MERMAID

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Socio-economic Analysis of the North Sea Site

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1 Introduction and scope of the deliverable

1.1 Goals and objectives of the deliverable

MERMAID aims at integrating and improving today's technology in an optimal way in order to enhance economic feasibility, reduce environmental impact and to increase the use of ocean space at specific sites, by means of Multi-Use Offshore Platforms (MUOPs). In MERMAID, business opportunities associated with MUOPs are investigated in four different locations in Europe through a financial assessment. In addition, MERMAID aims at identifying the impact on human welfare of MUOPs through a framework for socio-economic assessment. This framework takes into account the fact that human welfare is dependent on a wide range of social and economic aspects, including ecosystem services.

The overarching aim of this deliverable is to assess the sustainable development of the final conceptual designs of MUOPs. Sustainable development is described by a three-dimensional sustainability condition. In particular, in the framework of analysis, sustainable development is achieved when the following conditions are simultaneously satisfied:

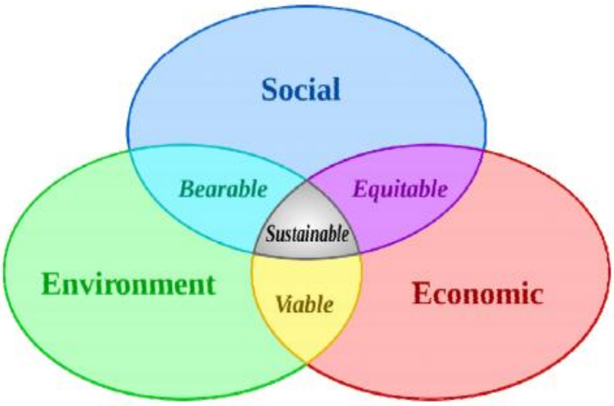

Figure 1 Spheres of Sustainable Development (W.C.O.E.A.D./Brundtland Commission, (1987); UN (2015)

a. Dynamic and Spatial Economic Efficiency and Sustainability: Economic efficiency satisfies the condition that the marginal (social) cost of each production activity under consideration equals the respective marginal (social) benefit. Hence, in this framework both private and social components of costs and benefits are considered in order to provide an integrated economic assessment in terms of efficiency. When the economic efficiency condition is satisfied over time (inter-generationally) and over space (intra-generationally) the economic sustainability of the considered production activities is achieved.

b. Dynamic and Spatial Social Equity and Sustainability: Social equity requires that the social effects of the production activities under consideration are bearable and equitable by the different social groups identified in the region under investigation. These affordability and acceptability conditions should be relevant spatially (intra-generational effects) but also dynamically (inter-generational effects).

c. Dynamic and Spatial Environmental and Ecological Sustainability: Environmental and Ecological Sustainability means that the environmental and ecological effects of the activities under consideration are sustainable over space (in the region under consideration) but also over time.

In this deliverable, we examine the possibility of sustainable development of the developed conceptual MUOP design, by socio-economically assess the envisioned MUOP to be placed in the Netherlands Exclusive Economic Zone of the **North Sea.**

The North Sea is characterized by relatively shallow waters and excellent wind conditions that are ideal conditions for offshore wind developments. Therefore, the largest installed capacity of offshore wind in the world is 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 Dutch 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.

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

In contrast, 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- and tidal 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. More detailed information about the decisions of the MUOP design can be found in the rest of MERMAID Deliverables (e.g. MERMAID D7.2, MERMAID D7.3).

Table 1 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^{o}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

1.2 Relationship to overall project objectives

This deliverable presents the results of the application of the Methodology for Integrated Socio-Economic Assessment (MISEA) which was developed in MERMAID (MERMAID D8.1) to socio-economically assess the different proposed designs of novel Multi-Use Offshore Platforms (MUOPs). MISEA assists on identifying, not only the potential range of impacts of a proposed investment such as the construction of MUOPs, but also the likely responses of those impacted by the investment project. Since it is anticipated that these novel designs of platforms will have considerable socioeconomic and environmental impacts, MISEA provides an analytical framework that lies in agreement with the sustainability conditions. MISEA assists on designing appropriate mitigation strategies to minimize negative and maximize positive socio-economic and environmental impacts. In this context, this methodology extends the standard process of financial analysis into an assessment that incorporates socio-economic, legal, technological environmental parameters.

In particular, the methodology allows a stepwise approach of integrating information produced in the previous work packages (WPs) of the project towards the socio-economic assessment of different designs (being built by the engineers of MERMAID in previous WPs) of MUOPs. The multi-disciplinary information, allows a direct comparison between different MUOP designs, including comparison between multi-use and single-use alternatives. Under MERMAID, the information produced by the different WPs was used for the socio-economic assessment in each selected site and platform design.

- Legal and policy analysis provided the policy and legal background required for the development of the particular platform designs. Stakeholders' analysis and more specifically the stakeholders' roundtables provided inputs to for the final design and the socio-economic assessment of the selected MUOPs with regards to social acceptance and potential conflicts between stakeholders (MERMAID D2.1, MERMAID D2.4 and MERMAID Repository[1]: Regional Profiling Datasets).

- The identification of innovative platform designs formed the background required for the collection of the financial data, as well as the socio-economic analysis and monetization of environmental externalities. (MERMAID D7.1, MERMAID D7.2, MERMAID D7.3, and MERMAID Repository[2]: Regional Profiling Datasets).

- The case-study specific environmental assessments (MERMAID Repository[3]: Regional Profiling Datasets) identified the environmental effects in relation to the suggested designs. MUOPs are related to a stream of new social/environmental goods and services (e.g., increase of employment, increase food and energy security, potential interactions with marine environment etc.) with no values readily observed in existing markets. Hence, it was required to follow non-market economic valuation methods to estimate these values (Economic Valuation Methods are explained in D8.1). Although the information was limited and based on experts' opinions and stakeholder's views, the economic values of the main environmental externalities were estimated successfully.

- The case-study specific financial feasibility assessment was crucial for the comparison between different offshore platforms. The data used in the financial assessment were the investment costs with regards to equipment, construction, labor and other costs, as well as operation data for the costs and revenues according to different functions used in the final design of each study site (e.g. energy/aquaculture production output, price, raw materials, energy used, maintenance costs, operating costs).

This methodology provided useful information on which economic activities should be implemented on the different sites, with the scope to avoid developments that would have negative socio-economic and environmental consequences, considering legal and technical aspects. This load of information assists on identifying challenges and opportunities towards the implementation of suggested MUOPs. A representation of the connections between the WPs' outputs used as inputs is given below.

[1] http://mermaid.madgik.di.uoa.gr/
[2] http://mermaid.madgik.di.uoa.gr/
[3] http://mermaid.madgik.di.uoa.gr/

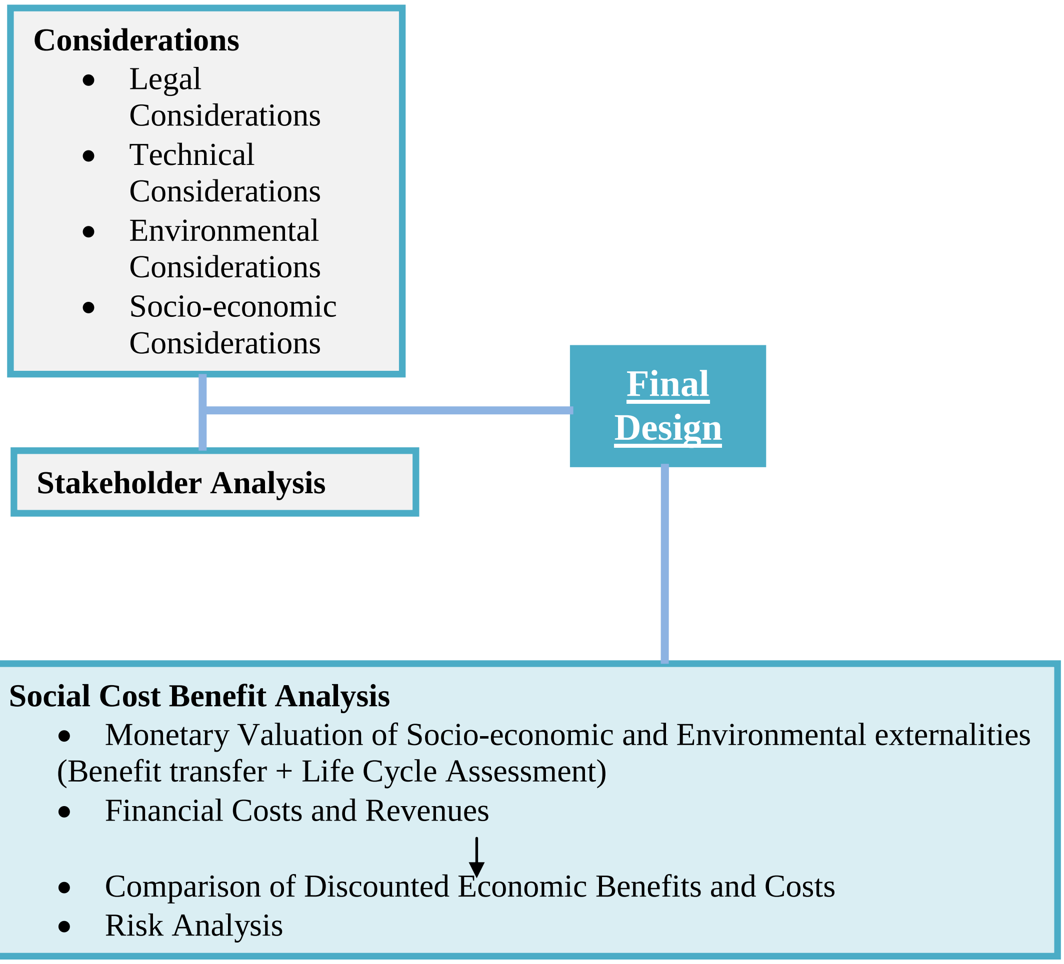

Figure 2 MERMAID Stepwise approach of integrating information

1.3 Outline for the reader

The document is divided into **6** different sections. **Section 2** describes the general methodology framework of the conducted assessment and introduces the online assessment tool as the application of this methodology. **Section 3** includes a regional description of the North Sea site. **Section 4** describes the economic valuation of environmental changes. **Section 5** includes the financial assessment for the North Sea site. **Section 6** includes the undertaken social cost benefit analysis and **Section 7** offers concluding remarks and recommendations.

2 General framework of the methodology and introduction to the Assessment Tool

2.1 The methodology for Socio-economic Assessment of MUOPs

In this section the Methodology for Integrated Socio-economic Assessment (MISEA) is described in detail. 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 aims to investigate the possible sustainable development of MUOP investments, by focusing on marine sustainable management, extending the standard process of financial analysis into an interdisciplinary assessment that incorporates socio-economic, technological, legal and environmental parameters, parameters, aiming at an estimation of the total impact on economic welfare in society.

