of the platform)***. It has been used to evaluate coupled effects due to the interaction between platform movements and mooring system response. DeepC have been calibrated with lab results. The main problem of this numerical model is that do not take into account the coupled interactions between the platform and the OWCs, therefore this numerical model do not allow evaluate the effects generated by the OWCs. Two models were created in DeepC: Model 1-chambers opened, and Model 2 – chambers closed (due to the effects of the chambers opening).

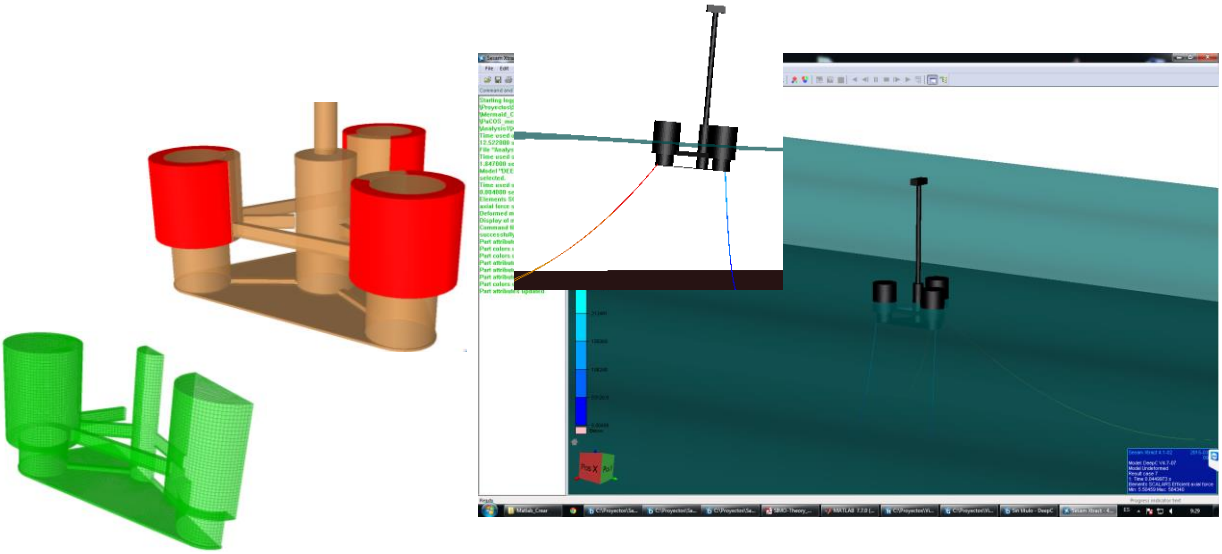


Figure 7-21 Numerical model simulations. Sesam simulations.

- ***In house model to evaluate wave energy production*** – to optimize the opening of the OWCs. Once the numerical model has been calibrated with lab results, the optimum chambers opening to maximize the wave energy production have been calculated.

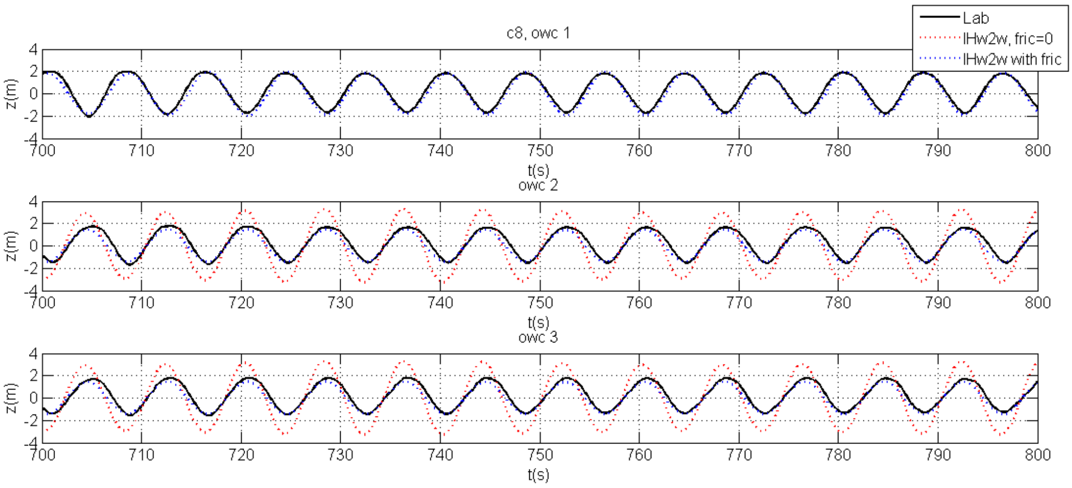
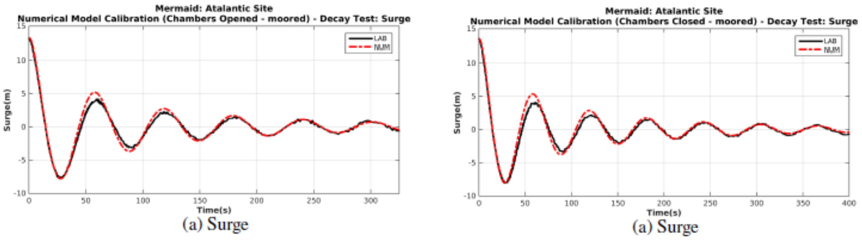


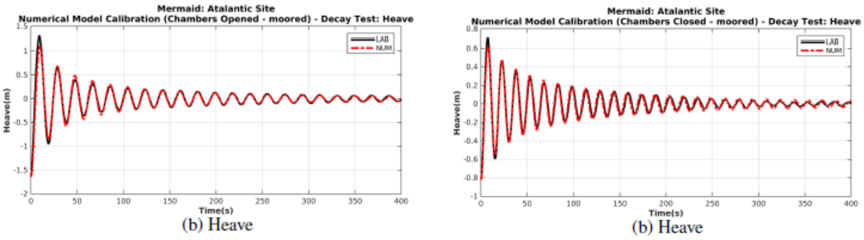
Figure 7-22 Numerical model simulations. Calibration of friction factor of OWCs.

- ***IH wave to wire (In house model to evaluate the coupled effects between the platform and the OWCs)*** – In this stage, the numerical study of a MUP has been done as a combination of the numerical models employed in the study of each technology. This numerical model allows studying the movement of a floating body using 6 DOFs. Also three OWC are integrated in the floating device, so the equation of each OWC have to be computed taking into account the couplings between the floating body and the OWCs. Furthermore, the floating body is affected by the force exerted by the wind over the wind turbine and the forces produced by the mooring system to retain the floating body in position. All these forces are included in the study of the floating body.

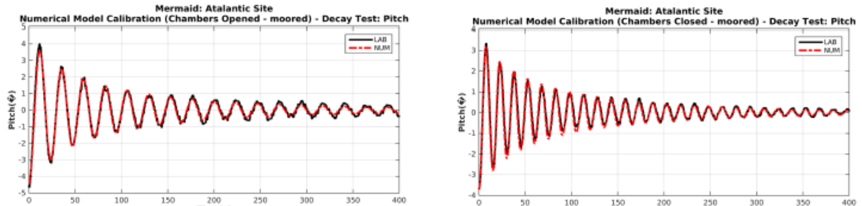
Four numerical models have been executed with four chambers opening of the OWCs.



(a) Surge (a) Surge



(b) Heave (b) Heave



(c) Pitch (c) Pitch

Figure 7-23 Physical model tests results. IH wave to wire. Decay tests calibration.

