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MULTI-PURPOSE
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PLATFORMS

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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.

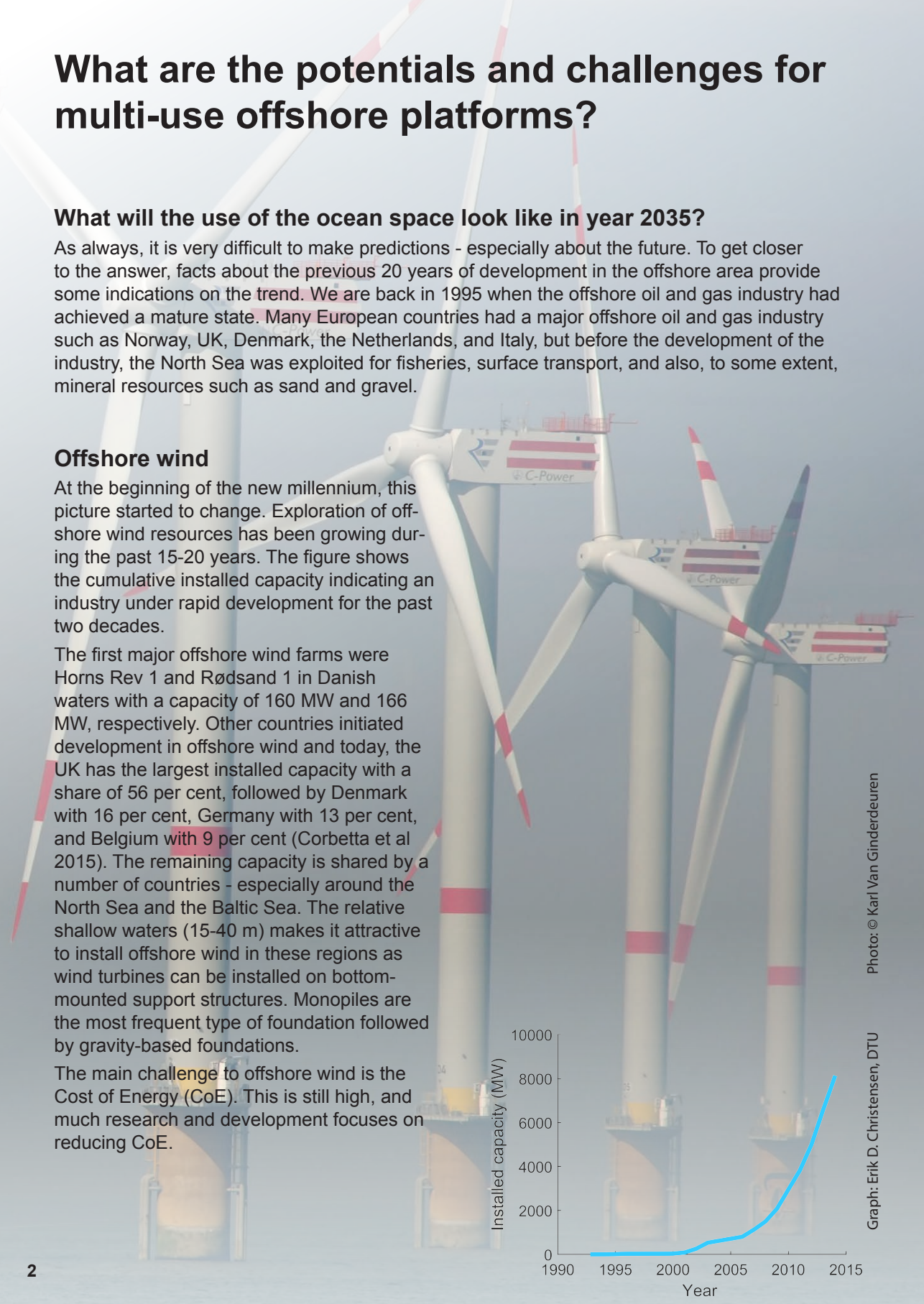


Photo: © Karl Van Ginderdeuren

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.

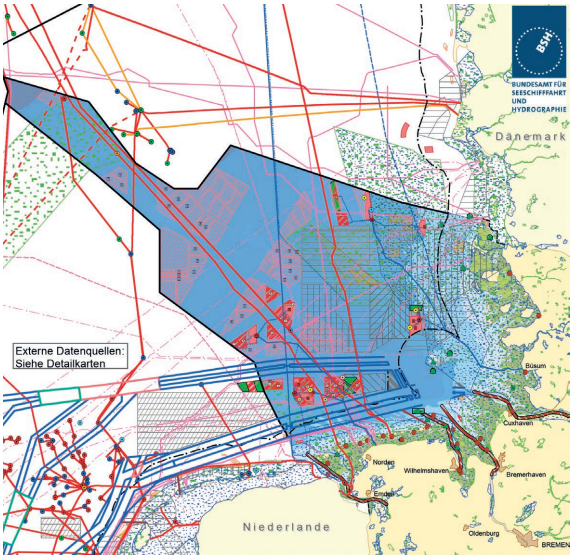
Photo: Casper Guldberg Petersen, Hvalpsund Net

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.