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 capture the total economic value of a project we need to consider the 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 the stakeholders’ views (MERMAID D2.4), MUOPs will create new employment opportunities and will have strong economic impact in the community. Enterprises will benefit by the development of new technologies and 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. Based on the MERMAID EIA manual, experts opinions of the MERMAID project and Life Cycle Assessment (LCA), environmental effects were identified. These were linked to human welfare and their value was elicited using economic theory.

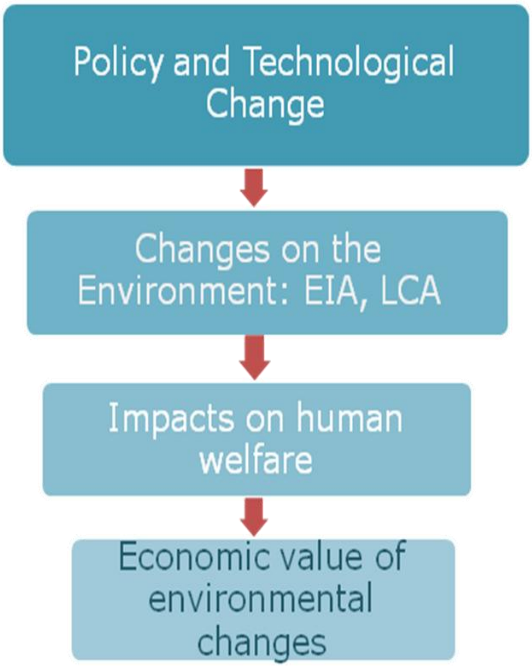

Figure 3 Overview of the impact pathway of policy and technological change

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). Natural resources and their ecosystem services are generally not traded in markets. As a result no market price is available to reflect the economic value of environmental changes. Hence, expressing these impacts in monetary terms using non-market methods is required (see Freeman et al., 2014). We present at the next figure the TEV framework and the economic techniques used in economic valuation of benefits derived from the ecosystem services (see D8.1 for more details).

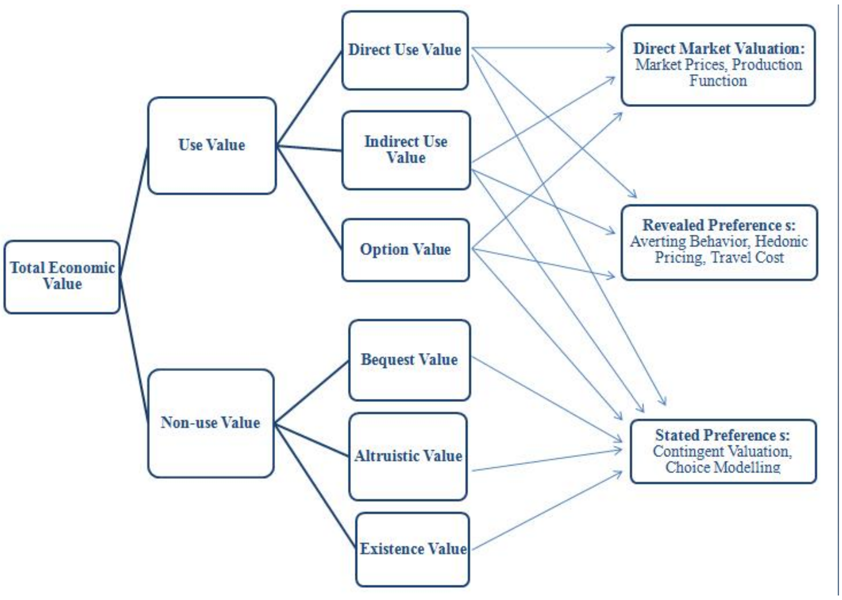

Figure 4 Techniques for monetary valuation of non-market services (Koundouri and Giannouli, 2015)

Primary valuation can be done either using stated preferences or revealed preferences techniques. However, in MERMAID, the benefit transfer method was applied for the socio-economic assessment, i.e. monetary estimates of the non-market value of impacts of MERMAID study sites were derived from earlier studies (Johnston et al., 2015). In addition, based on the Life Cycle Assessment (LCA), we compared each platform's CO_2 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, the financial costs and revenues from energy extraction and aquaculture production were included into the analysis.

More explicitly, MISEA consists of the following steps:

- **Scoping Phase** Defining boundaries, key impacts, key stakeholders, information availability

Socio-economic characterization of the existing situation in the site with regards to wind power production, aquaculture and transport maritime services: The collection of required data for the socio-economic characterization was performed during the implementation of the regional baseline characterization questionnaire (MERMAID Repository[4]: Regional Profiling Datasets). See section 3.

- **STEP 1** Socio-economic characterization per case study: Wind power, wave power and aquaculture production

Production-Side Analysis of Multi-use Space: This analysis is based on estimated financial costs of offshore structures, and also on the costs of environmental and ecological changes due to the proposed multi-use structure, as identified by the environmental impact assessment.

Demand-Side Analysis of Multi-use Space: This analysis depends on the evaluation of socio-economic consumption benefits related to the proposed structures and also on the benefits of environmental and ecological changes due to the proposed multi-use structure, as identified by the environmental impact assessment/environmental analysis.

- **STEP 2** Translated Externalities into financial flows: Benefit transfer and Life Cycle Assessment (LCA)

Costs and benefits produced by environmental change related to wind power, wave power and aquaculture production were estimated using benefit transfer methods (transferring monetary values from earlier studies to the policy site) and relying on the Life Cycle Assessment with regards to CO_2 emissions quantity change. (See section 4)

- **STEP 3** Recommendations based on economic tools: Social Cost-Benefit Analysis (SCBA)

The last step for assessing viability is the use of Cost Benefit Analysis (i.e. Social Cost Benefit Analysis for MERMAID Project). See section 6.

[4] http://mermaid.madgik.di.uoa.gr/

It should be noted that, a sensitivity analysis was also performed in order to incorporate the socio-economic uncertainty of the environment under which each MUOP design could be developed and operate (See MERMAID D8.6). Particularly, it is assumed that uncertainty about each parameter value can be captured by a probability distribution that will be used to compute the social costs/benefits. A subsequent step in including uncertainty requires experts to provide their estimates of the most likely value of parameters of interest, together with upper and lower bounds, assessing the likelihood that actual values would lay above or below these upper and lower estimates.

Overall, the methodology is used to evaluate the trade-offs with regard to socio-economic welfare between different proposed multi-use structures. Case-study specific recommendations are offered after employing Social Cost Benefit Analysis. See section 7.

2.2 The Assessment Tool

For the purpose of MERMAID MUOPs' assessment, an online assessment tool was developed (See Annex I). This tool incorporates the information produced during the project, comparing the socio-economic aspects derived from the MUOP to the baseline of each case study under consideration. This tool has the potential to be used for future sustainability analysis of multi-use projects.

The importance of this tool lies on its outputs and its capacity to provide a guideline to support decision-making. The MUOP assessment tool was applied in all four case studies and attempts to help all the stages of the research by indicating the pathway of choosing the most appropriate MUOP design with regards to the different aspects involved (socio-economic characteristics, technological, legal, environmental, financial and economic constraints and considerations). The tool helps to identify costs and benefits emerging from the MUOP specific design and thus provides important information for the Social Cost Benefit Analysis (SCBA). The assessment tool collects and systematizes multidisciplinary information for each case study. The different sections of the tool are the following and they are closely related to the MISEA:

A) Technical and Legal Feasibility Assessment;
B) Environmental Impact Assessment;
C) Monetization of Environmental Externalities;
D) Financial and Economic Assessment;
E) Social Cost Benefit Analysis and Risk Analysis

The sections of the assessment tool related to the North Site are presented in the Annex 1.

A. Technical and Legal Feasibility Assessment

The Technical and Legal Feasibility Assessment (TLFA) section of the assessment tool requires from the users to identify if the MUOP design is feasible by considering legal and technical considerations. Users are also required to take into account financial costs and revenues of the installation and operation of the platform, consider the project's time horizon, any existing possibilities of combined use and finally any other options for technological upgrades.

Simultaneously, a set of risks needs to be identified and taken into account. The set of risks include: technical uncertainty, financial uncertainty, impact diffusion (i.e. correlated risks between functions), political uncertainty and unclear definition of property rights.

The users select the appropriate answer which is then quantified accordingly as input into the tool. The first questions represent 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 displays a message of whether the user may continue with the rest of the process, or, a message could be shown based on the unmet technical or legal constraints, i.e. if the answers to the last questions are negative.

Table 2 Technical and Legal Feasibility Assessment and Significant Risks

A. Technical and Legal Feasibility Assessment (TLFA)	
a.	Approximations to production parameters (Costs: capital, Operation and Maintenance (O&M), administration costs and revenues)
b.	Definition of project's time horizon
c.	Possibilities of combined use
d	Possibility for technological upgrades
e.	Uncertainty about reliability of the techniques used
f.	Uncertainty about estimates of costs and revenues
g.	Impact diffusion (correlated risks between functions)
h.	Political uncertainty
i.	Unclear definition of property rights
j.	Is location feasible? (Take into account legal considerations)
k.	Is location feasible? (Take into account technical considerations)

B. Environmental Impact Assessment

Regarding the Environmental Impact Assessment (EIA), the users are asked to identify all significantly positive and/or negative environmental impacts (at local, regional and global levels). Also, they are asked if there is an EIA available for similar project(s) in the region. The set of risks identified for this section refer to the uncertainty about climate change and other environmental parameters, the possible non-linear environmental effects, as well as the irreversible environmental effects of the operation of the platforms. The table below presents the questions posed to experts and researchers, including the set of risks to be identified. The answers of the users, which should be based on an Environmental Impact Assessment or Environmental Analysis undertaken during the design phase of the MUOP, are quantified for the tool.

Table 3 Environmental Impacts Assessment and Significant Risks

B. Environmental Impacts Assessment (EIA)	
a.	Significant negative environmental impact (local, regional, global)
b.	Significant positive environmental impact (local, regional, global)
c.	EIA available for similar project in the region
d.	Uncertainty about climate change and other environmental parameters
e.	Non linear environmental effects & threshold identification
f.	Irreversible environmental effects
g.	Environmental considerations: is the location feasible?

C. Monetization of Environmental Externalities

The user is asked to choose the location of the MUOP. According to this choice, pre-estimated monetary values of the identified environmental change related to the specific location are incorporated into the final section of the assessment tool (see Section 4).