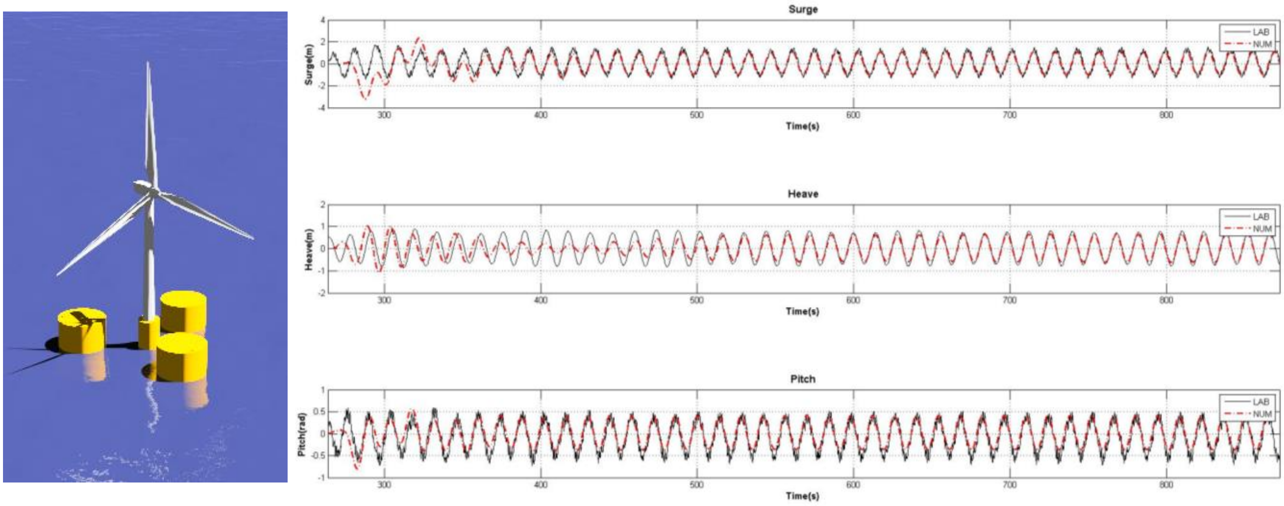


Figure 7-24 Physical model tests results. IH wave to wire. Regular wave tests calibration.

7.4 MUP farm layout

The design of the final layout of a MUP farm is based on the following assumptions:

- The distance between MUPs is determined by the optimal performance of wind turbines, which is more restrictive than OWCs.
- The layout will be regular in order to simplify the design.
- Layout will be oriented to the most powerful wind direction.
- The energy exportation system will be optimized to reduce the electric cable length.

The final design takes into account the limited area where the layout must be designed (the only degree of freedom is the orientation) and the range of depths at the site Figure 7-2.

As it can be seen in Figure 7-1 the available area for the MUPs deployment is from 3 km to 20 km offshore. It is finally considered to deploy the MUPs in an area of 10km to 6 km in order to guarantee the optimal depth for a correct mooring system performance.

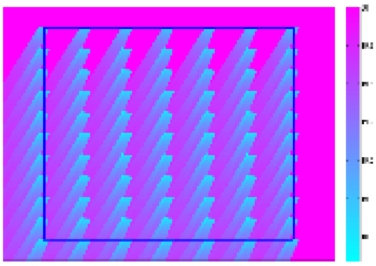


Figure 7-25 Wake effect model applied to the layout oriented to the North

The analysis of the optimal orientation is summarized inFigure 7-26. This analysis is based on the disturbances created by the wake of the wind turbines, which seems to be crucial in the optimization process. In this case, the optimal orientation is around 40º. It is related to the wind intensity rose from figure Figure 7-5 as the most powerful directions are W, E and S.

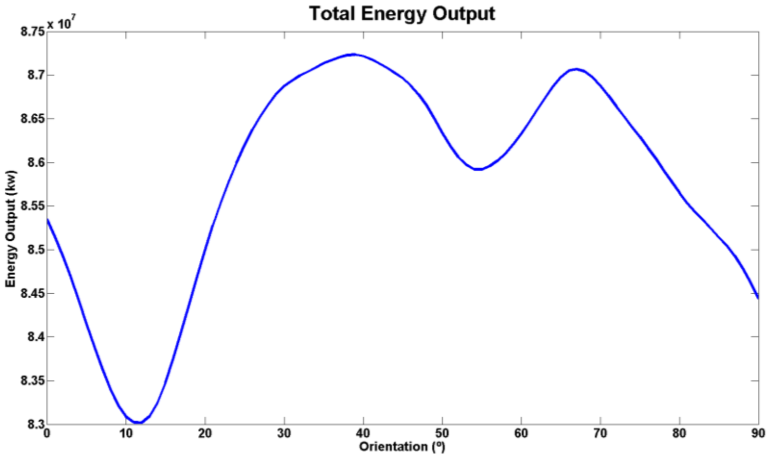


Figure 7-26 Energy output considering the orientation of the layout.

Based on the optimal orientation for the layout design, the final layout proposed is shown in Figure 7-27.

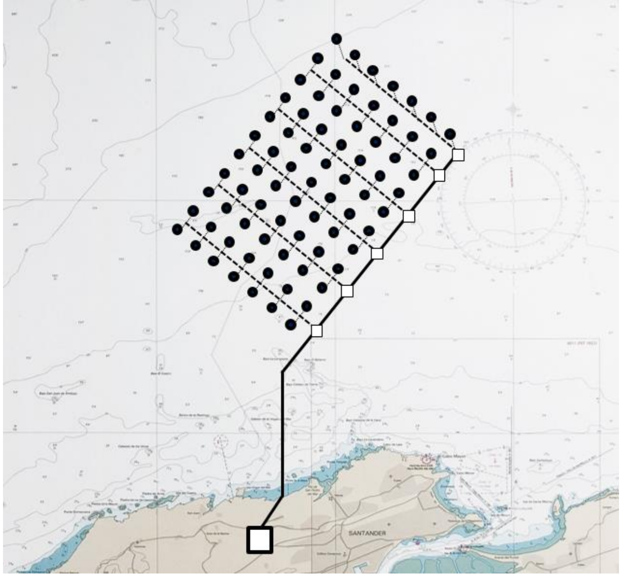


Figure 7-27 Final layout including general electric system scheme.

The distance between MUPs is one kilometre in order to reduce the effect of wakes. The wake effect of OWCs can be considered negligible. As it can be noticed, the electrical system is optimized to use the shortest cable length. The electrical scheme is shown in Figure 7-28.

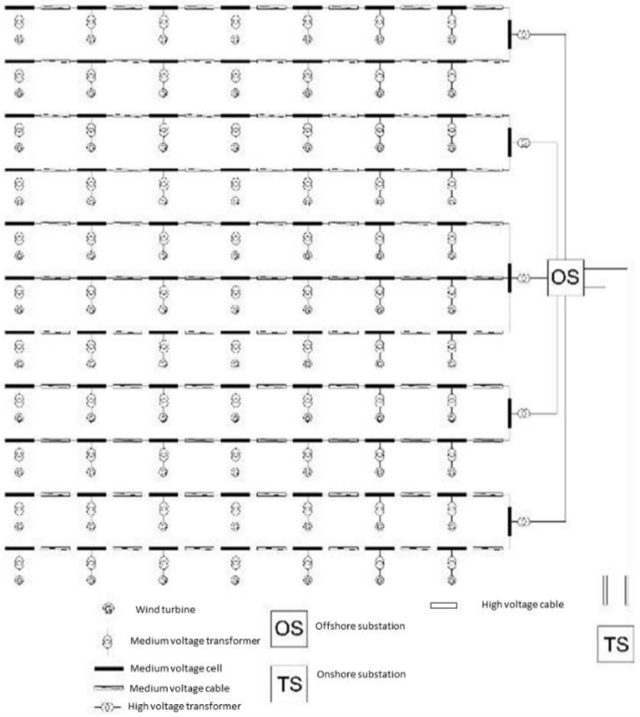


Figure 7-28 Electrical scheme of the MUP farm

7.5 Production and energy transfer

The MUP has a 5MW wind turbine and three 1150KW OWCs (Figure 7-29). This means that the total power capacity is up to 8.3MW. The production of the MUP farm is analysed considering the layout and the impact of the wake effect.

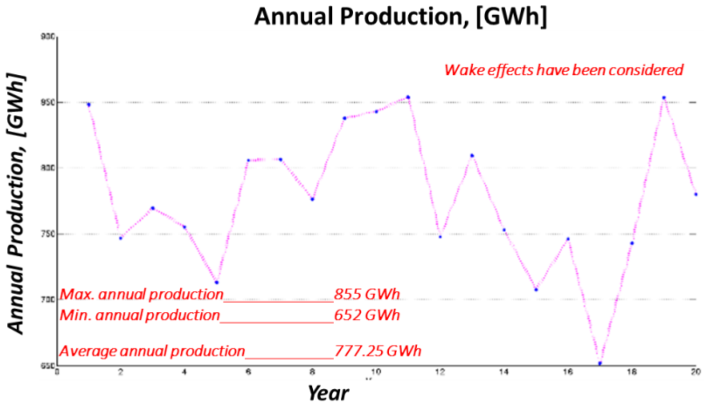


Figure 7-29 Annual production (GWh) of the Wind Converter MUP farm.

