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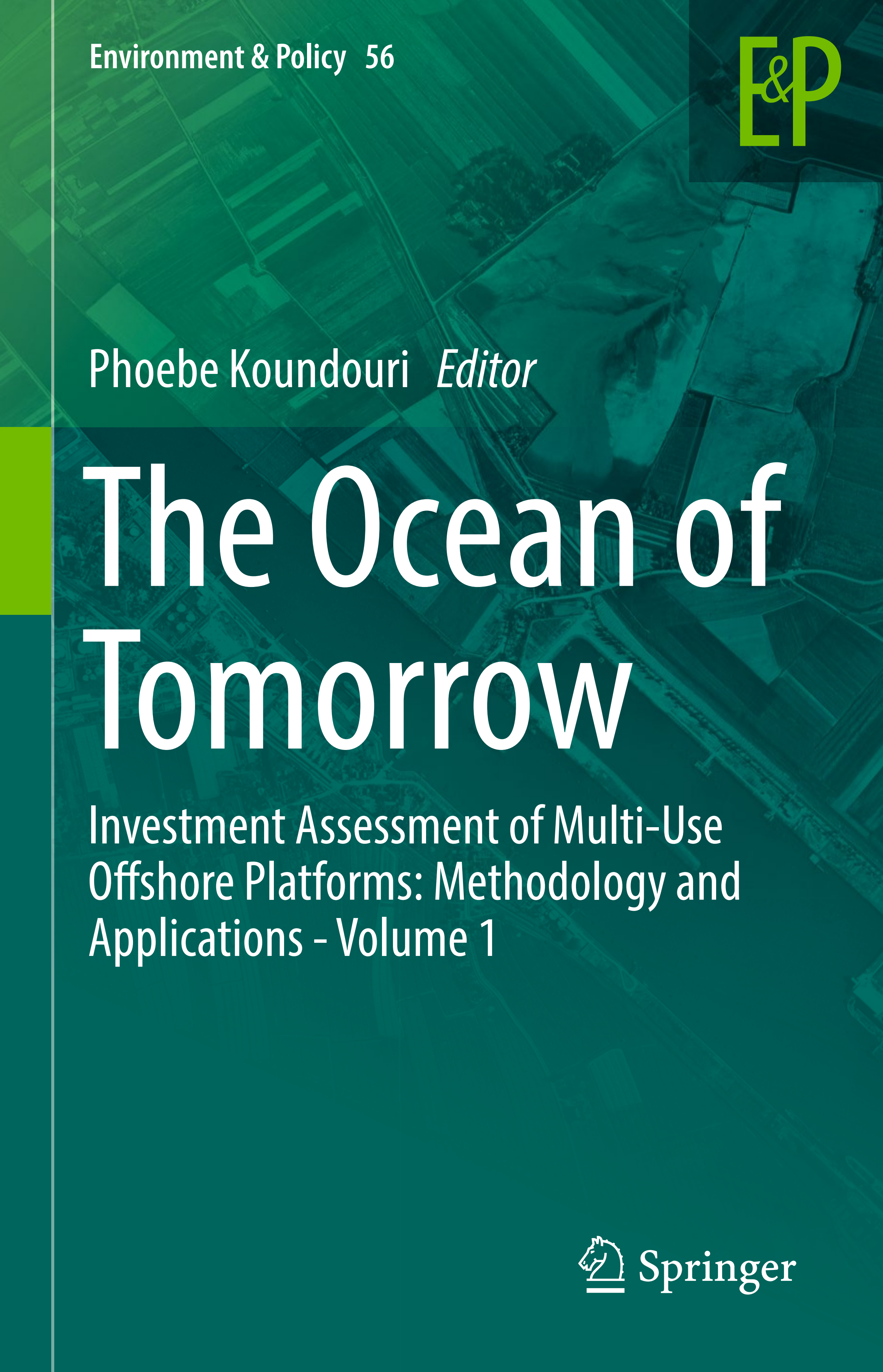

Phoebe Koundouri *Editor*

# The Ocean of Tomorrow

## Investment Assessment of Multi-Use Offshore Platforms: Methodology and Applications - Volume 1

Springer

**ENVIRONMENT & POLICY**

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## Investment Assessment of Multi-Use Offshore Platforms: Methodology and Applications - Volume 1

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**Example of a MERMAID project offshore platform**
Denis Lacroix, Ifremer and Malo Lacroix (Source: Lacroix and Pioch 2011, p. 133). Lacroix, D., & Pioch, S. (2011). The multi-use in wind farm projects: More conflicts or a winwin opportunity? *Aquatic Living Resources, 24*, 129–135.