D. Financial and Economic Assessment

The Financial and Economic Assessment (FEA) section of the tool attempts to extract the estimated financial costs (capital, operations & management, administrative) of the MUOPs. This section also requires the estimation of potential financial revenues as well as the efficiency gains from combined use of the platform.

The user can upload a csv (comma separated value) formatted file, a format that can easily be exported from all common spreadsheet software such as Microsoft Excel. Alternatively, the user can input manually the requested values at the appropriate input boxes. It should be noted that, the user will be asked to include the number of kWh and kg related to yearly energy production and aquaculture production, respectively. By this way, the corresponding change in CO_2 emissions due to MUOP operation is monetized through the social cost of carbon as an input to the SCBA (see Section 4).

E. Social Cost Benefit Analysis and Risk Analysis

This final section of the tool uses the financial and economic data, including monetized externalities, produced by the previous sections and run a Social Cost Benefit Analysis (SCBA) by comparing discounted flows of costs and benefits. The results indicate if the proposed design is socio-economically sustainable or not. The risks that may influence the results of this assessment concerns the uncertainty and missing information in estimation of external effects and in perception formation as well.

The tool 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 minimum and maximum values for each of the variables. The tool performs sensitivity analysis based on these inputs and produced visualizations so that the user is able to 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.

3 The North Sea Site Regional Profiling

The North Sea case-study is located north of the Wadden Sea, 55 km above the Wadden Sea Island called Schiermonnikoog, in an already licensed site to develop offshore wind farm, named Gemini. At this location, an offshore wind energy farm is being built and it is planned to be fully operational by 2017 onwards with a total capacity of 600 MW (www.geminiwindpark.nl). A yearly production of 2600 GWh is expected from a total of 150 wind turbines with a 4 MW capacity. The distance between Gemini and the nearest port Eemshaven is 85 km. Please see the figure below for the exact location of the Gemini offshore wind farm.

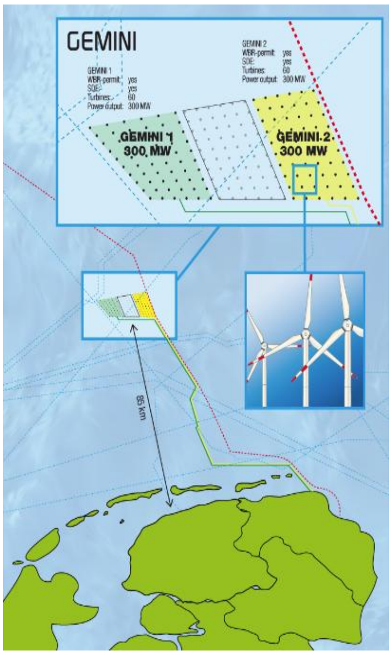

Figure 5 Gemini offshore wind farm

The description of the study site profile contributes to a better understanding of the effects of the selected multi-use activities on the local socio-economic environment. This section outlines the socio-economic context of the study site, describes the institutional framework, and identifies actors, i.e. economic sectors, individuals that may be impacted by the MUOP.

3.1 Demographics and Economic Activities

The total size of the Wadden Sea area is 68 km^2. It is located in one of the best offshore wind locations in The Netherlands with average wind speeds of 10 m/s, while soil conditions in the area are excellent. Water depth at this location ranges between 28 and 36 m.

The North Sea site will most likely belong administratively to NUTS I Noord Nederland, more specifically NUTS II Groningen and Friesland, which is subsequently divided in the NUTS III regions Delfzijl and surroundings, Overig Groningen and Noord-Friesland regions. See figure below for the exact location of these NUTS III regions.

Figure 6 NUTS III regions, source: https://nl.wikipedia.org/wiki/Noord-Nederland

Therefore, the socioeconomic profile of the study area is described at national, regional (Groningen and Friesland NUTS II regions), and local (Delfzijl and surroundings, Overig Groningen, and Noord-Friesland NUTS III regions, i.e. the most northern NUTS III regions) level.

The population of The Netherlands in 2012 accounts for 16,730,348 inhabitants, while the population of Groningen and Friesland amounts to 580,875 and 647,214 residents, respectively (Table 1). The population of the study site at national, regional and local level is rather balanced between male and female, while the range of the average household size varies from 2 to 2.3 persons per household (Table 4). The population at national level is characterized by a favourable educational attainment level. In particular, 64% of population has higher education (baccalaureate, graduate and postgraduate studies), while only 6% of the population has elementary education.

Table 4 Demographic data of the study site at national, regional and local level (2012) Source: CBS.nl

	The Netherlands	Groningen	Friesland	Delfzijl and surroundings	Other Groningen	Noord-Friesland
Population (persons)	16,730,348	580,875	647,214	48,724	381,369	332,742
Persons per household	2.2	2.1	2.3	2.2	2.0	2.2
% male	49.5%	49.7%	50.0%	49.8%	49.7%	50.1%
% female	50.5%	50.3%	50.0%	50.2%	50.3%	49.9%

Total labour in The Netherlands accounts for 7,387,000 persons, while regional employment in Groningen and Friesland amounts to 247,000 persons and 273,000 persons, respectively. Unemployment at national level amounts to 507,000 persons (or 6.4%), of which 54% is male and 46% is female. Groningen region exhibits the highest unemployment rate (7.5%). The analysis of sectoral employment can provide useful insight on the structure and organisation of the national and regional economies.

The national economy is purely services oriented since the tertiary sector accounts for more than 80% of total employment. The highest contribution of the secondary sector to total employment takes place in Delfzijl and surroundings region (26%), while the primary sector contributes by only 1% to total employment at national, regional and local level. The analysis of employment by branch of economic activity portrays that health and community services sector, property and business services sector and trade sector are the major sectors offering employment at national and regional level. With regards to the qualitative characteristics of the employees at national level, 35% has attained graduate and postgraduate studies, 43% hold baccalaureate and 22% have elementary and secondary education. The highest percent of employees with graduate and postgraduate studies (43%) is observed in the Other Groningen region, while the highest percent of employees with elementary and secondary education is observed in the Delfzijl and surroundings region.

With regards the value of regional production in the study site, the manufacturing and energy sector contributes by 68% and 56% in the Delfzijl and surroundings and Other Groningen regions, respectively, while the services sector contributes by 60% to the regional product generation in Friesland region.

3.2 Socio-economic Impacts of MUOP

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

Specific employment impacts of aquaculture are not available. With regards to wind-power production, it is expected that the Gemini wind-power park will create around 500 full time jobs during the construction and installation phase and another 120 full time jobs during the operational phase. Local tourist industry might also benefit from sightseeing trips to wind farms. The employment impacts of the transport maritime services are mainly concentrated on the redesign of fishing vessels towards multipurpose vessels, which may give fishermen the opportunity to carry out maintenance works, logistic and transport activities.

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

3.3 Institutional and Policy Framework

In the current Dutch energy policy, a clear policy for offshore wind energy is available. In earlier energy policy, offshore wind energy was identified as a less important sector, required to achieve formulated objectives. At that time, reservation of sufficient space in marine spatial planning was considered the main bottleneck for development of offshore wind energy. Also, offshore wind was considered to require too much subsidy. Until 2010, offshore wind energy was subsidized under the SDE program (Stimulering Duurzame Energie/Encouraging Sustainable Energy Production). The main current subsidy programme that targets the production of renewable energy is the SDE+

programme. From 2012 onwards, offshore wind energy was not eligible under the SDE+ program, since it was considered expensive compared to other production methods.

In September 2013 the Energy Agreement for Sustainable Growth, concluded by the government with employers, trade unions, environmental organisations and others, contains provisions on energy conservation, boosting energy from renewable sources and job creation. The government regards this agreement as a major step towards a fully sustainable energy supply. With regard to offshore wind this agreement aims to speed up and scale up offshore wind to 4450 MW capacity in 2023, under the condition that a cost reduction of 40 % per MWh will be achieved until 2024.

Under EU legislation 2009/28/EC, Member States are required to give renewable energy priority on the national grid. This requirement was implemented through an adjustment of the Dutch Electricity Law, but pending a discussion on the allocation of the cost of congestion management, the Law is not yet approved.

A different discussion issue on grid integration concerns the costs for connection of offshore wind energy parks to the national grid. Under current Dutch law, these costs are to be made by the project developer. However, based on the Energy Agreement for Sustainable Growth, a debate in the House of Representatives further revolved around the costs of the offshore grid which is now intended to be built and operated by the Dutch TSO TenneT. The investment costs for the offshore grid, which will connect the future offshore wind farms to the onshore grid, will be € 2.4 billion (excluding maintenance and financing costs).

The objective of the first Dutch National Water plan (Nationaal Waterplan 2009-2015) for the North Sea area is to "make the North Sea more sustainable" taking into account its first priority, i.e. safety and protection from floods. The National Water plan (accepted in 2009) integrated all water areas, from offshore and coastal to rivers and inland water. It also described the outline of spatial planning of future water-related developments. The National Water plan follows an area-oriented approach, while for each water basin, specific objectives are formulated and a spatial plan is made to accommodate developments. One of the ways to make the North Sea more sustainable is to reserve sufficient space for offshore wind energy parks, with a focus on multi use. Informed by a 4450 MW ambition (Energy Agreement), it was envisioned that three search areas needed to be reserved for wind park development. Future developments (after 2023) might require more space. Other developments, such as Carbon Capture and Storage (CCS) are also envisioned and the need for mutual adjustment between functions is emphasized. In the National Waterplan, the options for multiple uses of space are explicitly mentioned.

North Sea policies are further elaborated in the Policy Note North Sea 2009-2015 (Beleidsnota Noordzee 2009-2015). After a first identification of areas where offshore wind energy could be developed, a second step was to balance the interests of the various users of the North Sea. This exercise resulted in the identification of two areas for offshore wind development and two so-called "zoekgebieden" (search areas) for future developments. In this policy document, it is explicitly mentioned that co-use offshore wind energy parks, for example for recreation, fisheries and aquaculture, should be allowed as much as possible and needs to be discussed with the involved parties as the policy is implemented.

An offshore wind energy park requires a permit, based on the "Wet beheerrijkswaterstaatwerken" (Wbr). Before such a permit can be granted, project developers have to go through the environmental impact assessment procedure. When applying for a permit, they are obliged to deliver a "SIA" (strategic impact assessment) which assesses the environmental impact of their envisioned project. Before realization of the project, a "MER" is required to assess the environmental impact of the definitive project. If a project developer has gone through the procedures for EIA and permitting successfully, a 20-year concession is granted to build a wind energy park. The system of concessions stems from the Mining Act and grants the developer the possibility to build permanent structures and extract resource. In the concession, additional requirements can be included. For Dutch wind energy parks, restrictions for co-use stem from the concession in which the competent authorities have included "restricted" areas surrounding the wind energy constructions where no ships are allowed.