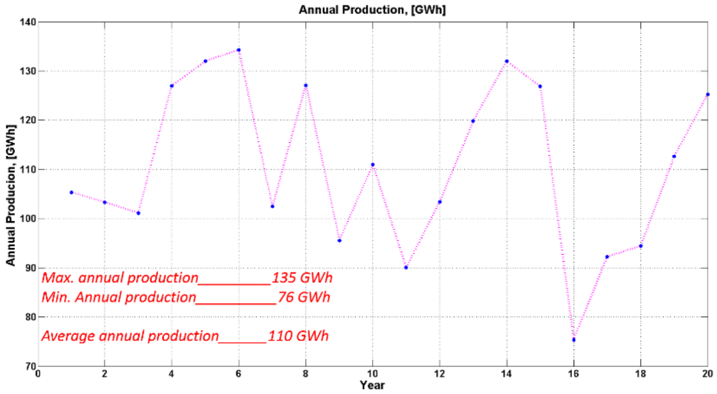


Figure 7-30 Annual production (GWh) of the Wave Converter MUP farm.

The last 20 years of time series are considered to calculate the energy production. As it is shown in the figures, the average annual production is 777.25GWh for wind converters and 110GWh for wave converters (Figure 7-29, Figure 7-30).

7.6 Operation and maintenance

The operation and maintenance of floating devices is a key point that is being investigated currently to reduce the potential costs and improve future strategies. In the case of floating MUPs, some advantages can be highlighted with respect to fixed platforms. The most important one is that floating devices can be transported completely operative from shore to their final location, reducing the investment in transport equipment. In the following, the principal vessels needed for the operation and maintenance of a MUP farm are presented:

- Personal transfer vessel (PTV) – Transport equipment and technicians from the harbour to the MUP to be maintained.
- Tug vessel – O&M transport of the MUP.
- Helicopter – O&M when it is not possible to use a boat because of the bad weather conditions.

Around 15 people may form the O&M personnel group, begin available full time. In some special cases, more people would be involved in O&M activities.

7.7 Technical assessment and risks

The technical barriers that may be faced in the COS locations are presented in the following:

1. The maritime transport may be considered. This problem can be easily solved by changing minimally the route (Figure 7-31).

Figure 7-31 Commercial maritime route.

2. The floating platform should be constructed in a dock. The docks in the area of Santander may not have the necessary area for the development of floating MUPs. Due to this, it is mandatory to find a feasible area.

3. The mooring system may be designed for each MUP independently; therefore special consideration will be paid to the harsh environmental conditions.

7.8 Environmental assessment and risks

The environmental restrictions that have to be considered in the area are related with:

- Windmill impacts on birds
- Soil effect due to interconnections
- Electrical interaction with local fauna
- Natural mobility disruption

The proposed concept is based on a floating technology. Therefore, the seabed will be only affected by the anchors and, up to some extent, by the mooring lines. Both impacts can be catalogued as low environmental impacts.

Moreover, recent experiences with floating structures in that area (Idermar project experience) has been a significant benefit identified. Thanks to the shelter given by the floating structure, around it the ictiofauna identifies that area like a safety area and an aggregate fish effect arise.

However, the site is close to the shore line (5-20 km); therefore visual impact may be critical. Since this impact have been identified like one of the most important one by the Cantabrian community. Wind energy generating should be implemented as far as possible from the shoreline. The current design operates far from the shoreline and only a small part of the wind turbines may be seen from the shore.

In terms of noise influence and birds impacts, specific studies must be carried out in order to identify the critical points.

7.9 Financial assessment and risks

In Figure 7-32 and Figure 7-33 the EPCI budget, CAPEX, OPEX and Project budget are summarized. As it can be seen, the total project budget is up to 3,739,899,031€. Almost the 60% is related to the CAPEX. It is important to notice the 23% of financing project cost considered due to the total investment required to develop the MUP farm. The main part of the budget is allocated to the power take-off (wind turbine and OWC) and the marine structure (72% of the EPCI budget and 53% of the CAPEX.)

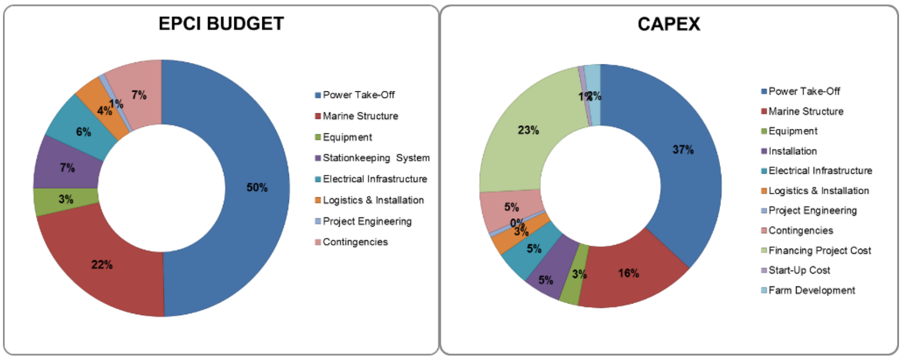


Figure 7-32 EPCI budget and CAPEX.

In this case, the power take-off devices as well as, the marine structures are not replaced. Consequently, the OPEX budget is spread into Operation and maintenance costs and insurance cost. They are almost equal (54%-46%).

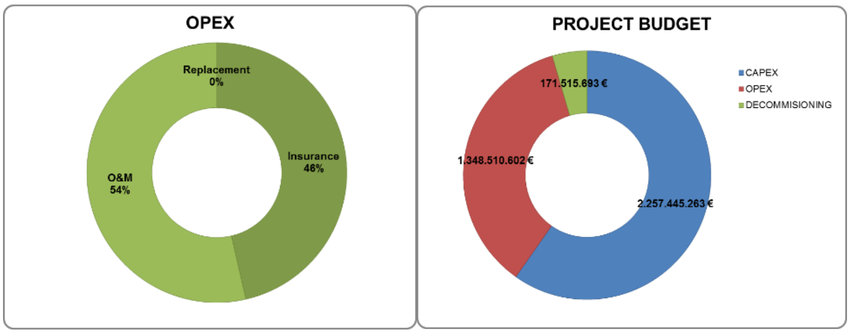


Figure 7-33 OPEX and Project Budget.

In Table 7-3 Costs per KW, the main parameters related to the investment costs are summarized. As it can be seen, the cost of energy of the MUP farm is almost 16.7€/MWh.

CAPEX	3,665	€/KW
OPEX	2,189	€/KW
PROJECT COST	6,071	€/KW
COST OF ENERGY	0.167	€/KWh

Table 7-3 Costs per KW

7.10 Socio-economic assessment and risks

The main socio-economic impact is related to jobs created. During construction phase it is expected to create more than 1000 jobs for three years. In O&M phase, considering direct and indirect jobs the total amount is up to 500.

The energy production expected could supply almost 200,000 houses, which is enough energy for all the zone.

Furthermore, the creation of green energy exploitations may increase the positive impact in the region as there are few renewable energy plants. It would attract external companies to be established in the region.

7.11 Conclusions and recommendations

One of the main conclusions that may be extracted from the present document is that, MUP are an alternative that may be considered in future blue economy developments. Even considering the design level achieved, TRL 3, there are several parameters that indicates that wind and wave combination may be considered as an alternative.

However, it has to be highlighted that due to wind energy matureness, nowadays plays a major role in comparison with wave energy which is still in an early stage of development. But what has been observed is that the combination of two or more power take-offs from different sources of energy leads to the combination of their advantages and mitigate their negative points.

Combining several uses in the same floating platform allows reducing the final cost of energy. As it is commented in the financial assessment, the first studies conclude that MUP platforms adapted to the specific location requirements may achieve competitive cost of energy.

8 Mediterranean Site

8.1 Site description

The selected area is the Northern Adriatic Sea, East of Italy, and specifically off-shore Venice (Figure 8-1, left).

Several challenges characterizes the area, among them:

- the mild slope of 0.35 m/km and the peculiar circulation patterns with a high seasonal variability;
- the large anthropogenic development, which leads also to erosion and land subsidence;
- the strategic area for marine fauna conservation, sheltering relevant seabird populations and endangered marine mammals;
- The vicinity of the city of Venice, with the associated high social sensitivity to the construction of new marine infrastructures.