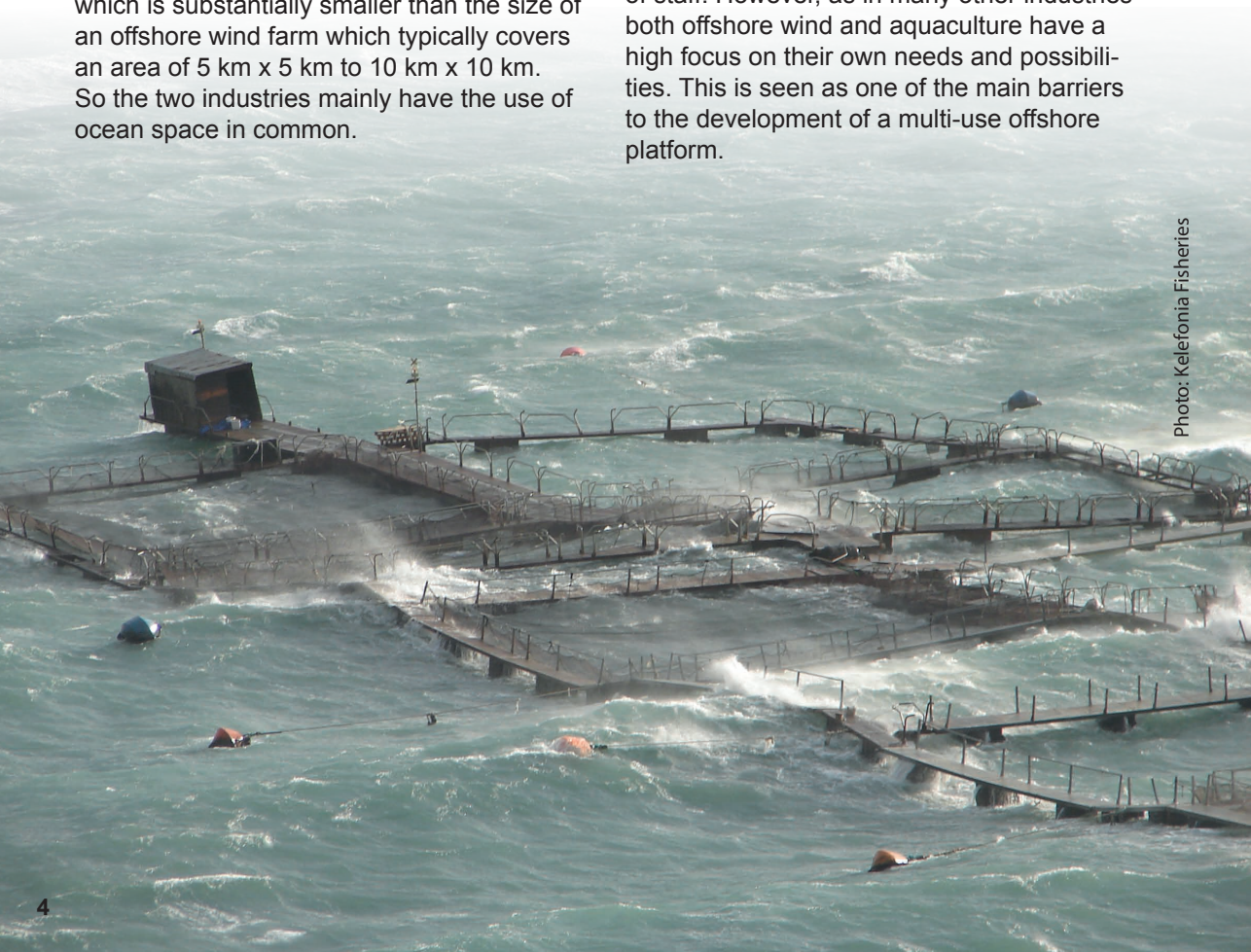


Photo: Kelefonia Fisheries

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

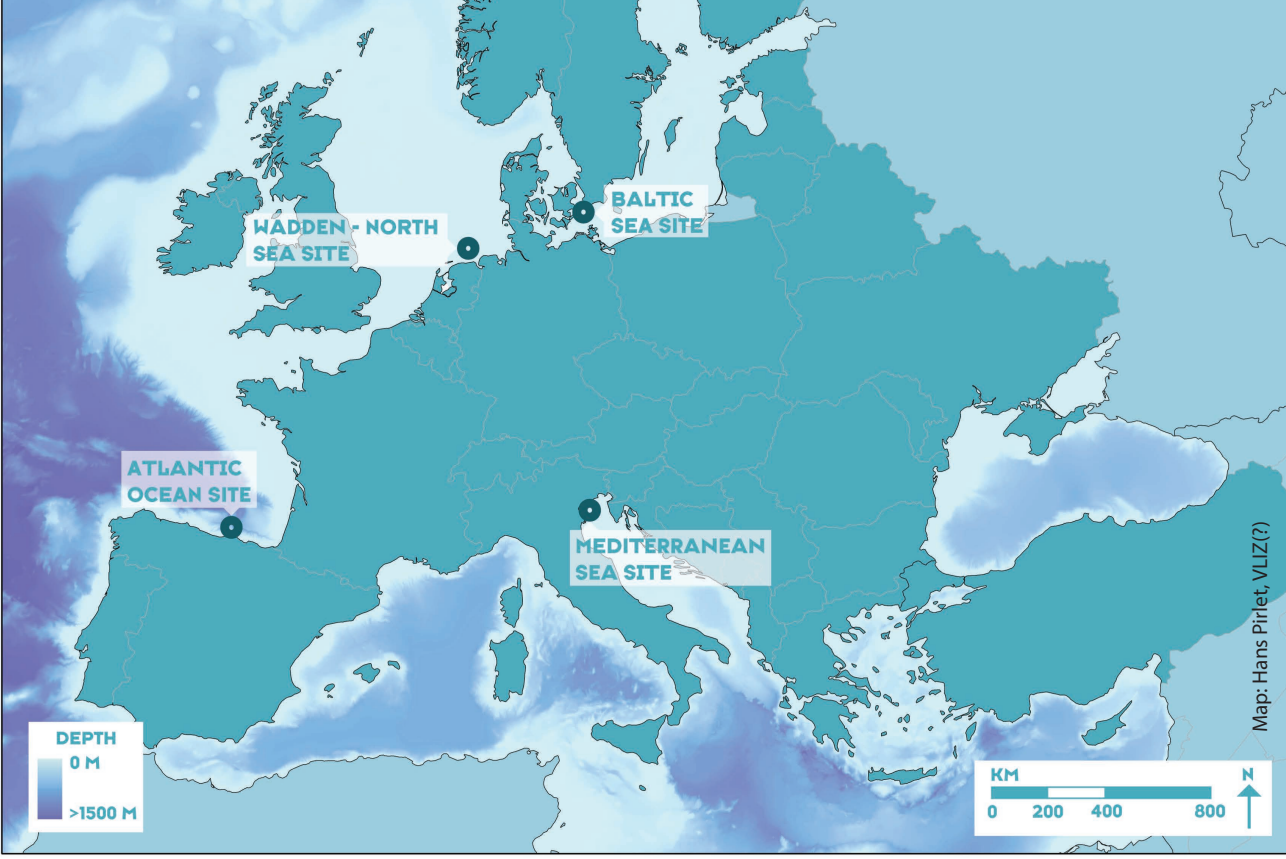
The sites represent specific challenges in relation to environmental, social, and economic conditions (as shown in the table) as well as the availability of data and the opportunity to link directly to local research teams, stakeholders, policy managers, SMEs, and industrial networks.