In The Netherlands the policy design and implementation of aquaculture is stimulated through the aquaculture innovation platform, while policies are distinguished into coastal aquaculture and offshore. Although, aquaculture inside offshore wind energy parks was mentioned as a possible smart use of space, providing opportunities for clever entrepreneurship, in the Integral Management plan for the North Sea there is no space allocated to offshore aquaculture for the Dutch part of the North Sea meaning that aquaculture activities in wind energy parks need to be applied for through permits. In addition to these permits there is an integral balancing framework aiming to help managers in coordinating permit restricted activities with efficient use of space and nature protection values. This framework exists of five tests: (1) defining spatial claim, (2) precaution, (3) usefulness and need, (4) location choice and spatial use, (5) reducing the effect and compensation. New activities have to reduce or prevent negative effects on the environment, which is tested using precautionary test. They have to address the importance of the activities in the North Sea using a social cost-benefit analysis. The space needed for the activity must be carefully chosen and sufficiently used and when the activity compromises important natural values these need to be compensated in another area. Moreover, the Integral Management plan for the North Sea states that it is unlikely fish cultivation on open sea to happen. Open systems are economically attractive but environmentally unfavourable in comparison to closed systems. Furthermore, it is scientifically questionable whether the environment in the Dutch parts of the North Sea allows for fish aquaculture.

For the offshore wind energy parks there is a safety zone of 500 meter around static objects such as turbines and all countries can designate such a safety zone. This restriction means that no shipping activities can take place within 500 meter of the turbine, which also affects the opportunities to combine aquaculture with wind power. However, exemptions on this rule could be made through permit application (IBN).

3.4 Controversies, Uncertainty and Implementation Obstacles

Controversies about wind power production have arisen due to the lack of trust between offshore wind sector and the fishery community. For fishermen, any new fishing restriction because of offshore wind farms is a major issue.

Also, controversies about aquaculture have arisen because the Integral Management Plan for the North Sea explicitly states that fish cultivation is unlikely to apply on open sea due to environmental constraints. It is rather questionable if the North Sea environment in the Dutch parts can allow for fish aquaculture. As a result, till now there is no area designated for aquaculture in the spatial plans for the North Sea.

The fact that the already awarded permits for the Gemini site are only for single use is a major obstacle for all types of potential multi-use is the fact that. An MUOP license for production is an important prerequisite for stakeholders, but this crucial issue has not been tackled till now.

The issue of the MUOP license to produce applies also for the cases of the transport maritime services and the wave energy production. In general, the current practice for offshore wind parks is to forbid other vessels to enter the designated parks in order to avoid questions on risks and responsibilities. As a result risks associated with third-party access cannot be assessed.

4 Monetization of Environmental Externalities

From the previous section it is concluded that due to the multidimensional character of the impacts (socio-economic and environmental of direct and indirect outcomes, i.e. at stakeholder, industry and community scale), a range of different information was needed in order to assess them. As a result, market data, secondary data for the performance of simulations, surveybased primary data, data provided from literature review, consultation with experts and stakeholders and information coming from environmental impact assessments were important in the framework of integrated assessment.

The North Sea offers a wide range of ecosystem services that provide several benefits to human society. Apart from negative environmental effects, MUOPs might have positive impacts on the provision of the ecosystem services such as:

(a) the foundation and scour protection of wind turbines become an artificial reef on which invertebrates do well and the foundations can be quickly colonized and create entire communities of marine life;
(b) production of healthy food in an environmentally sustainable way;
(c) seaweed aquaculture is a non-feed culture and instead of releasing nutrients, seaweed captures nutrients and will lead to improved water quality;
(d) high abundance of benthic filter-feeders such as mussels will increase transparency in the water column and that will improve light conditions for benthic vegetation.

Moreover, there are possibilities for improving sea life and ecological conditions that need to be further explored. Finally, science and education can be improved, using the structures as examples of innovative engineering and aquaculture that provides food and energy to people.

Table 5 Ecosystem Services Potentially Affected by the MUOP

North Sea Site				
Category of Ecosystem Services	Provisioning Services	Supporting/Regulating Services	Cultural Services	Habitat Services
Ecosystem Services	Food and Raw Materials	Nutrient Cycling	Cognitive Development	Diversity
Comments	Construction and Operation Phase	Operation Phase	Not relevant	Construction and Operation Phase

Source: Communication with Site Managers and Biologists

4.1 Life Cycle Assessment

Life Cycle Assessment (LCA) consists of four stages; a) objective and scope definition, b) inventory analysis, c) impact assessment and d) interpretation. LCA is a standardized method which follows ISO 1040 series (ISO, 2006a, b) and covers life cycle stages of a product or function. During the life cycle inventory stage, after constructing the flow chart of the product/function, for each process or activity inputs and outputs are listed with their quantities. The next step is converting emissions to the related impact categories using several methods like TRACI, CML 2001, etc.

An LCA study was carried out to obtain a quantitative evaluation of environmental impacts of designed MUOP for the North Sea site, ie. a wind farm, a mussel farm and a seaweed farm. The Gemini Wind Farm's total capacity is 600 MW[5] and it consists of 150 Siemens SWT 4.0 wind turbines. In the context of this study, Global Warming Potential (GWP) was the only impact category that was focused on as an input for the estimation of the economic benefit of changes in CO_2 emissions.

Environmental Product Declaration (EPD) of Siemens SWT 4.0 declares that for 1kWh energy produced, the greenhouse gas (GHG) emissions are 10 g CO_2 equivalents (CO_2-eq). The data represented in the EPD is derived from the full scale LCA which is carried out for a wind farm that consist of SWT 4.0 wind turbines, cables to grid, and substation. Therefore the results in the EPD are substitutable for Gemini wind farm. If the obtained GWP result is compared with GWP

[5] The capacity factor (average generated power divided by its peak power) varies between 25% and 50% roughly for Danish wind farms. A 600 MW (total capaciy) wind farm generates 2108.16 GWH/year if the capacity factor is 40%. However on the GEMINI wind farm web site this value is given as 2600 GWH/year.

potential of coal based electricity production (820g CO_2-eq, Schlömer et al., 2014), and European electricity mix value (ENTSO-E network) (462 g CO_2-eq/kWh, Itten et al., 2014), the difference is 810g CO_2-eq and 452 g CO_2-eq/kWh, respectively.

Secondly, in the context of the LCA study made for North Sea Site, an LCA in line with ISO 14040 and 14044 standards is carried out for mussel production using Ecoinvent integrated GaBi software to determine environmental impacts of mussel farm for its life cycle. For the calculation, the CML 2001 method was chosen as the methodology due to being a midpoint approach and a method widely used in LCA studies.CML 2001 method evaluates the potential environmental impacts in 11 different categories: Global warming potential (GWP), acidification, eutrophication, ozone layer depletion, abiotic depletion, abiotic depletion fossil, freshwater aquatic ecotoxicity, marine aquatic toxicity, human toxicity, terrestic ecotoxicity and photochemical ozone creation. The systems studied included production and installation of structure, operation and maintenance activities, disposal of structures as well as transportation of materials during the life cycle stages. Functional unit was selected as one kg of mussel harvested.

With regards to GWP, the information about the mussel farm is limited with capacity and technique (long-line mussel farming) of the proposed farm. There are two studies for calculating the carbon footprint of blue mussels cultivated using long-line technique. Fry (2012) calculated carbon footprint of Scottish suspended mussels and intertidal oysters. The study includes cradle to farm gate life cycle stages and the inventory data is collected from Scottish farmers. Fry (2012) reports material input and energy consumption data for one ton of cultivated and packed mussels and also compares the inventory data with the data reported by Winther et al (2009). Winther et al (2009) calculated carbon footprint and energy use of Norwegian sea food products. The report includes material and energy consumption data for 1 kg of edible mussel transported to the wholesaler, additional to Fry (2012), Winther et al. (2009) counts transportation to the wholesaler. It is reasonable to accept that the proposed farm would use the same amount of material and energy with these two studies because in both studies blue mussels are farmed by long-line technique and both countries have coast to the North Sea.

LCA of North Sea Case Study is carried out based on above mentioned inventories and the result is 0.622kg CO_2-eq for 1kg mussel in terms of GWP, assuming that the mussel production at the MUOP is not replacing any other production elsewhere.

Third usage in the North Sea Multi-use Offshore Platform is seaweed aquaculture. Total capacity of the seaweed farm is 480000 ton wet weight (WW)/year and the seaweeds will be grown using textile cable structure with buoys and metal spreader bars. However there is not enough information for carrying out LCA of this seaweed farm. Data produced by Fry et al. (2012) may be presented as an example of GWP of seaweed production in cradle-to-gate basis which is 0.0192 kg CO_2-eq of per kg harvested seaweed, assuming that the seaweed production at the MUOP is not replacing any other production elsewhere.

Table 6 Unit amount of CO_2 emissions per function of MUOP and the compared production technologies

Function	Parameter	Amount	Unit
MUOP Electricity Production	Amount of CO_2-eq production per 1 kWh	**10**	g CO_2-eq
Coal Based Electricity Production	Amount of CO_2-eq saved through MUOP electricity production per 1 kWh	**810**	g CO_2-eq
ENTSO-E Electricity Production	Amount of CO_2-eq saved through MUOP electricity production per 1 kWh	**452**	g CO_2-eq
Mussel Production	Total amount of CO_2-eq production per 1 kg	**0.622**	kg CO_2-eq
Seaweed Production	Total amount of CO_2-eq production per 1 kg	**0.0192**	kg CO_2-eq

Table 7 Total amount of CO_2 emissions per function of MUOP and the compared production technologies

Function	Parameter	Amount
MUOP Electricity Production	Amount of CO_2-eq production (assuming 2600 GWh/year)	10gCO_2-eq/kWh *2600GWh/year*20years = 520000ton CO_2-eq
Coal Based Electricity Production	Amount of CO_2-eq saved (assuming 2600 GWh/year)	810gCO_2-eq/kWh*2600GWh/year*20years = 42120000 ton CO_2
ENTSO-E Electricity Production	Amount of CO_2-eq saved (assuming 2600 GWh/year)	452gCO_2-eq /kWh*2600GWh/year*20years =23504000 ton CO_2-eq
Mussel Production	Total amount of CO_2-eq production (assuming 48000 t WW/year)	0.622tonCO_2-eq /ton mussel *48000ton mussel/year *20years = 597120 ton CO_2-eq
Seaweed Production	Total amount of CO_2-eq production (assuming 480000 t WW/year)	0.0192 ton CO_2-eq / ton seaweed *480000 ton seaweed/ year*10years = 92160 ton CO_2-eq

Based on the Life Cycle Assessment the economic benefit of changes in CO2 emissions due to MUOP construction and operation was estimated. For this purpose, the social cost of carbon was used, which refers to the monetary value, the shadow price of world-wide damage done by anthropogenic CO2 emissions (Pearce 2003). According to Arrow et al. (2014), the social cost of carbon is $19.50 per ton of carbon using the random walk model in Newell and Pizer (2003), $27.00 per ton using the state-space model in Groom et al. (2007), and $26.10 per ton using the preferred model in Freeman et al. (2013). The value used was the one produced using the state-space model **(22.5€ per ton[6], 2013)**.