Considering the numerous maritime uses in the area, one of the key challenges to be solved is the location of the platform, depending on the potential conflict of uses deriving from the harbours with their commercial and touristic maritime routes, the fisheries, the oil and gas platforms, the natural habitats and the restricted areas (see Figure 8-1, right).

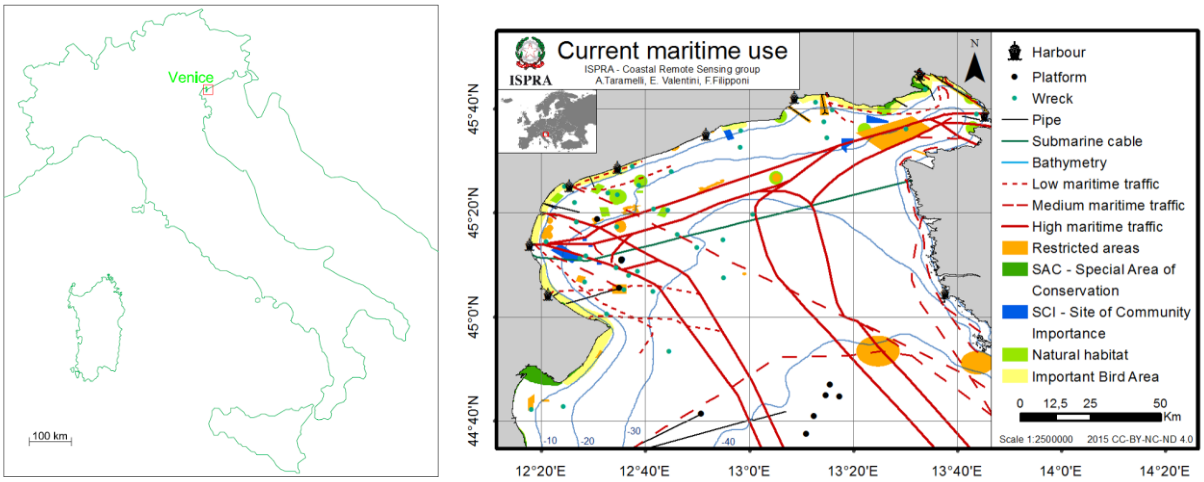


Figure 8-1 To the left: Location of the site highlighted with a red square; To the right: Different existing uses in the selected area.

8.2 Available resources

The meteo-marine climate is mild; see the diagrams in Figure 8-2. The maximum measured wave height is slightly higher than 4 m and the calm period is close to 40% (i.e. conditions with a wave height <0.25 m), resulting in a mean available annual wave power around 1.1 kW/m.

The wind velocity is in the range 3 and 4 m/s at 25 m height, and therefore its estimation at 100 m height is around 4.7 m/s.

Both wind and waves show two main incoming directions: one from the North East (Bora, between 0°N and 85°N) and a second from the South East (Scirocco, between 105°N and 175°N), being the Bora direction dominant both in intensity and frequency.

Since the Adriatic is a semi-closed basin, the site is characterized by a very low tidal excursion, so the tidal energy resource can be neglected.

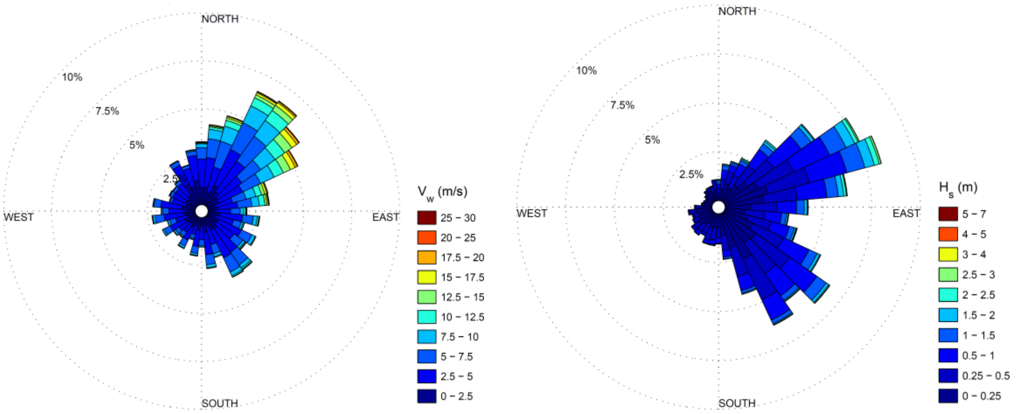


Figure 8-2 Rose diagram of the mean annual wind (to the left)

Existing installations of wave energy devices in Europe are located in areas with an available wave power ten times greater with respect to this site. Similarly, for the exploitation of off-shore wind energy Orecca FP7 Project established a minimum threshold value of 6 m/s at hub height that is higher than the average wind speed at this site. Therefore the available potential renewable energy resources –at the site– appear economically ineffective for single purpose installations.

The site is also suitable for aquaculture as there are already many near-shore aquaculture farms. The increasing demand on the global market, combined with the numerous existing space conflicts in coastal areas, has stirred interest in moving aquaculture further off-shore. Therefore the exploitation of the aquaculture at the site is also considered.

Based on the experience (over 30 years now) and the market in the Mediterranean, the suggested species are sea bass (*Dicentrarchus labrax*) and gilthead sea bream (*Sparus auratus*).

Yet, going off-shore leads to colder local temperatures, hence the standard average marketable size (~350 gr) is not sufficient to have a return of the investment within a feasible time period, so it is required a more refined fish size, which leads in turns to longer growing time but shorter time before the cash flow financing turns positive.

Additionally, to secure good fish health, i.e. to have an adequate renewal of the water around the cages and proper dispersal of the nutrients, the bottom depth at installation has to be around three times the depth of the sea cages (9 m based on national laws). Due to the mild slope, the required water depth of 25 m at least is reached at a distance of 27 km from the closest harbour, posing challenges to the on-shore grid connection.

8.3 The identification of the multi-use platform (MUP)

At the site, it is foreseen to combine wind and wave energy harvesting with the fish farm. Each combination is analysed under two configurations: one connected to the on-shore grid and one electrically independent from the on-shore grid. Two wind turbines and two wave energy converters have been investigated.

All the MUPs combination are summarized in Table 8-1, more details can be found in MERMAID, 2013.

Name	**Wave**		**Wind**		**Fish Farm**	**Electricity Connection**	
	WaveStar	**DEXA**	**Large**	**Mini**		**Stand Alone**	**Connected to Grid**
MUP 1	X		X	X	X	X	
MUP 2	X		X	X	X		X
MUP 3	X			X	X	X	
MUP 4	X			X	X		X
MUP 5	X		X		X	X	
MUP 6	X		X		X		X
MUP 7	X				X	X	
MUP 8	X				X		X
MUP 9		X	X		X	X	
MUP 10		X	X		X		X
MUP 11		X			X	X	
MUP 12		X			X		X

Table 8-1 Synthesis of the multi-purpose concepts to be explored.

8.3.1 Description of the devices

The “large wind” consists of VESTAS V112. This turbine has a 112 m rotor diameter and a rated power of 3.3 MW. By assuming the hub height equal to 100 m, the estimated productivity at the site is less than 1000 equivalent hours; leading to a capacity factor around 11% and to a production of 0.96 GWh/y per installed MW. If more than one turbine is installed, a spacing of seven rotor diameters (i.e. a distance of around 800 m) among each wind generator is suggested. These distances allow reducing up to 10% the energy losses due to wake effects. The basic module is therefore of four wind turbines with a total power production of 12.7 GWh/y (by neglecting the cable losses) and a total occupied space of 0.64 km^2 (see Fig. 3, left).

The “mini wind” refers to a Bergey EXCEL 10. This turbine has to be installed on a fixed platform; therefore it is suited for combination with a fixed wave energy device (i.e. WaveStar). By considering the climate at the site and the hub height of 25 m, the estimated equivalent hours are less than 800, leading to a capacity factor around 9% and to an energy production of 0.74 GWh/year per each installed MW. These mini-wind turbines are mostly installed as single turbines; occasionally, a single row of turbines might be installed perpendicularly to the prevailing wind direction, with a mutual distance of four diameters, i.e. around 30 m (see Figure 8-3, right). Considering not more than three turbines, a total power production of 0.02 GWh/y is achieved (by neglecting the cable losses), with a total occupied space of 900 m^2.