*As always, this book is dedicated to Nikitas,*
*my inspiration and resilience; Chrysilia,*
*Billie and our newborn, my happiness.*

# Foreword

The ocean is a vital resource to many people on the planet. Nearly 3 billion people rely on fish as a major source of protein, and fisheries and aquaculture assure the livelihoods of 10–12% of the world's population. It is also important in economic terms. By one estimate, the bounty of the ocean produces $2.5 trillion in gross marine product per year, a roughly 10% return on its asset value of $23 trillion.

In recent years, there has been a growing interest in these values and how they can be enhanced in a sustainable way, without damaging the sources from which they are derived. The marine economy and its potential are now commonly referred to as the blue economy and "blue growth". Critical to this interpretation of blue growth is an understanding of both the potential for using marine ecosystems to generate new services and possible damages to the natural capital from these services. It is important to have information on the costs of different methods of exploiting the marine environment, so that it can be done sustainably. Areas where new or increased use of the marine environment is taking place include multi-use offshore platforms, which are the topic of this book.

These structures offer a major role in promoting the blue economy, but it is critical that such a role is carried out with care for the natural environment. This book, based on interdisciplinary research carried out under the MERMAID EU-funded project, offers an excellent analysis of the ways in which the physical and natural structures interrelate and how design features have to reflect the very different types of local conditions we find across the different seas around the European continent. All such enterprises face risks, but as the book shows, they can be managed if they are recognized and addressed from the outset of the project. The book should provide useful material to researchers and practitioners alike in dealing with this exciting and challenging new field.

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# Preface

The aim of this book is to provide an integrated socio-economic assessment of multi-use offshore platforms (MUOPs) in selected EU sites in the North Sea, the Baltic Sea and the Mediterranean and the Atlantic coast. The assessment results from the interdisciplinary research carried out in the MERMAID Project (Innovative Multi-purpose Off-Shore Platforms: Planning, Design and Operation) funded under the EU FP7 call *OCEAN.2011-1: Multi-Use Offshore Platforms*. The book provides a first-time integrated assessment of the MUOPs and the relevant technology associated with the implementation of the Marine Strategy Framework Directive and the sustainable marine spatial planning. The socio-economic assessment uses the results from the natural and engineering sciences as inputs, boundaries and constraints. The analysis employs an interdisciplinary approach that combines expertise in hydraulics, wind engineering, aquaculture, renewable energy, marine environment, project management, socio-economics and governance.

The first chapter of the book introduces the reader to the MERMAID Project, the drivers and the needs for the development of the MUOPs in the EU waters and the importance of developing a sound integrated socio-economic assessment in terms of methodology and results obtained.

Chapter 2 presents the methodology used for the integrated socio-economic assessment of different designs of the MUOPs. The methodology employed allows for the identification, the valuation and the assessment of the potential impacts and their magnitude, considering a number of feasible designs of MUOP investments and the likely responses of those impacted by the investment project. The methodology is implemented for the assessment of the different sites and the results are summarized in Chaps. 3, 4, 5 and 6.

Chapter 3 presents the results of the integrated assessment with regard to the MUOP in the Baltic Sea, in the area of the Kriegers Flak in which an offshore wind farm of 600 MW is planned to be fully operational in 2022. The analysis investigates the combination of wind turbines and offshore aquaculture. Constrained by data availability, the analysis combined with expert views shows that the multi-use platform scenario may be expected to be economically viable in the long run.

Chapter 4 provides an integrated socio-economic assessment of a MUOP in the North Sea in the Netherlands Exclusive Economic Zone, the Gemini site where wind power generation can be combined with mussel and seaweed cultivation. The analysis shows that there exists political willingness to back up the development; nevertheless, a number of regulatory obstacles are also identified. The financial and economic assessment and the cost-benefit analysis indicate that adding mussel cultivation to the wind farm is likely to be both financially and socio-economically viable.

Chapter 5 presents the results obtained from the analysis of the multi-use design for the Cantabria offshore site in the Atlantic coast. The analysis identifies that the profitability potentials of a MUOP site remain uncertain, while ocean energy industry has not yet gained the necessary social acceptance in the region.