4.2 Benefit transfer

Gathering primary site-specific data is costly and time-consuming, which has made Benefit transfer (BT) a popular alternative for the valuation of ecosystem goods and services. BT uses existing economic value estimates from one location to another similar site in another location. In particular, it concerns an "application of values and other information from a 'study' site where data are collected to a 'policy' site with little or no data" (Rosenberger and Loomis, 2000, p.1097). That is the result of previous environmental valuation studies are applied to new policy or decision-making contexts. However, there are a number of criteria that have been identified in the literature for benefits transfer to result in reliable estimates as summarised in Brouwer (2000):

- sufficient good quality data
- similar populations of beneficiaries
- similar environmental goods and services
- similar sites where these goods and services are found
- similar market constructs - similar market size (number of beneficiaries)
- similar number and quality of substitute sites where the environmental goods and services are found.

Bergland et al. (1995) discussed three main approaches to BT: (i) the transfer of the mean household WTP, (ii) the transfer of an adjusted mean household WTP and, (iii) the transfer of the demand function. The first approach assumes similarity in good and socio-economic characteristics between the study and target site and the other two approaches attempt to adjust the mean WTP and re-calculate it respectively, in order to account for differences between the two sites in terms of environmental characteristics and/or socio-economic characteristics. See also recent BT reviews such as Navrud (2010), Johnston and Rosenberger (2010), and Johnston et al. (2015).

It was decided under MERMAID to apply an adjusted BT to account for potential environmental and socio-economic impacts. In order to choose the relevant studies, common socio-economic and geographical characteristics are considered between the policy site and the study sites

[6] Exchange rate 0.83 $/ €

of each examined paper. Since it is hard to find studies related to offshore multi-use platforms, research has to be expanded on case studies that include similar environmental and social effects in the marine area without explicitly referred to offshore platforms. The aim is to estimate the effects produced - moving from the baseline to the final platform design - on the ecosystem services defined under the environmental assessment.

Based on the policy site characteristics and the information provided by the site manager and biologists, mussel growth leads to a reduction of nutrients, and thus it can contribute to a better water quality. However, since the North Sea study site is located offshore, where all nutrients are below the target level, water quality would not be highly improved due to mussel growth. Furthermore, the estimation of economic values for all the possible effects on ecosystem services was not possible due to lack of data.

More explicitly, it was supported from the expert biologists and literature that the net effect on nutrient cycling and biomass would be positive due to the final MUOP design. Less fish and benthos are killed due to trawling, and the farm attracts fish and increases the abundance and species numbers (see Krone et al. (2013) and Reubens et al. (2014)). On the other hand, hard structures in a soft sediment environment through MUOPs could serve as “stepping stones” for invasive species, which might have negative effects on the ecosystem, such as reduced overall biodiversity. Since it is not clear which effect would prevail, it was chosen not to account for this effect on biodiversity. This means that no environmental externalities besides CO_2 emissions were monetized using BT for the SCBA.

5 Financial and Economic assessment

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

Despite some similarities with the Baltic Sea site, both including wind farm combined with aquaculture - mussels and seaweed farming in the North Sea site and fish and seaweed farming in the Baltic Sea -, it was not possible to take advantage of it, as detailed information was not made available to be used for the North Sea site.

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

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

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

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

The table below provides a summary of the financial characteristics for the North Sea Site, as previously described. Note that future revenues/costs are at this stage of the analysis not discounted for the computation of annual figures. Additionally, decommissioning costs can be estimated to 3 % of total costs, based on Climate Change Capital (n.d.) and Januário et al (2007).

Table 8 Summary of the financial characteristics for the North Sea site

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

Two extreme scenarios can be considered as illustrations: 1) one providing the maximum profitability, when combining the lowest investment and O&M cost with the highest revenues; 2) one resulting in the lowest profitability, when the highest investment and O&M costs occur at the same time as revenues have their lower value. By taking into account the range of values previously mentioned, the two situations are presented in the following tables. For the case of seaweed farming, both situations indicate a negative financial profitability. However, as was noted in Table 9, the future development of the marked price of seaweed products is highly uncertain. In order to indicate at what market price offshore seaweed farming can start to become interesting from a business perspective, a break-even price was estimated to approximately 620 € per ton DM of seaweed for the maximum profitability scenario and to about 1400 € per ton DM of seaweed for the minimum profitability scenario.

Table 9 Lowest investment and O&M cost and highest revenues illustrating a case of maximum profitability for the North Sea site

	Offshore wind	Mussel farming	Seaweed farming
Investment costs	2800 M€ (year 1); 1800 M€ (year 16)	7 M€ (every 5 years)	21 M€ (year 1); 10 M€ (every 5 years)
O&M costs	60 M€ /year	8.5 M€ /year	47 M€ /year
Revenues	442 M€ / year (given the subsidy scheme available at least the first 15 years) 112 M€ / year (16th year and followings)	45 M€ / year	48 M€ / year
Financial profitability	Yes, as long as there are subsidies	Yes	No. However, the development of the price of seaweed products is highly uncertain, and a higher price of seaweed products can result in a profitable situation.

Table 10 Highest investment and O&M cost and lowest revenues, illustrating a case of minimal profitability for the North Sea site

	Offshore wind	Mussel farming	Seaweed farming
Investment costs	2800 M€ (year 1); 1800 M€ (year 16)	11 M€ (every 5 years)	400 M€ (every 10 years)
O&M costs	140 M€ /year	57 M€ /year	68 M€ /year
Revenues	442 M€ / year (given the subsidy scheme available at least the first 15 years) 112 M€ / year (16th year and followings)	45 M€ / year	17 M€ / year
Financial profitability	Yes, as long as there are subsidies	No	No

6 Social Cost Benefit Analysis

The Social Cost Benefit Analysis (SCBA) assesses the monetary social costs and benefits of an investment project over a time period in comparison to a well-defined baseline (reference) alternative. In this way the costs and benefits of MUOPs are evaluated and compared to estimate the economic efficiency of implementing the project. As a rule, a project is deemed to be socially profitable if total discounted benefits exceed total discounted costs (positive net present value (NPV)). The NPV results reveal whether the net benefit generated by the investment project of Multi-Use platforms is positive and significant well into the future, conditional on the utilized discount rate scheme. A general calculation of the NPV is the following:

$$NPV = -\sum_{t=0}^{N} \frac{K_t}{(1+r)^t} + \sum_{t=0}^{N} \frac{B_t - C_t}{(1+r)^t}$$

Where Kt is the construction cost, Bt is the stream of benefits, Ct is the stream of operation and maintenance costs and r is the discount rate. Monetized values of externalities are also included in the benefits or costs terms.

Furthermore, the Internal Rate of Return (IRR) has been estimated. IRR is the discount rate that makes the NPV equal to zero. The higher a projects IRR, the more desirable is to undertake the project. Any project with an IRR greater than the discount rate used for the project is a profitable one.

For the North Sea site the financial costs and revenues, together with the benefits derived by the reduction of CO_2 emissions were included in the SCBA. For the case on CO_2 emissions due to wind energy production both comparisons were used in the analysis (i.e. reduction of CO_2 emissions compared to coal energy production and ENTSO-E production).

A 20-year time horizon was selected for the SCBA. Given this time horizon, the SCBA has to cope with the fact that the timing of re-investments in installations because of wear and tear is not synchronized across the three MUOP uses of wind energy, mussel farming and seaweed farming. This issue was handled by adapting the re-investment structure for the SCBA in the following way:

- For wind energy, a major re-investment in wind turbines and foundations is planned for year 16, because they last for 15 years. However, re-investments in offshore cables and offshore sub-stations can be expected to be necessary after 20 years, i.e. in year 21. Given the time horizon of 20 years, it is therefore assumed that the wind energy operations stop in year 15. However, decommissioning is assumed to take place in year 20 in order not to disturb mussel and seaweed operations during year 16-19.
- For mussel farming and seaweed farming, decommissioning is assumed to take place in year 20, instead of having an otherwise necessary re-investment in this year.

Triangular distribution was used for Mussels Investment, Seaweed Investment, Mussels Operating Cost, Seaweed Price and Seaweed Operating Cost. The triangular distribution was regarded as the best choice since maximum and minimum profitability for these items is available. It is reasonable to assume that the maximum and the minimum are associated with the minimum probabilities of occurrence and the average of the two with the maximum in the triangular distribution.

Normal distribution was used for Energy Output, Mussels Output, Mussels Price and Seaweed Output. Since there was no information about the specific distributions and only a central value for each of the items, a normal distribution with mean the given central value was assumed. The structure of the normal distribution was determined such that the mass included in the interval of ± two standard deviation from the mean has boundaries at a distance of $\pm\gamma$ % of the mean the choice of γ was consistent with the data of the specific case. That is $\mu \pm 2\sigma = \mu \pm \gamma\mu$..

Two alternative values of 3% and 4% were used for the discount rate. These values are consistent with values obtained from the Ramsey formula for the long lived projects: $r = \rho + \eta \cdot g$

- where $\rho = L + \delta$, is the rate at which individuals discount future consumption over present consumption
- Catastrophe risk (L): catastrophe risk is the likelihood that there will be some event so devastating that all returns from policies, programs or projects are eliminated, or at least radically and unpredictably altered.
- Pure time preference (δ): pure time preference, reflects individuals' preference for consumption now, rather than later, with an unchanging level of consumption per capita over time.
- Annual growth in per capita consumption (g)
- Elasticity of marginal utility of consumption (η)

Finally, the Monte Carlo simulations involved 1000 repetitions. Risk analysis results are presented in deliverable 8.6. The results of the SCBA are summarized in the tables below.