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.



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.

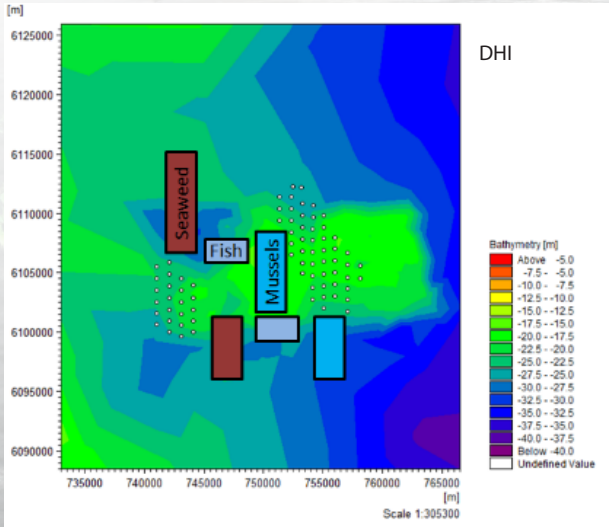
Wind and fish farms

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)

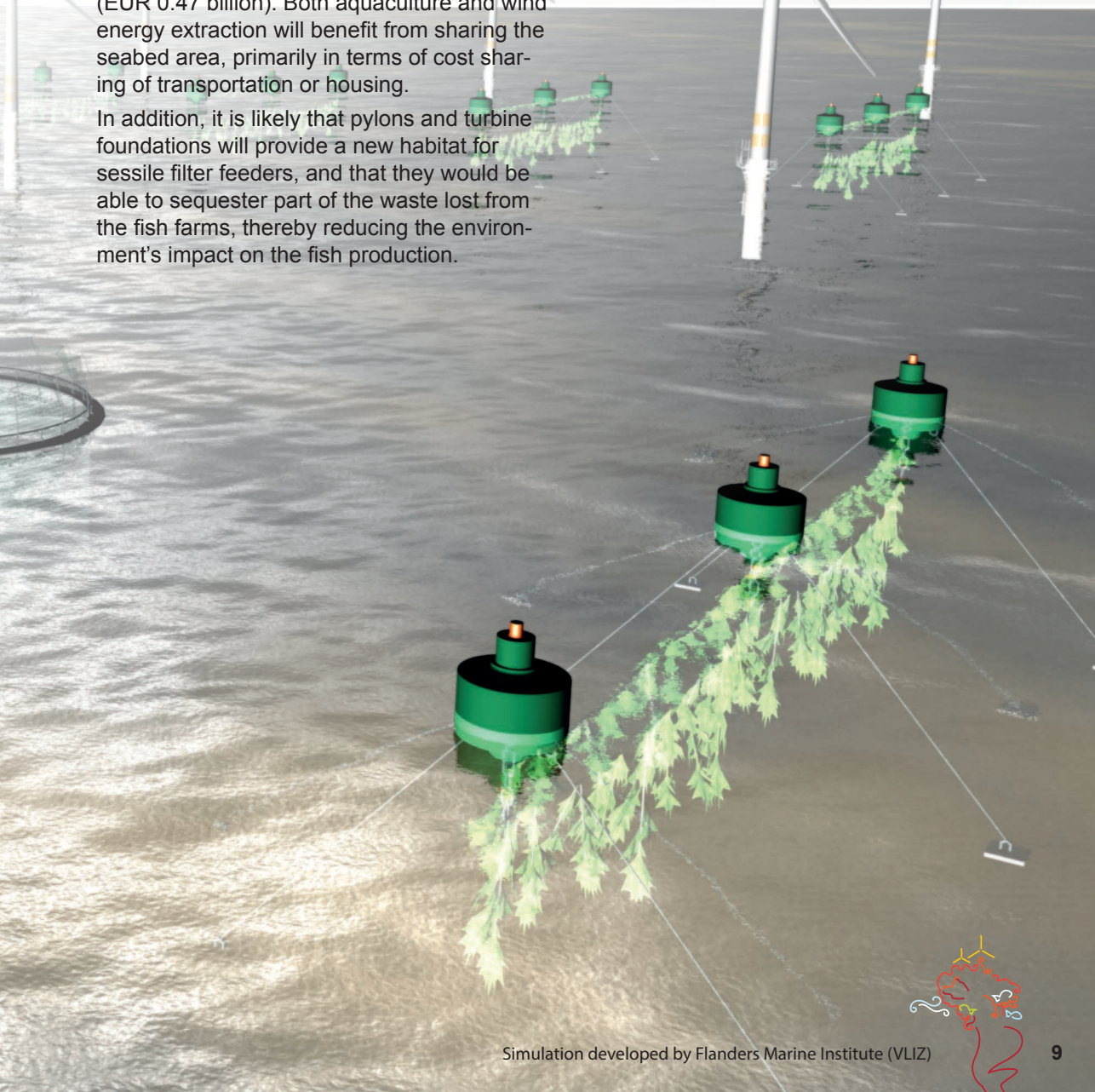
Creating new jobs

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.