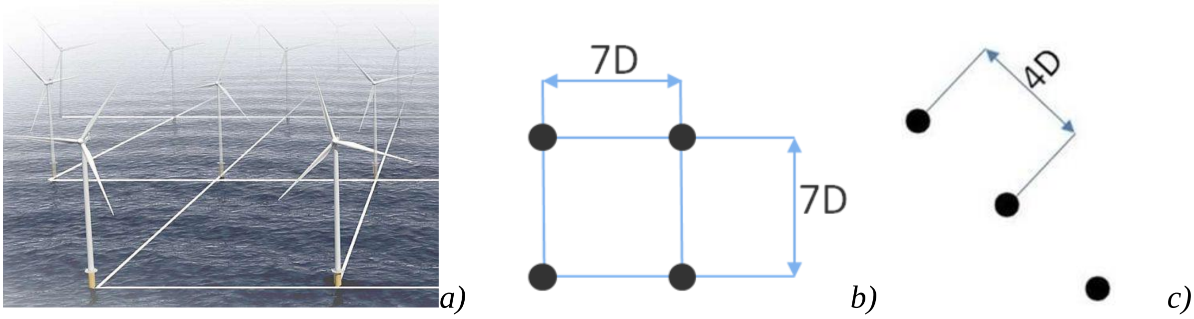


Figure 8-3 The two selected wind turbines: rendering of an off-shore VESTAS installation (a), layouts of VESTAS V112 (b, with D=112 m) and Bergey Excel 10 installations (c, with D=10 m).The two chosen wave energy converters are DEXA and WaveStar.

DEXA is a floating device consisting of two rigid pontoons with a hinge in between, which allows each pontoon to pivot in relation to the other (see Fig. 4). The Power Take-Off system is activated by this relative motion. The draft is such that, at rest, the free water surface passes in correspondence of the axis of the four buoyant cylinders.

This device has been selected because it is effective also when the sea conditions are not extreme, such as in the Mediterranean site. Furthermore, it has a low environmental and visual impact since it is floating and without highly emerged parts.

The power production at the site has been estimated on the basis of small-scale physical tests.

The efficiency is maximum when the device length is equal to the wave length. Since the average value of the wave length at the site is of 30.4 m, the device length *l* is assumed to be equal to 30 m, and therefore the device width *b* is imposed equal to 15 m, in order to optimize the stability with the squared shaped pontoons and keep the aspect ratio similar to the proposed Danish prototype.

By assuming that there is no energy loss due to device re-orientation under oblique waves, each device produces about 77 MWh/year.

A basic module of five staggered devices is proposed (see Figure 8-4, right). The module has a power production around 0.4 GWh/year (by considering only the hydraulic efficiency and neglecting re-orientation energy losses, cable losses, etc.) and an occupied space of 0.09 km^2.

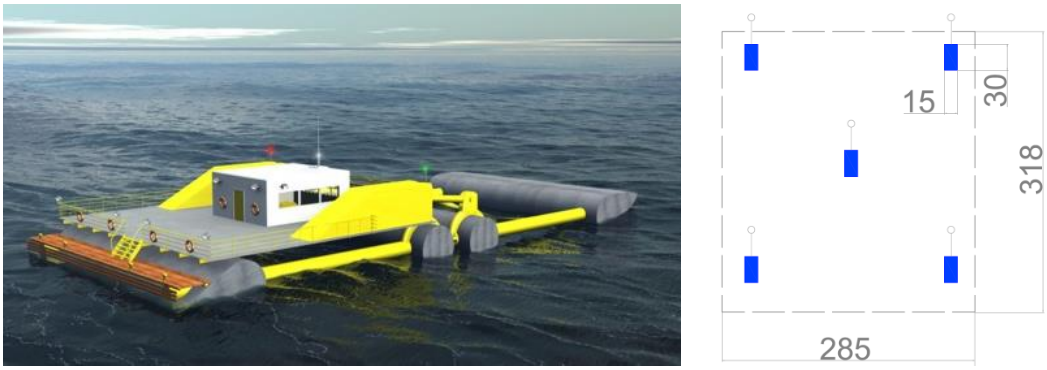


Figure 8-4 DEXA concept (left); proposed module layout with five staggered devices, *measures are in meters (right).*

The Wave Star draws energy thanks to many floats that rise and fall with the up and down motion of waves. The floats are attached by arms to a fixed platform, which includes all the electrical and mechanical parts. The platform stands on legs driven into the sea floor and it is sufficiently high above the water surface, so even the highest waves cannot reach the structure (see Figure 8-5, left). The Wave Star is designed with multiple platforms (each one with a length at least equal to the main wave length) in order to optimize the power production regardless of the incoming wave direction.

This device is at an advanced state of progress, since it is already grid connected; it is a point absorber, therefore it is particularly suited to this site, where the energy is associated with two main directions. Furthermore it can be easily combined with other uses, for example by integrating wind piles into the supporting platform piles. However the installation of this device requires an adequate sea-bottom geotechnical investigation.

The WaveStar is supposed to be placed on 20–25 m depth and composed of three platforms, up to 80 m long with ten floaters on each arm (gap width between the floaters equal to 5 m, i.e. half the floater diameter). Each floater has a diameter of 10 m (see Figure 8-5, right).

The power production is based on the results of numerical simulations. Each floater produces around 10 MWh/year. The basic module of three platforms achieves a power production of around 0.6 GWh/year, with an occupied space of 0.04 km^2.

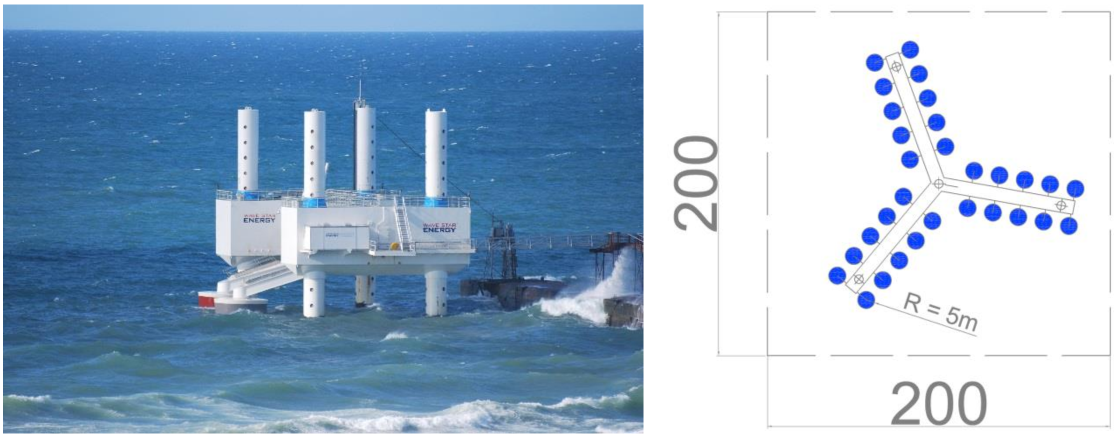


Figure 8-5 To the left: Wave Star prototype (with only two floaters) installed at Hanstholm, DK. To the right: the proposed module layout with three platforms, measures are in meters.

8.3.2 The selection procedure of the MUP

A procedure for the evaluation of different design concepts has been developed. The procedure (whose details can be found in Zanuttigh, et. al. 2015a, b) consists of: a pre-screening phase, to assess the feasibility of the single purpose installations, and a ranking phase, where the MUPs performance is scored based on selected criteria (i.e. exploitation potential, innovation, environmental impact, risks, costs) and sub-criteria that account for technological and non-technological issues relevant to installation, operation and maintenance. The criteria and sub-criteria have been chosen taking into account the results of local stakeholders' focus groups.

The experts/users of the methodology provided scores for each sub-criterion, then the score of each criterion is determined as the un-weighted mean of the scores of the sub-criteria.

By ordering the ranked MUPs from the most to the least successful, the best alternative is achieved. This solution has then to be discussed based on the local stakeholders' expectations.

8.4 The final MUP

The selected MUP includes wind turbines and fish farming and it is grid connected (see Figure 8-6).

Despite the great distance between the MUP and the shore (27 km from the closest harbour) a grid connection solution is selected, because the energy required by the fish feeding system is low but constant. The local renewable energy resources, due to the inactivity windows, would not always supply such energy, and would require the installation of a local generator system. Therefore, in case of non-connected-to-grid solution, most of the produced wind energy would have to be dissipated and additional energy would have to be provided anyway.