Table 11 Net Present Value estimations for Single and Multi-use Platform (discount rate: 3%)

	mean NPV (3%)	st. dev. NPV (3%)
Single-use: Wind function operation compared to coal energy production	1252.50	98.08
Single-use: Wind function operation compared to ENTSO-E electricity production	1020.93	95.92
Single-use: Seaweed function operation	-614.58	110.99
Single-use: Mussels function operation	122.47	32.94
Multi-use: Wind & Seaweed scenario compared to coal energy production	621.71	150.92
Multi-use: Wind & Seaweed scenario compared to ENTSO-E electricity production	410.14	149.67
Multi-use: Wind & Mussel scenario compared to coal energy production	1369.55	105.73
Multi-use: Wind & Mussel scenario compared to ENTSO-E electricity production	1140.58	105.49
Multi-use: Seaweed & Mussel scenario	-490.53	116.32
Multi-use: Wind & Seaweed & Mussel scenario compared to coal energy production	755.70	156.77
Multi-use: Wind & Seaweed & Mussel scenario compared to ENTSO-E electricity production	527.13	150.41

All values in million euros

Table 12 Net Present Value estimations for Single and Multi-use Platform (discount rate: 4%)

	mean NPV (4%)	st. dev. NPV (4%)
Single-use: Wind function operation compared to coal energy production	1009.27	90.96
Single-use: Wind function operation compared to ENTSO-E electricity production	799.64	91.46
Single-use: Seaweed function operation	-573.86	106.82
Single-use: Mussels function operation	110.95	29.47
Multi-use: Wind & Seaweed scenario compared to coal energy production	444.01	137.16
Multi-use: Wind & Seaweed scenario compared to ENTSO-E electricity production	212.48	141.39
Multi-use: Wind & Mussel scenario compared to coal energy production	1123.43	96.44
Multi-use: Wind & Mussel scenario compared to ENTSO-E electricity production	904.54	94.57
Multi-use: Seaweed & Mussel scenario	-459.30	108.17
Multi-use: Wind & Seaweed & Mussel scenario compared to coal energy production	539.25	146.77
Multi-use: Wind & Seaweed & Mussel scenario compared to ENTSO-E electricity production	332.75	144.37

All values in million euros

Table 13 Internal Rate of Return estimations for Single and Multi-use Platform

	mean IRR	st.dev IRR
Single-use: Wind function operation compared to coal energy production	9.79%	0.51%
Single-use: Wind function operation compared to ENTSO-E electricity production	8.68%	0.50%
Single-use: Seaweed function operation	-	-
Single-use: Mussels function operation	135.80%	71.95%
Multi-use: Wind & Seaweed scenario compared to coal energy production	6.64%	0.86%
Multi-use: Wind & Seaweed scenario compared to ENTSO-E electricity production	5.43%	0.89%
Multi-use: Wind & Mussel scenario compared to coal energy production	10.30%	0.49%
Multi-use: Wind & Mussel scenario compared to ENTSO-E electricity production	9.23%	0.50%
Multi-use: Seaweed & Mussel scenario	-	-
Multi-use: Wind & Seaweed & Mussel scenario compared to coal energy production	7.25%	0.84%
Multi-use: Wind & Seaweed & Mussel scenario compared to ENTSO-E electricity production	6.01%	0.86%

All values in million euros

The estimates of mean NPV and its standard deviation suggest that the multi-use platform scenario of Energy, Seaweed and Mussels passes the NPV test (positive NPV) and the IRR test (IRR greater than the discount rate) under all alternative assumptions regarding the discount rate and savings related to the reduction of CO_2 emissions. However, the wind farm is already under construction and is therefore assumed to be already in operation. Hence, the single-use of Energy is regarded as the baseline scenario.

Using the Energy function as the baseline the Mussels scenario passes the CBA test while the Seaweed scenario does not pass the test (negative NPV and undefined IRR). Due to the strong negative NPV of the seaweed project the combined seaweed-mussels scenario does not pass the CBA test. The energy-seaweed scenario passes the test rather marginally, while the energy-mussels scenario passes the test and it is highly profitable.

It should be noted that in the benefit cash flow for energy production from year 2 until year 15 the price of energy was 170 €/MWh, while from year 16 until the final year drops to 43€/MWh. If the price was to drop to 43€/MWh for the entire duration of the project due to subsidy removal, then the energy scenario (single-use), including CO_2 emissions, in the deterministic maximum profitability case is marginal for a discount rate of 3% and does not pass the CBA test for a discount rate of 4%. This is shown in the table below.

Table 14 Net Present Value and Internal Rate of Return estimations for wind energy production

	NPV (3%)	NPV (4%)	IRR
Single-use: Wind function operation compared to coal energy production	45.76	-68.81	3%
Single-use: Wind function operation compared to ENTSO-E production	-183.93	-281.52	1%

All values in million euros

It should be noted that subsidies to the wind function operation were included in the NPV calculations of table 12. Inclusion of these subsidies in the SCBA for renewable energy can be justified by the argument that these subsidies aim to cover installation cost of renewables with the purpose of capturing the positive externalities of renewables not only in terms of CO_2 and other GHG reductions, but also in terms of more general positive network externalities that promote technical change and support the transition to low carbon economy. Economic theory suggests that activities which generate positive externalities should be subsidized, because market equilibrium without subsidies will not provide the correct amount of the externality generating activity. In this case, absence of subsidy could lead to a situation where the market economy will not install the socially desirable amount of renewables and society will lose positive external benefits. Subsidizing a positive externality is the opposite of imposing taxes to restrict activities that generate negative externalities. So, in the case of the wind function operation, subsidies are not a form of supporting the income of a pressure group but a means to secure the benefits accruing from positive externalities. The results of table 14 suggest that without these subsidies the project is marginal. If in addition to the subsidies benefits from coal substitution are also removed, in the context of financial analysis, then the financial NPV for the wind function operation will be negative. The subsidy provided on the price of wind energy can thus be regarded as capturing benefits from positive externalities not monetized otherwise, which justify the project in terms of SCBA.

Discussion and Recommendations

The main conclusion from the assessment is that adding mussel farming to the single-use wind farm at the studied site is likely to be economically viable both from a financial and a socio-economic perspective. While this supports an MUOP undertaking at the studied site, this does not mean that the site is an optimal location for such an MUOP. From a mussel farming perspective, sites situated closer to the Dutch shore is likely to provide conditions that entail an improved financial and socio-economic performance. The assessment also indicates that adding seaweed is not economically viable under current technical (investments and O&M costs) and economic (market prices) conditions.

Validation and generalization of the conclusions should consider the following issues:

- Accordingly to what is stated in Chapter 4, **monetization of environmental externalities** included CO_2 emissions, whereas no other potential externality became part of the quantitative assessment, primarily because of missing information on ecological consequences such as impact on biodiversity. This might result in a bias whose magnitude and direction is unknown.
- On the other hand, and as mentioned in Chapter 5, the **financial and economic assessment** was mainly supported by data from literature review and expert judgment, as limited site-specific data was available. Consequently, there is a risk for inconsistencies because of different sources and different assumptions, and considerable uncertainties associated with estimated values (large intervals). Additionally, the lack of site-specific data on sub-categories of costs makes it difficult to estimate efficiency gains from combined use.
- The previously mentioned issues imply the need for interpreting the conclusions above based on the **Social Cost Benefit Analysis** cautiously. For example, if additional information becomes available through, for instance, a wider monetization of environmental externalities or a more precise investigation of synergy opportunities, this could potentially change some of the conclusions. For example, precaution should be taken to not exclude (completely) seaweed farming as a possible and eventual profitable use in a future MUOP, as knowledge gaps in the assessment are significant.

These issues illustrate the difficult choice in a research project between either include data and results that are relevant though with high uncertainty (e.g., apply not site-specific data), or to only gather data that is accurate with high certainty (e.g., site-specific data). Aspects such as data availability (lack of data), focus of the research and time availability drove the **research in a certain direction, with the presented outcomes**. The outcomes could have been different if other or complementary inputs and approaches had been used, such as: 1) different design of the site (e.g., capacity installed, size of the site), 2) comparison of the NPV of seaweed farming standing in a offshore MUOP, an offshore SUP, an onshore seaweed farming close to the North Sea or seaweed farming in the conventional markets (e.g. Asia), 3) analyzing offshore mussel farming in comparison to more near-shore mussel farming, 4) assessing externalities associated with an offshore location in comparison to a more coastal one, taking into account that coastal areas are already subject to considerable environmental pressures, (5) longer time horizons in the SCBA than 20 years.

A particularly considerable uncertainty is related to the opportunities of synergies when combining uses. As mentioned in Chapter 5, literature suggests that a 10% cost reduction is possible because of the possibility of efficiency gains in combining different uses in a MUOP. Such a reduction would not change the qualitative conclusions above about the economic viability of adding mussel farming and/or seaweed farming synergies, but it should be emphasized that the opportunities of synergies were not investigated with site-specific data. More detailed information could have improved or worsened the case for any of the multi-use options.

Furthermore, realizing MUOPs hinges crucially on a number of governance issues to be resolved, like permitting and the possibility to obtain insurance in case of a MUOP. Those issues are studied in detail in other MERMAID deliverables, such as D2.4 and D2.7.

Finally, in order to justify subsidization of the development of MUOPs in the future due to societal benefits produced by the MUOP requires to take into account that:

- Although, it is certain that different uses have different time horizons and costs, significant uncertainties are associated with quantifying synergies and risks, as well as costs and revenues.. Moreover, wind farming, which is the one with components with the highest lifetime and costs, is already benefiting from subsidies.
- According to the results in Section 6, and the assumptions considered in Sections 4, 5 and 6, MUOP can accommodate mussel farming. Complementary research about combined use with seaweed could be done for instance by incorporating this use as pilot installations in planned single-use installations or MUOP, to increase the existing, even if limited, know-how and therefore decrease uncertainty about this use. Such pilot installations entailing low investment costs might be easily accommodated within subsidized projects with high investment costs such as wind farming.
- The financial viability of mussel farming and seaweed farming would improve if there would be subsidies available for ‘start-ups’ for offshore production of mussels and seaweed, although our results indicate that for seaweed production, the subsidies required would be substantial. However, introducing subsidies might introduce a risk that investors are not making maximum efforts for discovering and utilizing multi-use synergies. In the medium/long term, combined uses and associated synergies should replace subsidies, or at least, make it possible to provide lower subsidization.