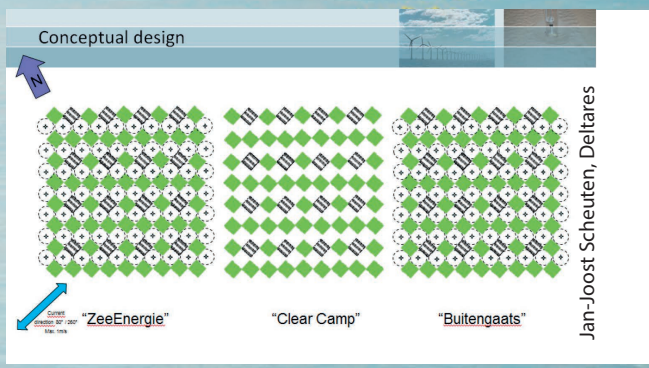
The Gemini project

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.



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.

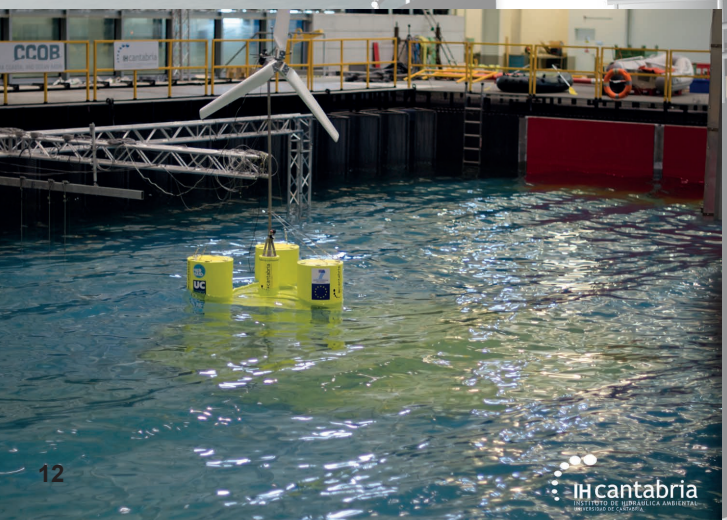
COS is situated 10 km North from the coast of Santander (Cantabria) and it covers to 60 km2 of sea. COS ocean conditions are severe and challenging. The 50 year return period significant wave high and average expected wind speed will be around 9m and 27m/s respectively. A number of 77 units of multi-use 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.

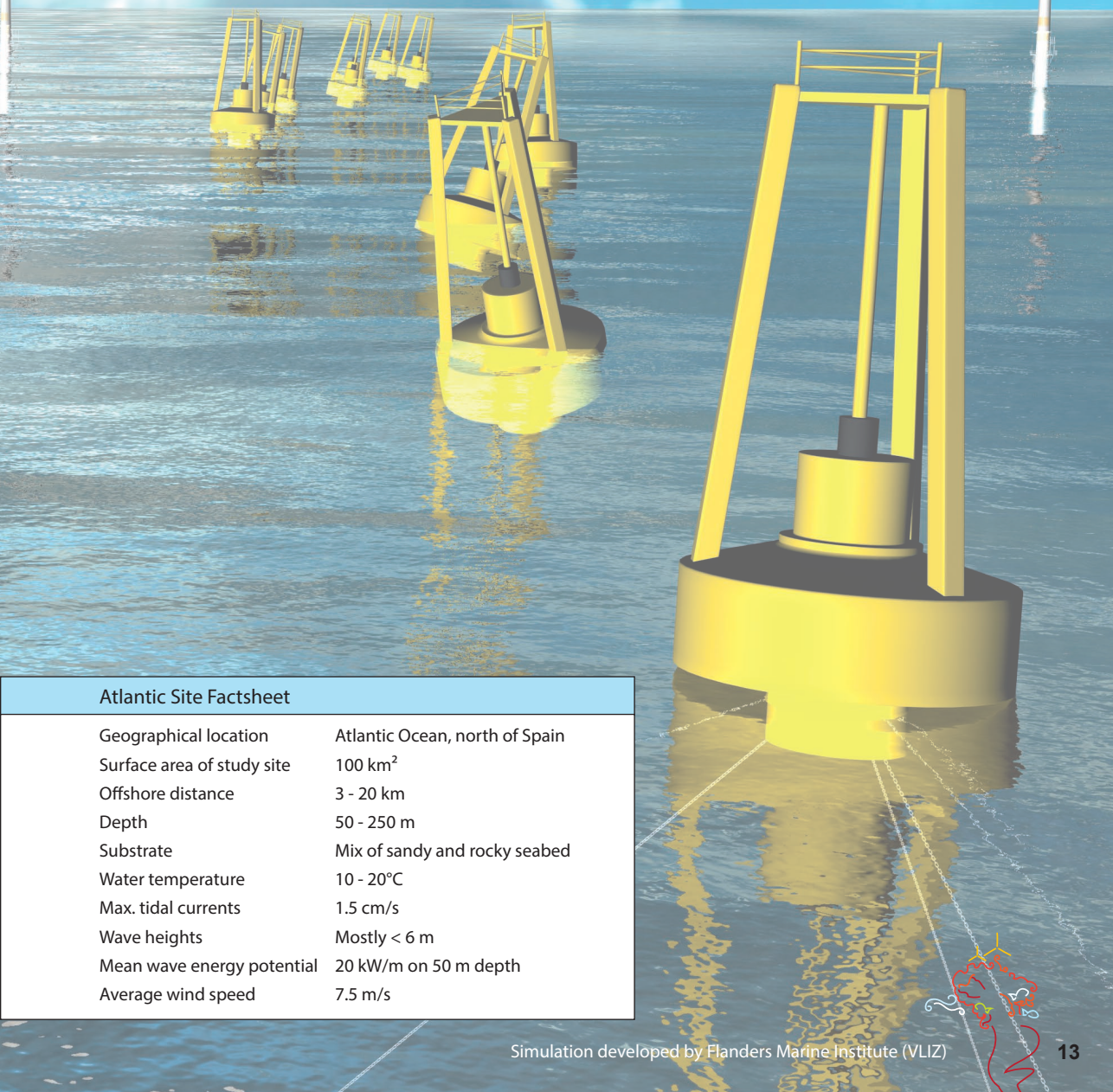
The mooring system will be based on conventional catenary mooring lines in order to reduce technical risks and lower costs.