The final MUP does not include wave energy converters for the following reasons:

- the presence of wave energy converters does not reduce the inactivity window of energy production, because wind and wave are correlated;
- wave energy converters are less mature as technology advancement with respect to wind turbine, leading to higher installation and operation costs, and much greater occupied marine space to reach a similar energy production;
- higher potential of environmental impacts, for example for floater failure and debris or fouling, etc.

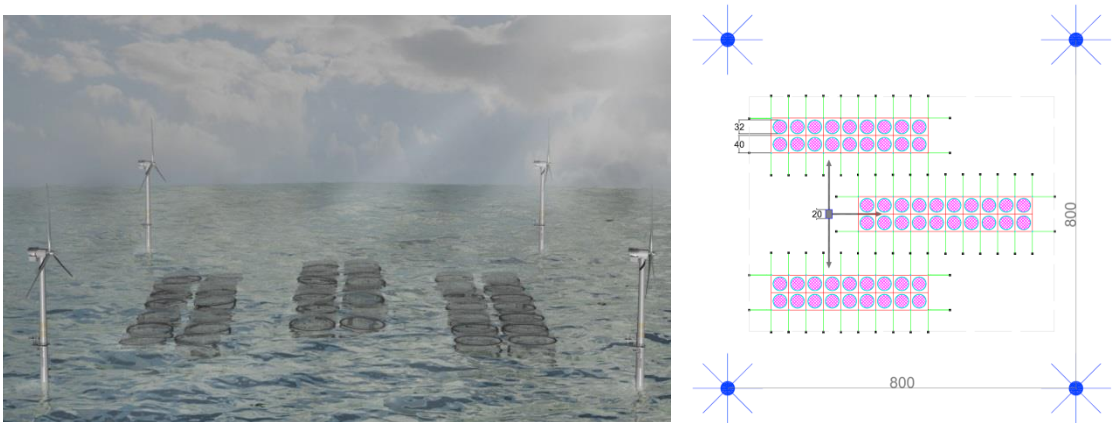


Figure 8-6 Representation and layout of the selected multi-use platform (MUP), with 56 cages for aquaculture and 4 VESTAS wind turbines in the corners (grid connected). By courtesy of VLIZ.

The wind farm consists of a single module of four VESTAS V112, with a total estimated production of 12.7 GWh/y. The wind piles are driven into the sea-bottom.

The fish farm is designed to support a 2000 ton annual production capacity, equally divided between the sea bream and sea bass species. The fish farm is made of 56 sea cages of 32 m diameter, and 9 m depth. The total cages footprint is 600 m in cross-shore and 540 m in cross-shore, leading to a total occupied space of 0.36 km^2. An additional space around each cage and around parks of cages (at least of 100 m) must be preserved for feeding, water re-circulation and sailing of the harvesting vessel as well as other vessels. The feeding system is located in a small platform placed among the cages at a maximum distance of 300-400 m.

Considering also the additional space, the fish farm is design to be placed in the space among the wind turbines, leading to a total occupied space for the MUP of 0.64 km^2.

One of the challenges of this MUP is the environmental impacts on the soft assemblages at the bottom due to the wind pile perforations and to the numerous anchors of the moored cages.
As regards the operational maintenance of the MUP, a frequent maintenance (twice a month) with regular barges/vessel is foreseen, whereas the wind turbine should not require frequent maintenance operations.

The fish and the wind farms are designed for 20 and 30 years operational time respectively. At the end of the MUP lifetime, a complete removal of cages and wind turbines is expected, while the feeding platform could be maintained for research purposes.

The proposed MUP can be considered as a module to be repeated, however:

- the fish demand is not so high to justify an extensive module reproduction;
- the fish farm may increase organic matter and nutrients and therefore a detailed EIA should be carried out;
- the conflict with other uses has to be accounted for.

8.5 Installation, operation, maintenance and decommissioning

8.5.1 For fish farming

Operation: for operation purposes of the fish farm, the main requirements that have to be fulfilled are those of space availability in between adjacent sea cages and neighbouring cage parks (which have been incorporated in the proposed design). Operations include feeding (in cases where the automatic feeder is not used), harvesting and daily surveillance of proper function. No special requirements other that the ones mentioned at the beginning occur.
Maintenance: There are no major maintenance works needed to be done at the fish farm, except for the occasional change of the nets at the cages (this can take place every 3-8 months depending on the efficiency of the water currents to naturally protect nets from fouling and the net’s mesh size). Change of nets does not require special equipment or vessel, other than the ones used in daily operations.
Decommissioning: When decommissioning the site, the cages are simply transported by vessel to the shore, where they can be dismantled. The only thing left behind is the concrete blocks from the mooring systems of the fish farm, which are highly probable to have formed substrata for ecosystem enhancement.

8.5.2 For the wind farm

Installation: requires the transportation of the piles to be driven into the seabed. The size of the piles depends on the force acting on the system and on the geotechnical characteristic of the seabed.
Decommissioning: the piles will remain in place at the installation site.

8.5.3 Onshore power transportation

Cable protection is essential in order to avoid trenching or damage to the cables, mainly by inshore fishing activity and dragging anchors from coastal vessel traffic. As it can be expected, the export cable is much more exposed than distribution ones to this kind of damage.

Cables are therefore generally buried at a certain depth under the sea bottom or, as an alternative; cables can be laid on sea bottom and then protected by means of various techniques, like for example rock burial, concrete mattresses and sand bags.

Cable installation methods adopted to date have included simultaneous lay and burial, using a variety of subsea trenching and burial equipment deployed from both barges and Dynamic Position vessels. Post lay burial using special jetting or mechanical trenching tools is also possible the most correct method will depend on several factors, with the important remark that the cable must be type approved for the installation method to be used.

According to the desired burial depth and the geology and geomorphological characteristics of the sea bed (sandy, rocky, gravel), different burial machines can be used, like cable burial ploughs, burial sleds or even swimming ROVs with cable burial capability.

Also, even if not offshore specific, onshore works will be needed to provide onshore substation connection to the shore and export cable. Directional drilling might be needed in the transition between onshore and offshore area.

Decommissioning of buried sea cables is very likely to cause a relevant impact on the seabed and therefore cable might be left in its position at the end of the MUP lifetime. Otherwise, specific vessel tow under-running devices able to de-bury the installed cables.

The offshore substation has the function of collecting the power generated by the energy converters and stepping up voltage transmission level to shore and/or having switchgear capabilities if needed. It can be located either above or under the sea level and can be fixed to seafloor or floating.

It is normally located close to the centre of the offshore site to minimize array cable lengths. Offshore sub stations designs generally have until now comprised complete topside module installed onto a piled jacket or mono-pile foundation. Their installation is normally carried out using a floating heavy lift crane barge, with transportation of the foundation and topsides also carried out by the installation barge or by using a dedicated transportation barge. Also self-installing design has been proposed and may have an important role in the near future.

At the end of the project the substation decommissioning is envisaged.

8.6 Technical assessment

The foundations of the large wind turbines (Vestas V112), given the properties of the bottom soil and the water depth, are foreseen as monopiles. It is also to be evaluated the possibility of using innovative methods such as bucket foundations (suction caissons).

The following table summarizes the main MUP risks (Table 8-2).

Function	Risk
Fish farm	Structural Stability *Cable failure* Pollution *Fish feeding and increase of nutrients*

Wind farm	Structural Stability *Overloading on piles* *Scour at pile foundations* *Syphoning of foundations* Pollution *Debris in case of micro-wind*

Table 8-2 Synthesis of the possible MUP risks

8.6.1 Environmental impact assessment (*)

(*This section is based on work carried out jointly by WPs 4 and 7 and is already part of D7.1).