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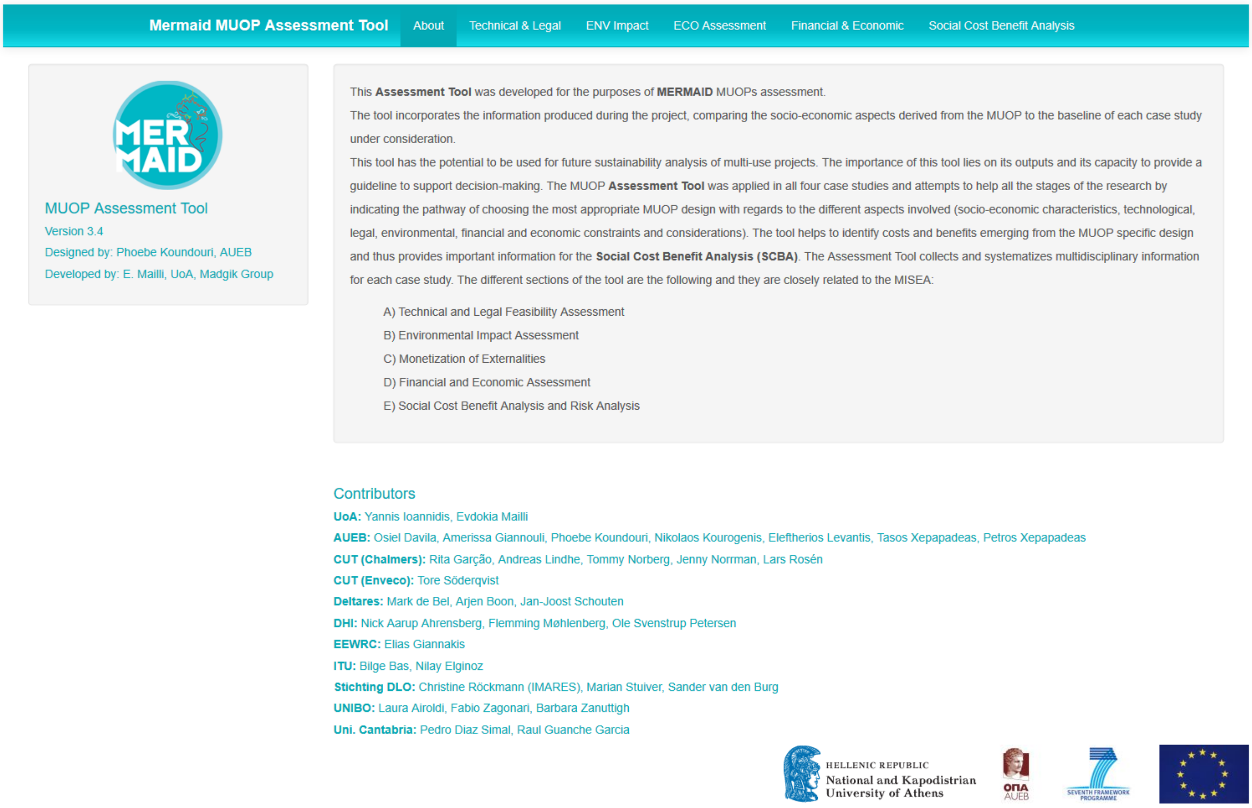
Annex I The Assessment Tool



Mermaid MUOP Assessment Tool | About | Technical & Legal | ENV Impact | ECO Assessment | Financial & Economic | Social Cost Benefit Analysis

MUOP Assessment Tool
Version 3.4
Designed by: Phoebe Koundouri, AUEB
Developed by: E. Mailli, UoA, Madgik Group

This **Assessment Tool** was developed for the purposes of **MERMAID** MUOPs assessment.

The tool incorporates the information produced during the project, comparing the socio-economic aspects derived from the MUOP to the baseline of each case study under consideration.

This tool has the potential to be used for future sustainability analysis of multi-use projects. The importance of this tool lies on its outputs and its capacity to provide a guideline to support decision-making. The MUOP **Assessment Tool** was applied in all four case studies and attempts to help all the stages of the research by indicating the pathway of choosing the most appropriate MUOP design with regards to the different aspects involved (socio-economic characteristics, technological, legal, environmental, financial and economic constraints and considerations). The tool helps to identify costs and benefits emerging from the MUOP specific design and thus provides important information for the **Social Cost Benefit Analysis (SCBA)**. The Assessment Tool collects and systematizes multidisciplinary information for each case study. The different sections of the tool are the following and they are closely related to the MISEA:

A) Technical and Legal Feasibility Assessment
B) Environmental Impact Assessment
C) Monetization of Externalities
D) Financial and Economic Assessment
E) Social Cost Benefit Analysis and Risk Analysis

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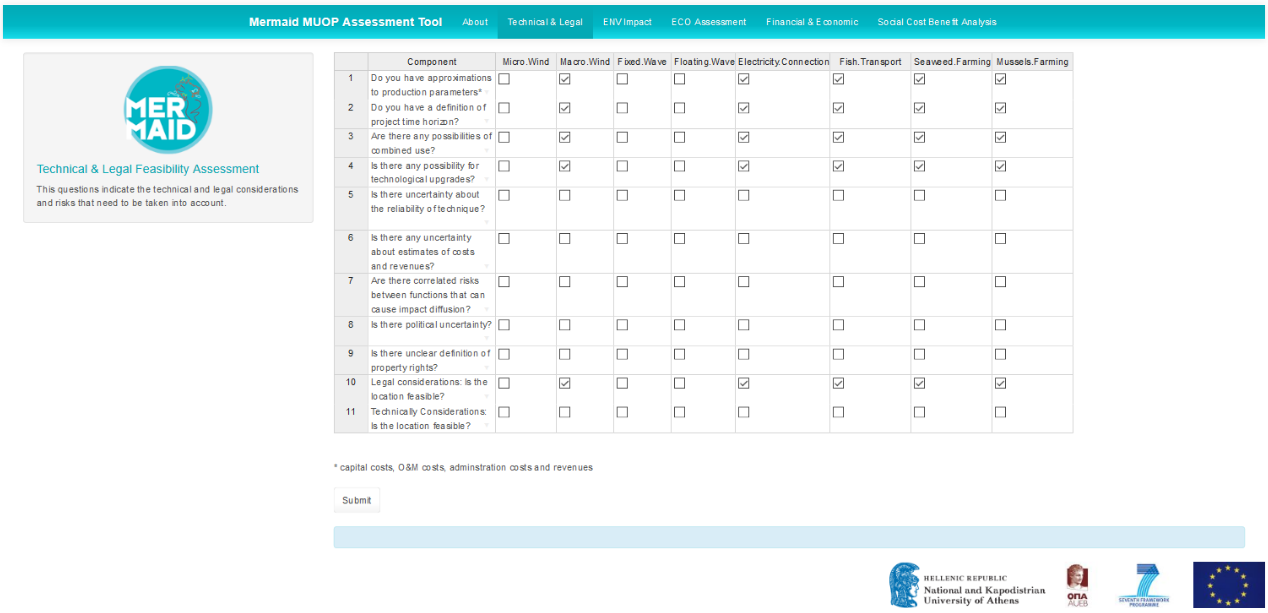
Techinal and Legal Feasibility Assessment



Mermaid MUOP Assessment Tool | About | Technical & Legal | ENV Impact | ECO Assessment | Financial & Economic | Social Cost Benefit Analysis

Technical & Legal Feasibility Assessment
This questions indicate the technical and legal considerations and risks that need to be taken into account.

	Component	Micro.Wind	Macro.Wind	Fixed.Wave	Floating.Wave	Electricity.Connection	Fish.Transport	Seaweed.Farming	Mussels.Farming
1	Do you have approximations to production parameters*	☐	☑	☐	☐	☑	☑	☑	☑
2	Do you have a definition of project time horizon?	☐	☑	☐	☐	☑	☑	☑	☑
3	Are there any possibilities of combined use?	☐	☑	☐	☐	☑	☑	☑	☑
4	Is there any possibility for technological upgrades?	☐	☑	☐	☐	☑	☑	☑	☑
5	Is there uncertainty about the reliability of technique?	☐	☐	☐	☐	☐	☐	☐	☐
6	Is there any uncertainty about estimates of costs and revenues?	☐	☐	☐	☐	☐	☐	☐	☐
7	Are there correlated risks between functions that can cause impact diffusion?	☐	☐	☐	☐	☐	☐	☐	☐
8	Is there political uncertainty?	☐	☐	☐	☐	☐	☐	☐	☐
9	Is there unclear definition of property rights?	☐	☐	☐	☐	☐	☐	☐	☐
10	Legal considerations: Is the location feasible?	☐	☑	☐	☐	☑	☑	☑	☑
11	Technically Considerations: Is the location feasible?	☐	☐	☐	☐	☐	☐	☐	☐