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.



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

Simulation developed by Flanders Marine Institute (VLIZ)

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

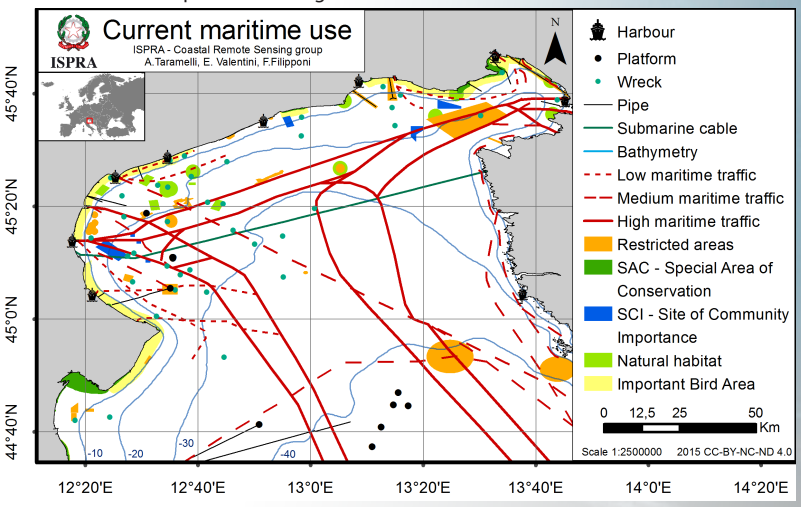
The fish farm is designed to support annual production capacity of 2,000 tons, equally divided between the sea bream and sea bass species. The fish farm is made of 56 sea cages of 32 m in diameter. To assure good fish health, the bottom depth at the installation is 25 m, i.e. around 3 times the depth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

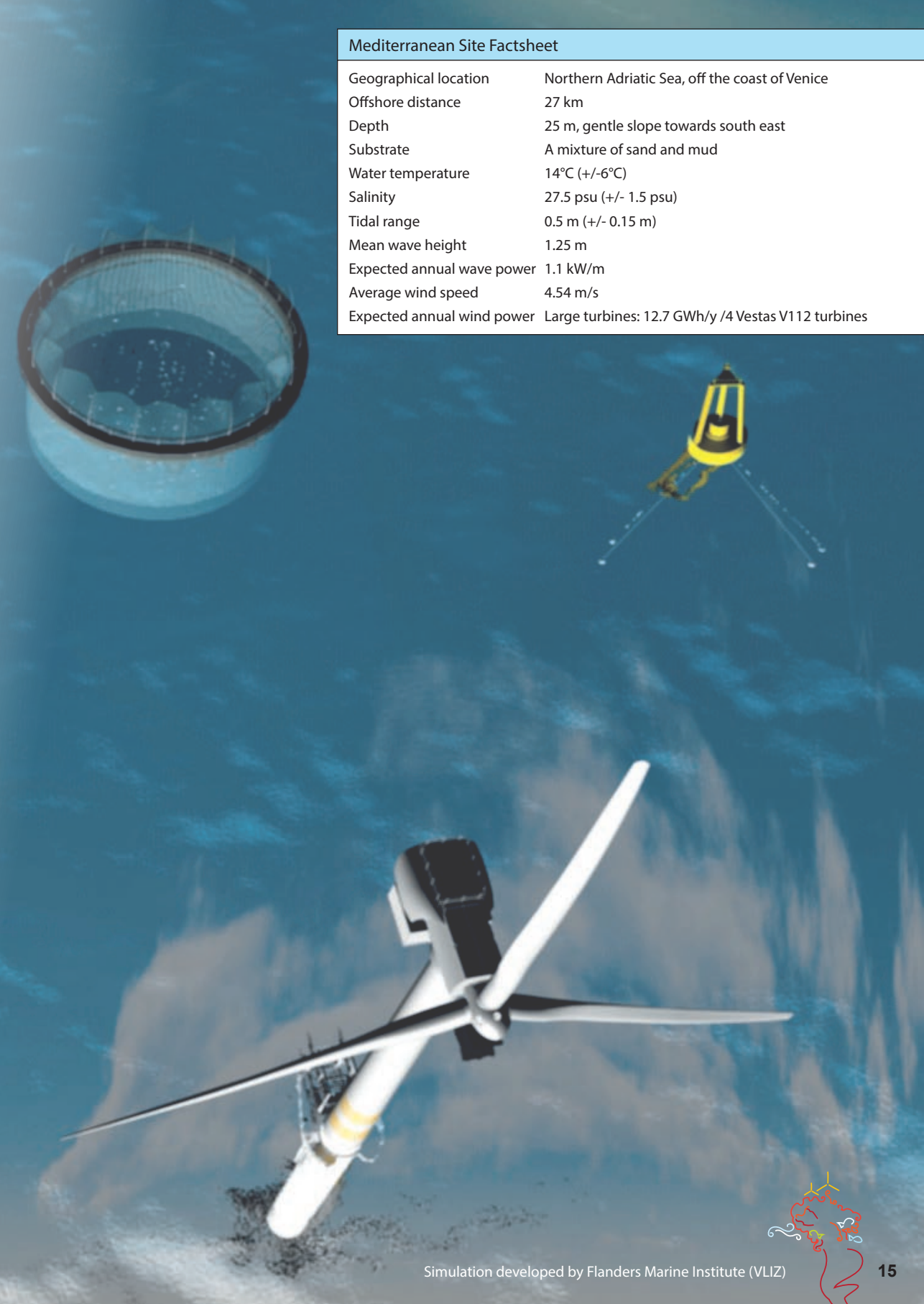
One of the main challenges of this MUOP is connection to the grid, due to the costs induced by the long distance to shore (27 km from the closest harbour) and the environmental impacts of the cables on the soft bottom.