8.6.2 Habitat modifications

The construction of marine infrastructures, including MUPs, typically involves the replacement of natural, most often sedimentary, substrata with harder surfaces of stone, concrete, asphalt, metal or other artificial material. These habitat modifications altered the distribution of a number of species, which thrive on these anthropogenic surfaces. For this reason marine infrastructures are sometimes perceived as an opportunity for habitat enhancement, providing local benefits associated to hard substrata where none previously existed, or potential refugia for rare or threatened native rocky species (Inger et al. 2009, Martins et al. 2010). At the same time, the long-term and regional consequences of these extensive habitats modifications are debated (Airoldi et al. 2005a). The ecological value as habitat of shorelines that have been altered to create new hard substrata can vary in relation to many structural and environmental factors (Moschella et al. 2005, Dugan et al. 2011). Also there is evidence that marine infrastructures can offer particularly favourable substrata to many non-indigenous species NIS (Bulleri and Airoldi 2005, Neill et al. 2006, Glasby et al. 2007, Vaselli et al. 2008, Dafforn et al. 2012, Mineur et al. 2012). NIS may colonize from nearby natural rocky habitats or could spread out of ports, harbours, marinas, or other sources of introduction. When multiple artificial structures are built relatively close to one another, along stretches of coast comprising predominantly soft sediments, these structures can sometimes function as pathways or stepping stones, facilitating the spread and connectivity of both native and non-native marine species (Moschella et al. 2005). It is worth noting, however, that resistance of a community to the establishment of non-native species may increase with higher native species diversity (Stachowicz et al. 2002), especially if certain functional groups are present (Arenas et al. 2006). The risk of facilitating the spread of non-native species through the construction of artificial hard structures may thus be minimised through the incorporation of a variety of habitat features into the structure, if successfully colonised by a diverse biological community.

These issues are particularly relevant in the Adriatic Sea due to the large abundance of marine infrastructures. In the region exploitation of gas reservoirs began in the 1960s, and more than 100 platforms have been installed since then. The shape and the size of the platforms are variable, mostly depending on the depth of the sea bed at which the structures lay. In order to resist to different oceanographic conditions, structures range from monopods to multi-legs with the former mostly concentrated at shallow depth. Produced water is the major discharged effluent, and eco-toxicological studies have found no major pollution effects from the activity of gas extraction (Gorbi et al. 2008).

The sandy coastline is also highly urbanized (Cencini 1998). Along this entirely sedimentary coastlines, a variety of hard artificial structures have been built in the past 50 years, for harbours, ports and marinas and for protection of the coast, comprising > 100 km of groynes and breakwaters, > 60 km of seawalls and > 40 km of jetties. Previous work has documented the prevalence of assemblages characterized by low species and genetic diversity on these structures, which favour flora and fauna that often represent an early stage of succession, comprising opportunistic and invasive species. This has generally been attributed to the high levels of disturbance in these environments, although the prevalence of non-indigenous species in these systems has not been analysed in a broader regional context.

Overall the northern Adriatic Sea can be considered a hotspot of species invasions. In particular, the Lagoon of Venice in the northern Adriatic Sea, with its crowded recreational and commercial harbours, as well as a flourishing mariculture activity, is the Italian locality with the highest number of marine aliens (Figure 8-7): 39 species, including 12 algae, 9 molluscs, and 9 crustaceans.

Other processes could also contribute to shape benthic assemblages in the region, either amplifying or masking the effects of offshore platforms. For example, in the North Adriatic sea commercial trawling is intensive (Pranovi et al. 2000), and the system is considered to have entered a “fished state” sensu Jennings and Kaiser (1998), where additional disturbances may no longer lead to clear responses in assemblage structure. Offshore structures provide some degree of refuge from trawling activities (De Biasi and Pacciardi 2008, Terlizzi et al. 2008) as for safety reasons it is forbidden to navigate closer than a distance of between 200m and 1000m from offshore platforms (Art. 28 del D.P.R. 886/79). Trawling is known to modify deep benthic systems, causing reduced species’ abundances and changes in species composition, with an increase in deposit feeders and a decrease in suspension feeders with increasing fishing pressure (Thrush et al. 1998). The effects of trawling tend to be particularly evident in homogeneous sediment types that are usually less affected by natural physical disturbances (Kaiser and Spencer 1996).

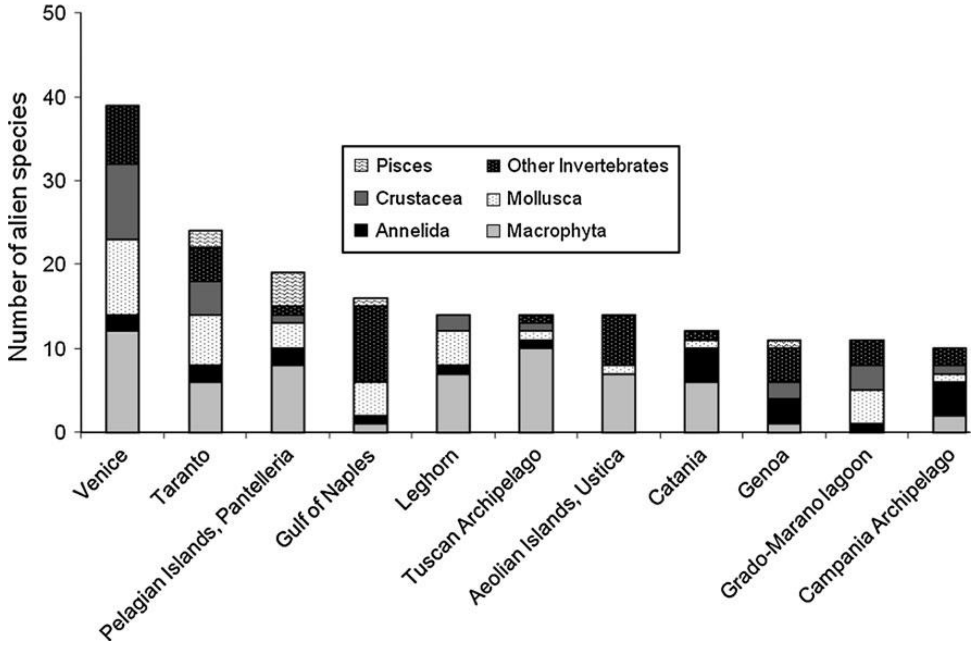


Figure 8-7 Number of alien species recorded in the hotspots of introduction along the Italian coast (Occhipinti-Ambrogi et al. 2010).

8.6.3 Fish farming

Research carried out in the Mediterranean sea has documented significant changes in the physical, chemical and biological attributes of sediments and the water column around off-shore aquaculture farms (Sarà et al 2004, 2011, Pusceddu et al 2007, Aubin et al 2009, Luna et al 2013, Martinez-Garcia et al 2013), including:

- increasing organic matter contents and compositional changes of the sediment below fish cages
- altered inorganic and organic chemistry of farm water and sediments;
- altered abundance, biomass and biodiversity of micro-, meio- and macro-benthic communities;
- modified distributional patterns of phyto- and microplankton abundance and production.

Although large scale modification of the trophic status (i.e. nutrient concentrations and phytoplankton biomass) of marine areas have been described as a consequence of fish farming (Aubin et al 2009, Sarà et al 2011), most of the described impact are normally confined to within 1 km of the farm (Forchino et al 2011).

The introduction of pathogens, alien species, and new genetic strains have also raised environmental concern, but little is currently known about these aspects (Rigos et al 2005).

Experimental work has shown that the environmental impact of marine fish-farming can vary greatly depending on species, culture method, stocking density, feed type, hydrography of the site and husbandry practices, and that the effects can be significantly reduced by careful site selection, control of stock density, improved feed formulation and integrated culture with macroalgae, filter-feeders and deposit-feeders (Borja et al 2009, Keleey et al 2013).

It is therefore recommended that all operations are carried out according to the relevant legislations and the method of fallowing is applied (periodic rotation of the site of cage parks every 3-5 years, so that the seabed underneath the cages is left to recover), as it has been show that these practice can significantly mitigate the environmental impacts (Karakassis 2000, 2001).

8.6.4 Wind turbines

The presence of piles, scour protection at piles, and anchors affects the soft bottom assemblages and increases habitat biodiversity, however it should not change the habitat at the seabed at large scale and it should also not increase the spreading of invasive species. The scour protection at the piles in case of the fixed farm and the anchors for the floating farm might also attract valuable species.

Since the wind farm is placed in deep water, the impact on the coast due to the modest variation of sediment transport patterns induced by wave reduction and change of wave direction will be also very limited.

8.7 Financial, economic and social assessment*

(*This section is based on work carried out jointly by WPs 8 and 7 and is already part of D8.5).

8.7.1 Financial and Economic assessment

The MUP requires 44 million euros for the establishment of the wind farm and it is expected to produce 1 million euros per year for 20GWh per year for the energy extraction. However, no more information is available. Hence, it was not possible to run the social cost benefit analysis for this function.