* capital costs, O&M costs, adminstration costs and revenues

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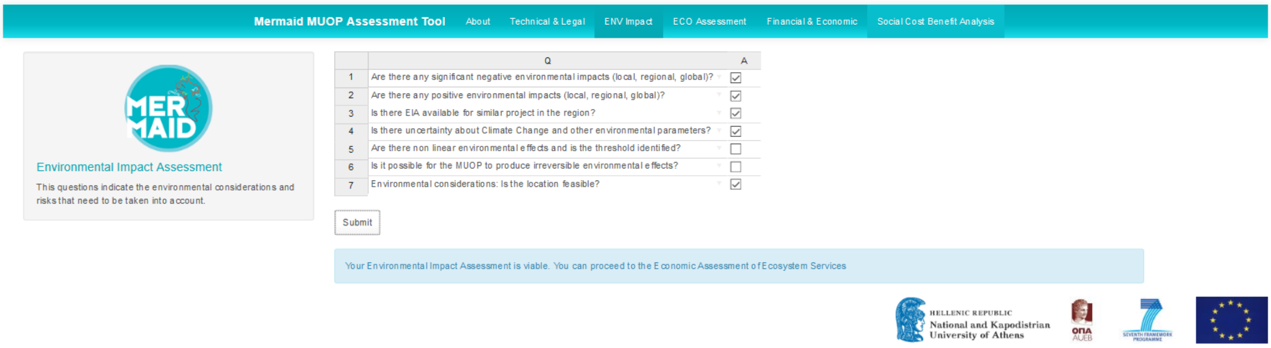
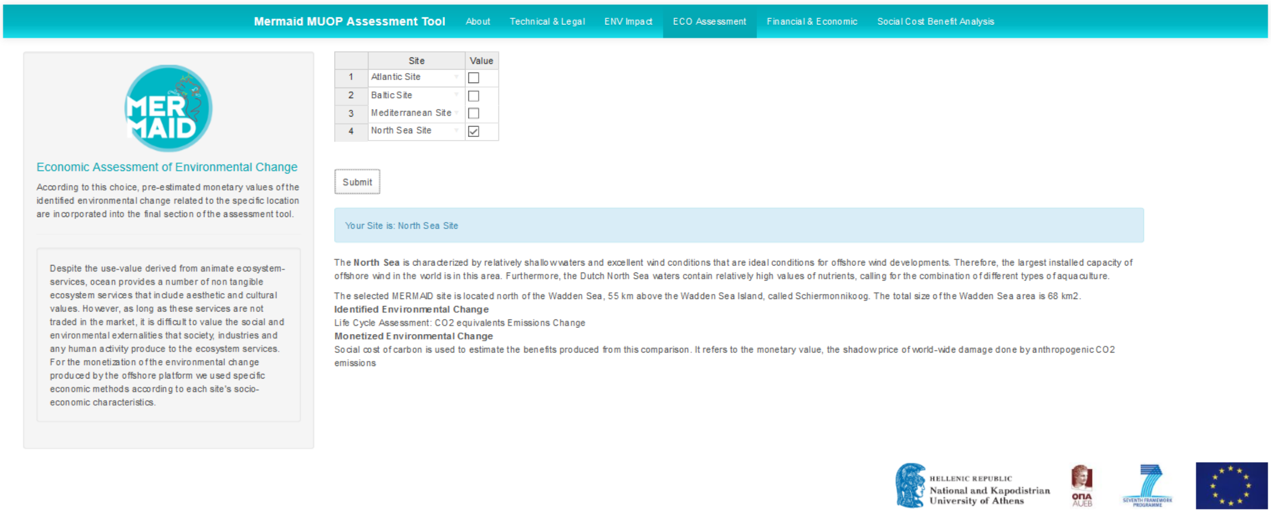
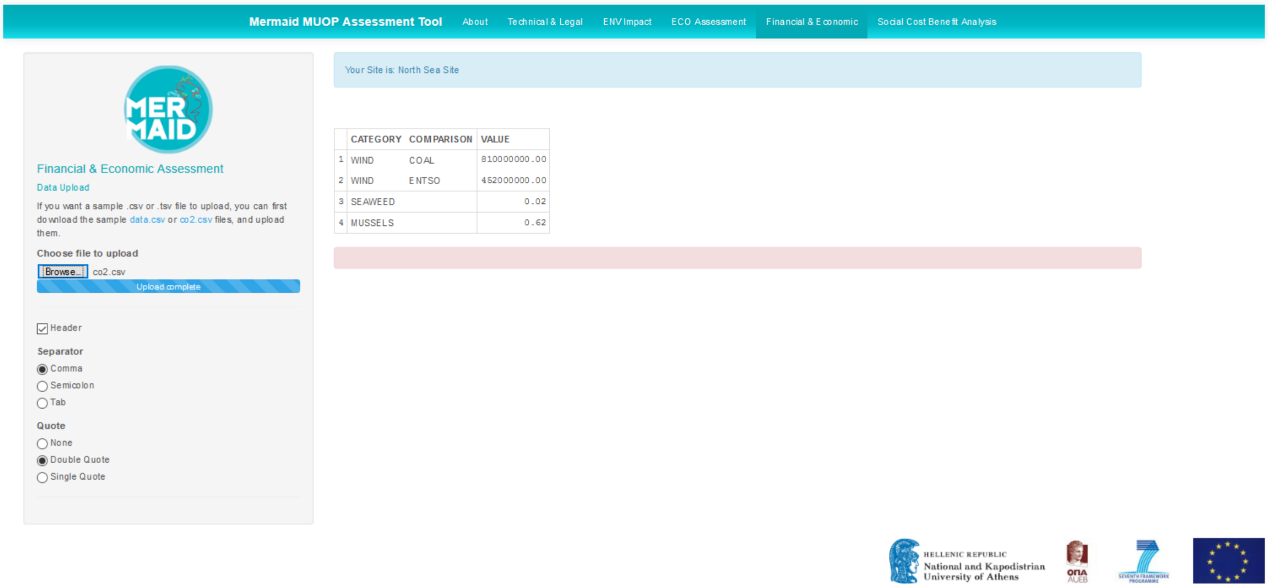
Environmental Impact Assessment

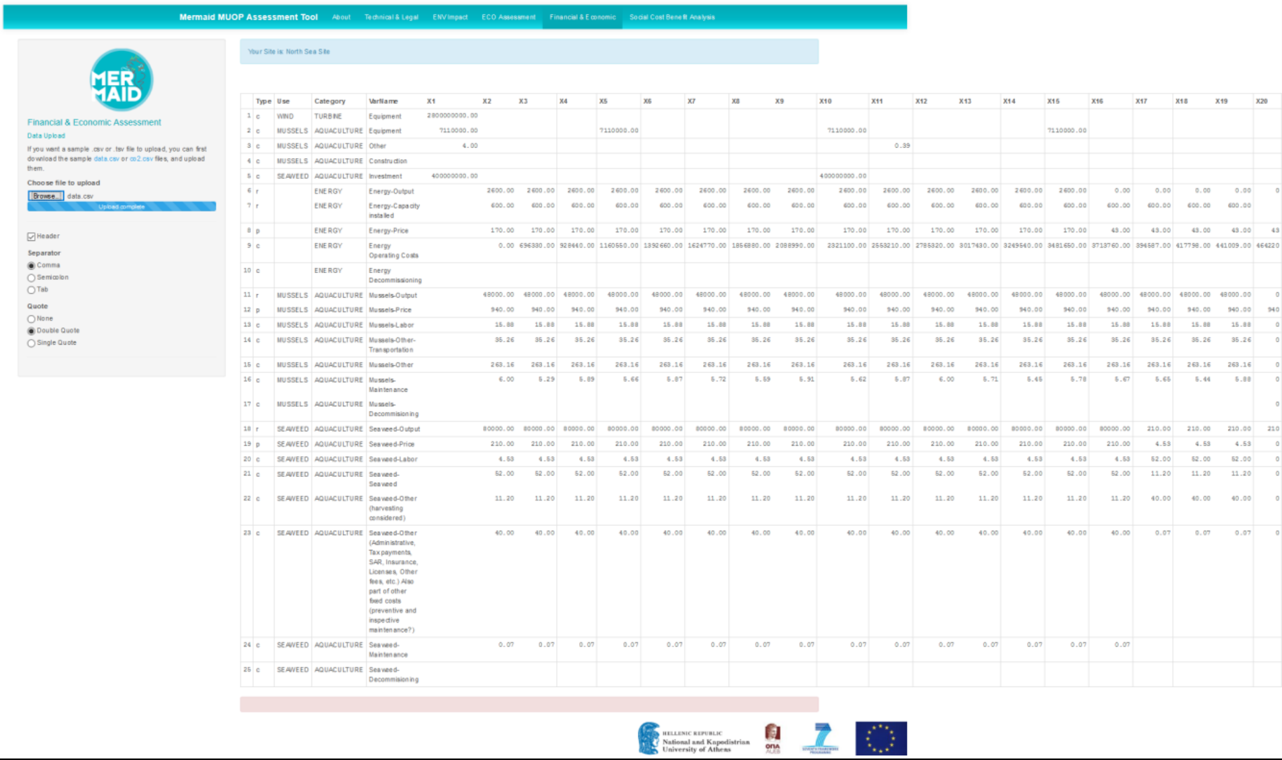


Monetization of Environmental Externalities



Financial and Economic Assessment





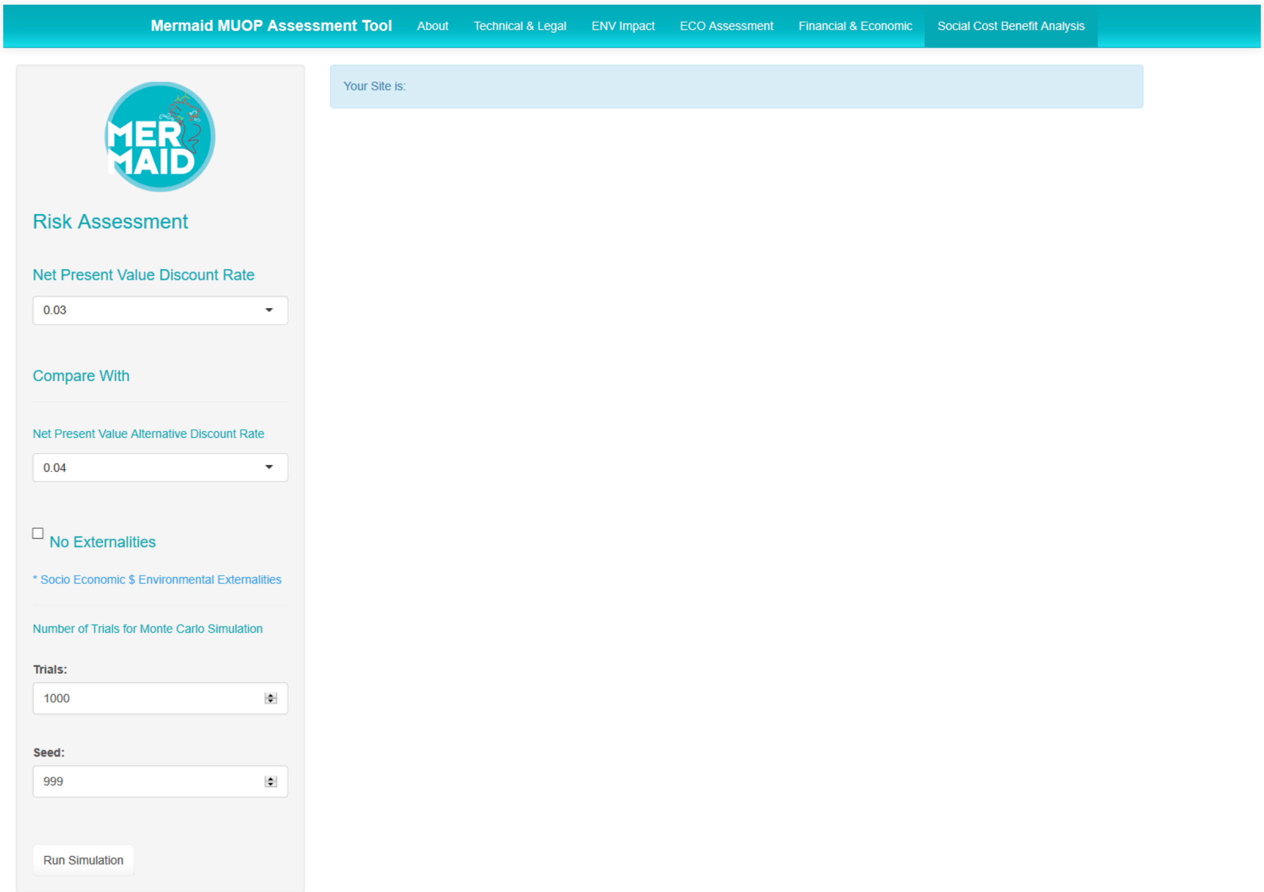
The user inserts specific requested data for the estimation of economic and financial benefits and costs.

Social Cost Benefit Analysis and Risk Analysis

It should be noted that the tool is able to compare at the same time the estimated net present value under different discount rates.

Furthermore, the tool calculates and compares the net present value for the case of including the monetized externalities and for the case where these are not included.

The detailed description of the tool and the user guide will be published in future publications.



Due to the complication of the data, we can provide the graphically represented results of this particular section of the tool under request.