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:

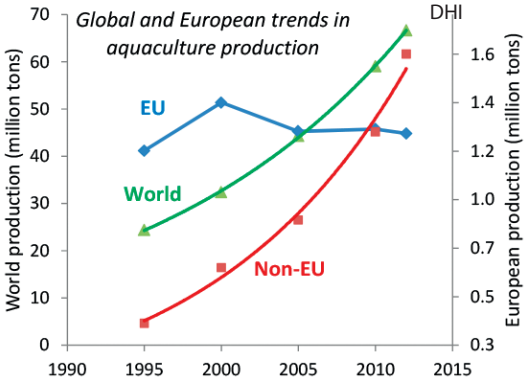
- the national level of power grid development (is the grid ready for receiving local and variable inputs?),
- the national technical skills of the managers (who need interdisciplinary skills, besides technical ones, to understand the projects before approval),
- the sensitivity of the population to 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

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.

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.

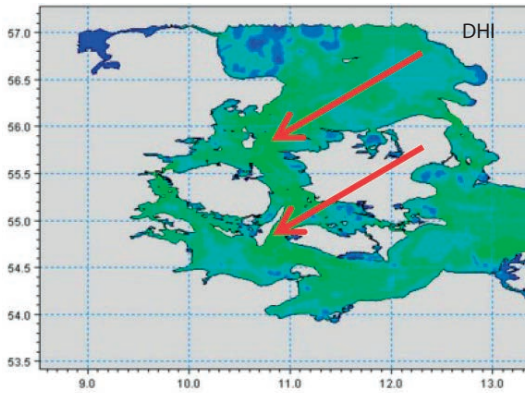
Mussel farms placed near fish farms have been suggested as a means to sequester part of the particulate waste lost from fish farms. However, only a few percentages of the waste are available to mussels because the bulk consists of large particles outside the size range for ingestion, and the residence 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.

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.

Photo: Hortimare.

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

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 debureaucratized 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.

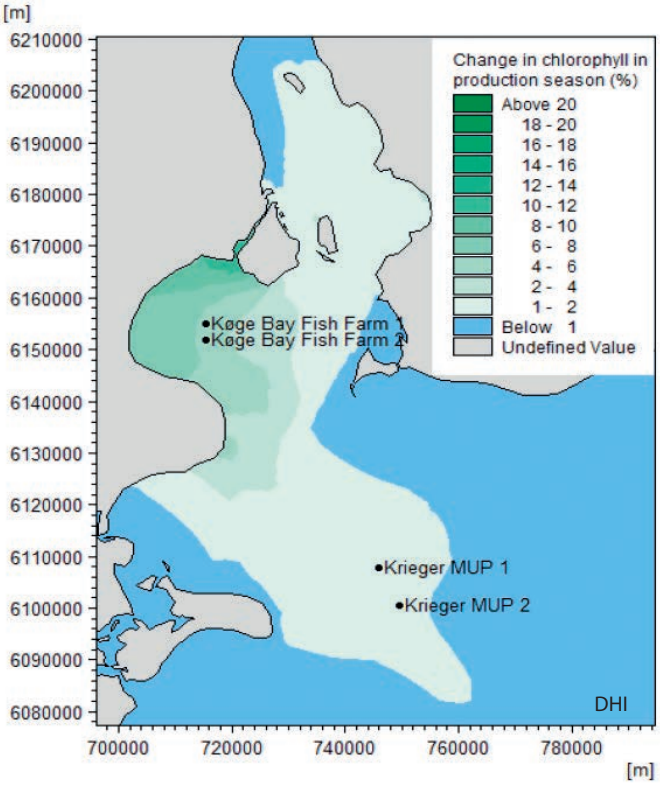
Example: EIA for fish farming

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 bio-geochemical 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.

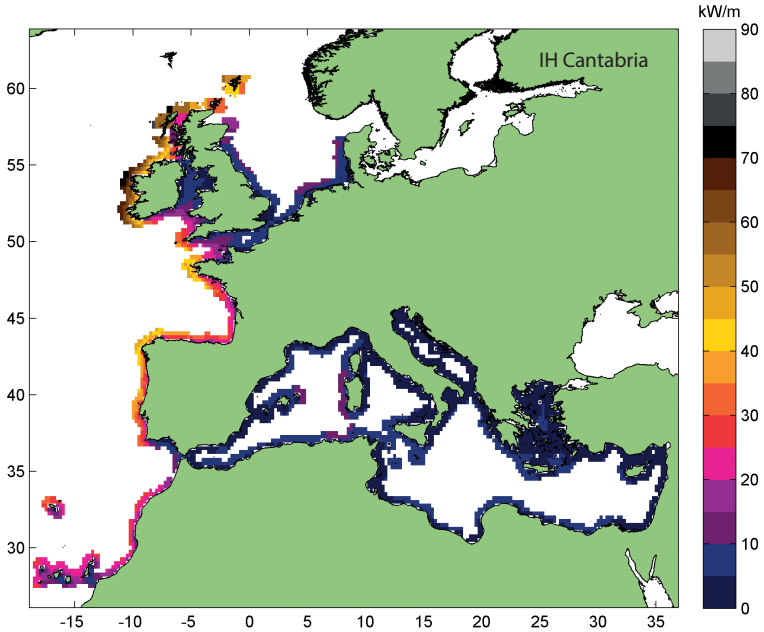
Offshore wind energy is currently growing dramatically worldwide, motivated by its many benefits:

- 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".