On the other hand capital expenditure for the establishment of the fish farm, over the 22 year period is estimated to be 3.7 million euros, of which 3.5 M € is required over the first 7 years, where the fish farm reaches its optimum operational capacity. At year 7 revenues from the sales of the fish produced are expected at 14.7 M€ (at an operating expenditure of 12.5 M €). Given the current market status (prices, days payable/receivable etc.) the total fish farming investment is estimated at 18.8 M € and is expected to break even at year 13. At year 22, revenues from sales reach 19.9 M €, yielding an EBITDA of 4.1 M€ and EAT of 3.3 M €. The Net Present Value (NPV) of the fish farm investment is estimated at 7.2M € (over the 22 year period, at a discount rate of 6 %). Data for fish production (production rates, production costs etc.) is produced by a production model developed in Kefalonia Fisheries (Table 8-3). Other assumptions used for calculating prices and revenues (discount rates etc.) are based on mean values that are currently true for the market.

Cost of Juveniles	This cost category varies depending on the size of the juveniles at the time they are transferred to the sea and whether it is fish fry grown on the fish farm's hatchery or purchased fry from a supplier
Cost of feed	This cost category is the most important in fish farming of the specific species (carnivorous species and feeds must contain substantial amounts of fish meal and fish oil)
Cost of labour (Depending on the size of the fish farm, number of staff changes. Staff is occupied with daily operations & maintenance work)	• Production manager • Workers/Feeders • Divers • Captain/seamen
Energy cost (energy consumption related to the cage farm operations)	• Fuel for the vessels (transportation of feeds from the onshore silo to the cages, use of the vessel for feeding and inspection of cage condition etc.) • Energy required for the operation of air compressors used for supplying automatic feeders with feed • Energy required for the operation of air compressors used for filling divers' oxygen tanks • Operation of the crane (for harvesting and changing the nets) • Lighting • Other energy needs (plugs for electrical devices)
Other consumables	• Medicines- any kind of necessity for medical treatment of fish stock (either precautionary vaccinations or treatment of a disease outbreak) • Nets
Insurance-Rent-Maintenance	• Insurance • Rent • Maintenance costs- for equipment, cages, nets, vessels,

	structures
3rd party fees and Services	• Veterinary, legal and other fees • Maintenance etc. services in case of repairs which cannot be performed by staff
Administrative Expenses	• Unit manager • Secretary • Rent • Other expenses- travel, electricity, water, telephone
Sales Expenses	• Sales costs- cost of operation of the sales' department • Transport & repackaging- cost of transport of the goods to the client and intermediate repackaging
Packaging	• Packaging consumables- polystyrene boxes, plastic sheets, stretch film, straps, labels etc. • Labour-packaging unit staff • Energy-room cooling, sorting machine, ice machine, scales, computers etc. • Other consumables

Table 8-3 Cost categories of an on-growing site - Source: KEFALONIA Fisheries.

Social Cost Benefit Analysis

The Social Cost Benefit Analysis (SCBA) assesses the monetary social costs and benefits of an investment project over a time period in comparison to a well-defined baseline (reference) alternative.

For the Mediterranean site the financial costs and revenues, together with the costs derived by the CO_2 emissions produced due to fishing operation were included in the SCBA. Benefits derived from the reduction of CO_2 emissions were not included in the SCBA, since due to lack of information only the single-use scenario was examined. The estimated time horizon in the SCBA was 22 years. Triangular distribution was used in fish investment and fish revenue. In the absence of any information regarding the stochastic factors affecting wind investment, the triangular distribution was considered as a reasonable assumption, with central value the given investment cost and boundaries at ± 15% of the central value.

Normal distribution was used in: fish labour, raw material, other, maintenance, operating costs and energy output.

Risk analysis results are presented in deliverable 8.6.

The estimates of mean positive Net Present Value (NPV) and its standard deviation suggest that the fish production scenario passes the CBA test both in terms of NPV (positive NPV) and Internal Rate of Return (IRR greater than the discount rate) under all alternative assumptions regarding the discount rate and costs related to the production of CO_2 emissions.

Discussions

There are no detailed data on financial costs and returns or on environmental, social and economic impacts for each single activity or all activities combined as suggested by the final design for the Mediterranean case study.

However, all preliminary, although tentative, analyses lead to the same conclusion. In the short term, going offshore is not sustainable. In the long-run, coastal and marine spaces might become more limited, and then going offshore will become more important to avoid unplanned and crowded uses in the future. More explicitly, for the case of aquaculture, going offshore provides better health of farmed fish, since it is supposed to provide better water quality to the farmed fish, lessen the possibility of infectious agents being transferred to them and provide a water current regime that will promote better renewal of water and waste dispersal.

Indeed, in the Mediterranean case study, the internal rate of return for *all activities combined* is likely to be negative, if based on financial analysis, and it is likely to be positive but very small, if based on economic analysis, where social and environmental impacts are taken into account. However, from a future public point of view, where future benefits are considered, it may be wise to move offshore some fish and energy activities.

This decision is likely to be opposed by current stakeholders for two main reasons: a) they might be expected to bear costs today for benefits arising (for others) tomorrow: think of larger fuel costs to reach an activity offshore or the larger risk to implement an activity offshore; b) they might not perceive the obtained benefits today: think of the reduced environmental impacts.

A subsidisation of offshore activities could solve the first concern (i.e. current private costs are turned into current public costs), whereas information campaign on environmental benefits could solve the second concern (i.e. current private benefits are highlighted). In other words, while private decision-makers are unlikely to perceive future benefits from moving offshore, by emphasising current costs only, public decision makers could impose an inter-generational distribution of costs and benefits, provided that the estimated future benefits are large enough.

8.8 Conclusion

The area off-shore Venice is characterized by a relatively mild climate that allows in principle a safe installation of an off-shore platform but at the same time strongly limits the benefits of a single–purpose installation, both because of the limited available energy and because of the high distance from the shore due to the flat sea-bottom.

Therefore the site is particularly suited for a multi-purpose design, which based on this preliminary analysis of constraints and feasibility will consider extraction of power from wind and fish farming, with a direct transfer to shore.

8.9 References

Airoldi L, Abbiati M, Beck MW, Hawkins SJ, Jonsson PR, Martin D, Moschella PS, Sundelöf A, Thompson RC, Åberg P (2005) An ecological perspective on the deployment and design of low-crested and other hard coastal defence structures. Coastal Engineering 52:1073-1087

Inger R, Attrill MJ, Bearhop S, Broderick AC, Grecian WJ, Hodgson DJ, Mills C, Sheehan E, Votier SC, Witt MJ, Godley BJ (2009) Marine renewable energy: potential benefits to biodiversity? An urgent call for research. J Appl Ecol 46:1145-1153

Martins GM, Thompson RC, Neto AI, Hawkins SJ, Jenkins SR (2010) Enhancing stocks of the exploited limpet Patella candei d'Orbigny via modifications in coastal engineering. Biol Cons 143:203-211

MERMAID, 2013. Site specific conditions. Deliverable 7.1. Zanuttigh B., Schouten J., Guanche R., Petersen O. editors, http://www.mermaidproject.eu/sharepoint/func-startdown/362/

MERMAID, 2015. Socio-economic Analysis of the Mediterranean. Deliverable 8.5. Koundouri P., Xepapadeas T., Giannouli A., Mailli E., Gonzalez Davila O., Levantis E., Kourogenis N., Zanuttigh B., Zagonari F., Airoldi L., Giannakis E., D. Troianos, Y. Krontira, A. Frentzos, N. Elginoz, B. Baş Stichting, C. Röckmann , M. Stuiver, S. van den Burg

Zanuttigh B., Angelelli E., Bellotti G., Romano A., Krontira Y., Troianos D., Suffredini R., Franceschi G., Cantù M., Airoldi L., Zagonari F., Taramelli A., Filipponi F., Jimenez C., Evriviadou M and Broszeit S., "Boosting Blue Growth in a Mild Sea: Analysis of the Synergies Produced by a Multi-Purpose Offshore Installation in the Northern Adriatic, Italy" *Sustainability* 2015, *7*, 6804-6853; doi:10.3390/su7066804, ISSN 2071-1050

Zanuttigh B., Angelelli E., Kortenhaus A., Koca K., Krontira Y. & Koundouri P. "A methodology for multi-criteria design of multi-use offshore platforms for marine renewable energy harvesting" submitted to Renewable Energy 85 (2016) 1271-1289