Chapter 6 presents the results from the integrated assessment of a MUOP site in the area offshore Venice with potential combination of fish farming and wind energy production. Limited financial data on wind energy suggest a negative net present value, whereas proper financial data on fish farming produce a slightly positive NPV. The effects are significant and positive in terms of the monetized effects of reduced $CO_2$ emissions. The results show that in the short run the MUOP might not be profitable or gain social acceptance but these results may be subject to change in the long run.

Chapter 7 undertakes a risk analysis and a sensitivity analysis of the application of the methodology for integrated socio-economic assessment with regard to the different proposed designs of the MUOPs. The chapter integrates the results of the assessment discussed in the previous chapters and presents and compares the sensitivity analysis and Monte Carlo simulation results.

The last chapter concludes with the discussion of the challenges and obstacles to the MUOP development and of the recommendations that future decision making on blue growth should consider.

Athens, Greece
London, UK

Phoebe Koundouri

# Acknowledgements

The assistant editor of this book is Dr. Stella Tsani. Without her excellent editorial work and dedication, this book would not have been completed.

My gratitude goes to all the world-class contributing authors of this book for their devotion to the completion of their chapters and for putting up with my, seemly endless, suggestions for revisions.

I am also personally in debt to Prof. Barbara Zanuttigh, my colleague and friend, who introduced me to MERMAID (Innovative Multi-purpose Off-Shore Platforms: Planning, Design and Operation) FP7 Integrated Project consortium. Moreover, I am grateful to Prof. Erik Damgaard Christensen, the coordinator of the MERMAID Project, and the whole of the MERMAID consortium, who gave me a leading research role in it, as well as suggested me as the socio-economic research coordinator of the three projects funded under the call OCEAN.2011-1: Multi-Use Offshore Platforms, namely, MERMAID (Innovative Multi-purpose Off-Shore Platforms: Planning, Design and Operation), TROPOS (Modular Multi-use Deep Water Offshore Platform Harnessing and Servicing Mediterranean, Subtropical and Tropical Marine and Maritime Resources) and H2OCEAN (Development of a Wind-Wave Power Open-Sea Platform Equipped for Hydrogen Generation with Support for Multiple Users of Energy). The Ocean of Tomorrow projects have been a continuous source of inspiration for my research.

My overwhelming debt goes to my colleagues at the Athens University of Economics and Business, especially those involved in the ReSEES (Research tEam on Socio-Economic and Environmental Sustainability) Laboratory that I direct, as well as my colleagues at the London School of Economics, Grantham Research Institute on Climate Change and the Environment.

Last but not least, I am in debt to my colleagues at ICRE8 (International Centre for Research on the Environment and the Economy) that I also direct. They are my "research island"!

Phoebe Koundouri

# Contents

**Part I Socio-economic Assessment of Multi-use Offshore Platforms**

**Part II Risk Analysis**

# Contributors

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**Vasilis Babalos** received his PhD in finance from the University of Piraeus (2010); he holds a master's degree in finance in 2004 and diploma in statistics and insurance science in 2001 from the University of Piraeus. Since 2011, he has been an adjunct assistant professor at the Technological Educational Institute of Peloponnese. Moreover, he is a research associate of the Department of Banking and Financial Management, University of Piraeus. He has published several papers in refereed journals in the area of financial economics such as *Journal of Banking and Finance*, *Journal of International Financial Markets*, *Institutions and Money*, *Economics Letters*, *International Review of Financial Analysis* and *European Journal of Finance*, among others. His academic research has been cited in scientific journals such as *Journal of International Financial Markets, Institutions & Money*, *International Review of Financial Analysis*, *International Review of Economics & Finance*, *European Journal of Operational Research*, *Journal of Multinational Financial Management*, etc.

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**Arjen Boon** is a senior researcher/consultant at the Department Ecosystem Dynamics within the Marine and Coastal Systems of Deltares unit. He is a marine ecologist with a 20-year professional background in fundamental and applied marine ecological research and consulting. His disciplinary background is in benthic ecology, marine process ecology and marine ecosystem dynamics. He has an extensive and in-depth knowledge of scientific ecological issues relevant to marine science, policy and management. The sustainable implementation of human activities in the marine and coastal environment is always at the core of his work, with ecosystem-based management being the underlying approach. In more recent years, Arjen applied and further developed the concept of ecosystem services as a powerful approach to combine the marine natural environment to the socio-economic domain. He has extensive experience on impact assessments (on biodiversity and ecosystem functioning) of maritime activities such as marine sand extraction, coastal extensions (Port of Rotterdam) and offshore wind farms.