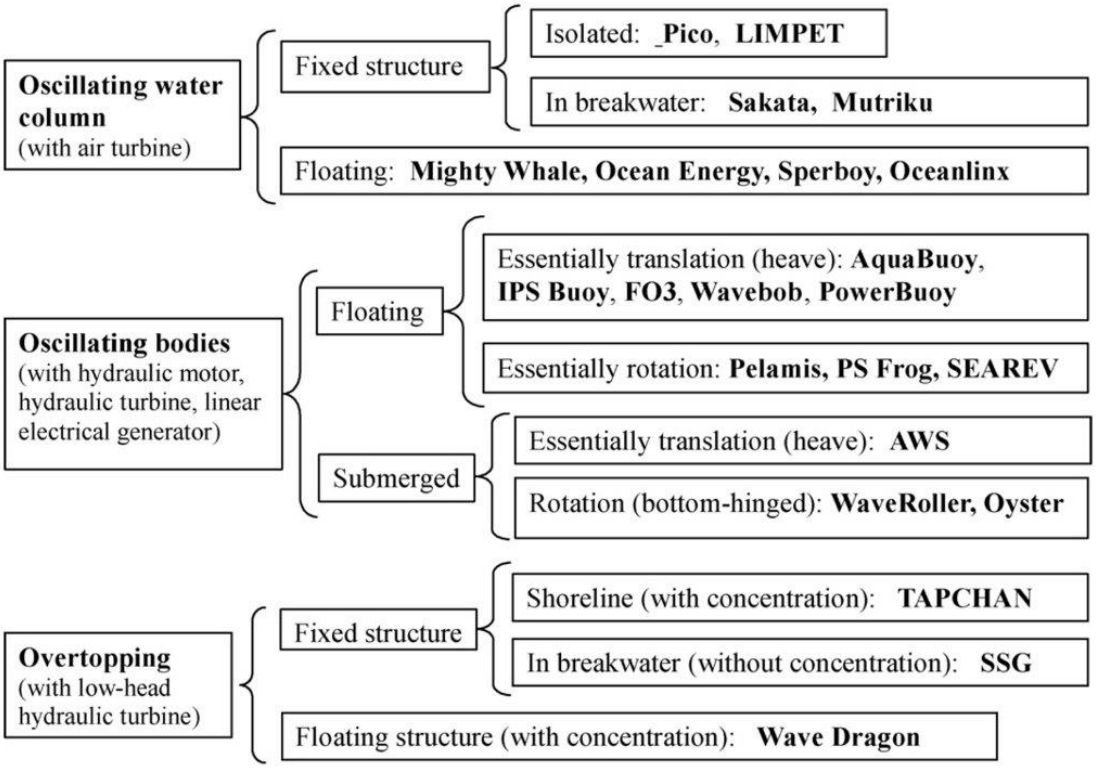
Then, it is clearly stated that in order to absorb the wave in an optimum way, the device has to oscillate with a certain amplitude and phase.

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)

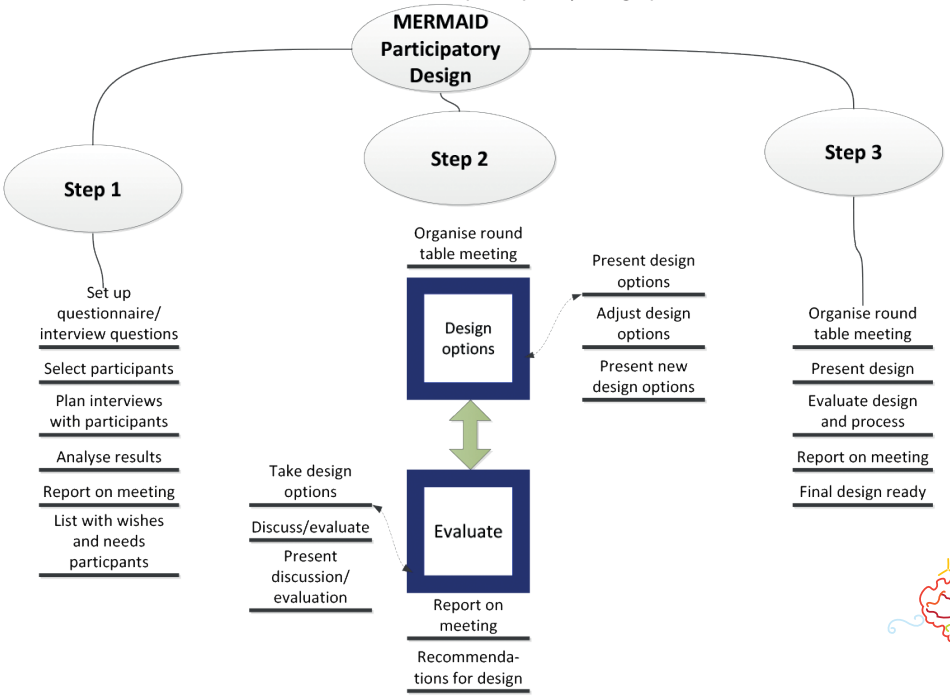
STEP 3
Evaluate the design by organizing interviews and a session with all MERMAID stakeholders (result D2.4)

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.

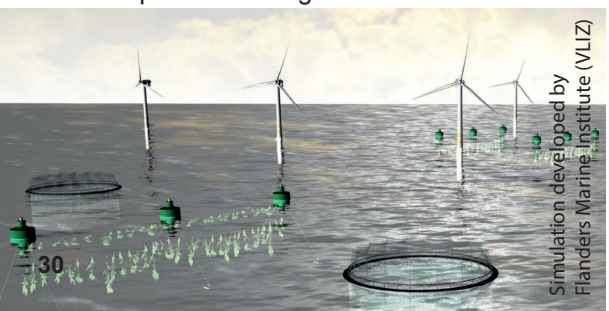
Step 3 comprised interviews and an internal consultation where the final design concept was evaluated with the participating stakeholders. This ultimately led to a design concept which was thoroughly analysed, technically feasible, and preferably supported by all the stakeholders represented at the round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

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 suboptimal 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?

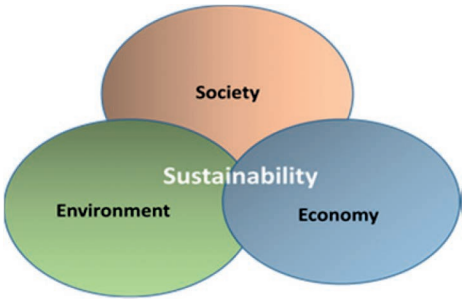
An interdisciplinary framework for assessing the socio-economic impact of MUOPs

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.

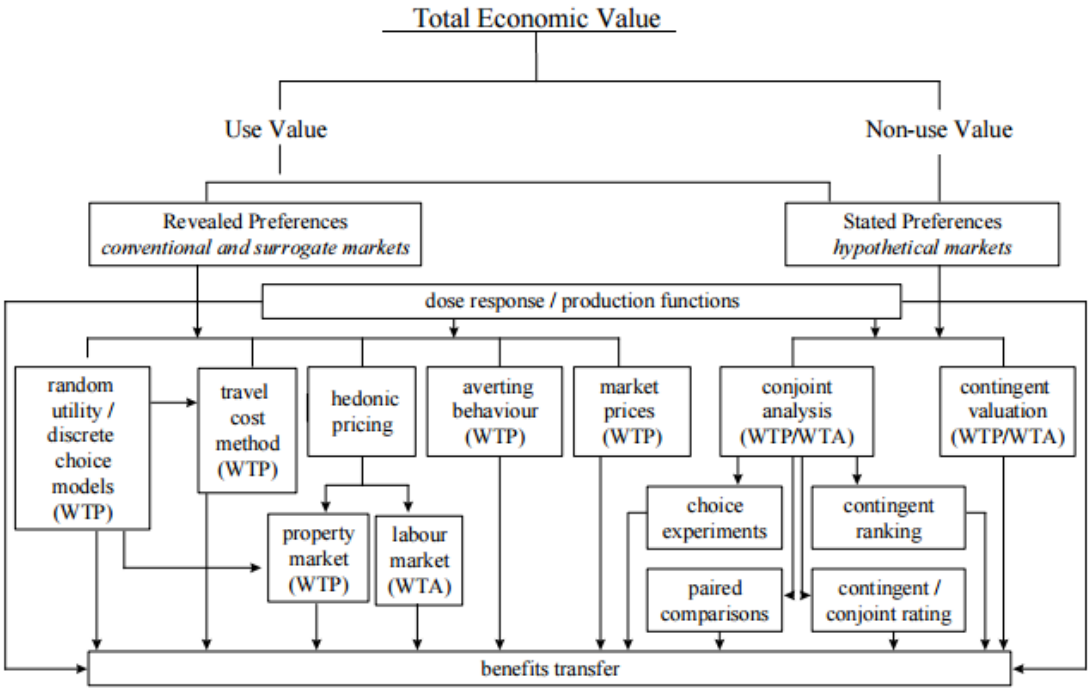
Accordingly, implementing an MUOP would affect the environment and the ecosystem services. Ecosystem services are defined as services provided by the natural environment that benefit people (Defra 2007). Individuals place values on the environmental resources and their ecosystem services for given changes 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
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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

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Deliverables

D9.1 Inception report with a exploitation plan

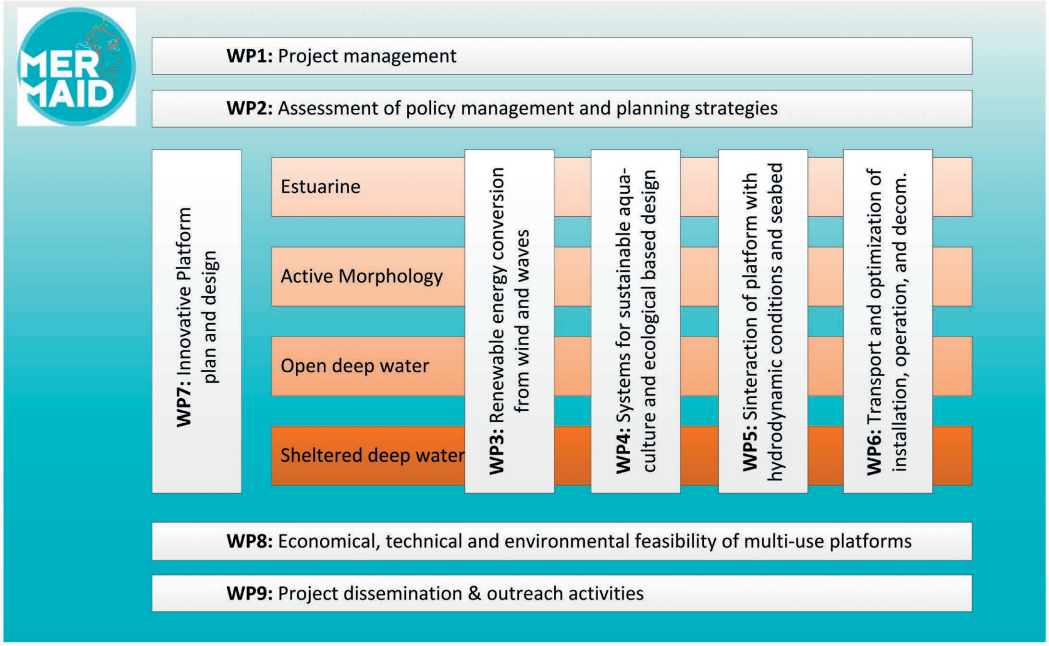
D9.2 DVD – Films on youtube

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

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Endnote

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

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