**Stefanie Broszeit** studied marine biology at Plymouth University and then went on to do an MSc at the Centre for Tropical Marine Ecology, in Bremen, Germany. She then carried out intertidal surveys in SW Ireland before joining Plymouth University as a research and teaching technician. She obtained her PhD in marine ecology at University College Cork, Ireland, after studying spatial and temporal patterns of soft sediment communities affected by strongly variable current regimes and seasonal hypoxia. After her PhD she did a postdoc looking at the effects of artificial structures on marine benthic assemblages in the Italian Adriatic. She is currently employed at Plymouth Marine Laboratory, working on ecosystem services.

**Matteo Cantu** is a chemical engineer, who joined Enel in 2007. He worked for Enel Research and Innovation till 2016, where he was research programme manager of projects dealing with the integration of renewables in electric systems, distributed generation, co-generation, energy management systems development, active distribution grids modelling and demonstration, virtual power plants and demand response, batteries and energy storage systems and marine energy. He worked on several funded projects, both at national and at European level. Since the end of 2016 he has moved to the energy management business line in Italy, where he works in Strategic Short-Term Planning and Pricing area.

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**Mark de Bel** is an expert advisor economy at Deltares. He believes that traditional solutions are no longer adequate in facing challenges from climate change. There is a need for innovative solutions and advocacy towards inclusive solutions for making optimal use of our planet's resources. Within Deltares he works towards developing and assessing solutions in recognition of economic development and stakeholder preferences, through the latest technological insights and a philosophy of "open source works".

**Fernando del Jesus** is civil engineer specialized in offshore wind energy. His PhD thesis entitled "Analysis of Climate Variability Influence on Offshore Wind Farms" contributes to offshore wind characterization, floating platform design and economic feasibility of offshore wind farms. He has published in the main journals of the sector, such as *Wind Energy*, and he has participated in several conferences, including OMAE, EWEA and Offshore, among others. Fernando has also been part of INORE (International Network for Offshore Renewable Energy) as committee member for 3 years acting as research manager.

**Nilay Elginoz** has been a lecturer at Istanbul Technical University, Department of Civil Engineering, since 2011. She has completed her PhD titled "Interaction Between Posidonia Oceanica Seagrass Meadows, Wave Features and Beach Morphology" in 2010 at ITU. Her major fields of interests are environmental impacts of coastal structures, wave-vegetation interaction and marine hydrodynamics. She has published several journal and conference papers. She is an active member of the Chamber of Environmental Engineers of Turkey.

**Athanasios Frentzos** studied biology at the University of Athens and ichthyology at Victoria University of New Zealand. He was a scientific collaborator of the Marine Research Institute of New Zealand and the national coastal management programme in Greece. He has been with Kefalonia Fisheries S.A. since the very beginning, 1981, being the first general manager, and as such may safely be considered as one of the founders of sea bass and sea bream farming in Europe. He was the first to introduce fry of sea bass and sea bream in cages and was responsible for the design and construction of the first marine hatchery in Greece. Over the years, he has participated in and compiled numerous studies on the development of marine farming for the public and private sector and served as lecturer in universities and academic conferences on marine fish farming. He is currently an executive member of the Board of Directors of Kefalonia Fisheries S.A. He speaks Greek and English.

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**Amerissa Giannouli** holds a BSc in economics and MSc in international and European economic studies (European economic policy). She has worked for 2 years as a junior researcher at the Athens University of Economics and Business and the International Centre for Research on the Environment and the Economy. Her research interests include political economy, socio-economics and ecological economics. Her work focuses on sustainability, social innovation and education.

She is currently a social researcher and works with civic society organizations as junior project manager, youth worker, facilitator and trainer.

**Raul Guanche Garcia** has PhD and MsC in civil engineering and is responsible for the Offshore Engineering and Marine Renewable Energies research group of the Environmental Hydraulics Institute of the University of Cantabria. He has developed an intense research career and collaborated with engineering firms through the development of techno-scientific projects in different areas related with the ocean engineering sector. In the last 8 years he has participated in more than 50 projects with national and international companies in the field of offshore engineering and more specifically in the marine renewable energy sector, having developed tools and methodologies for a large number of companies. He has more than 50 techno-scientific publications, most of them in specialized journals like *Ocean Engineering*, *Renewable Energy* or *Wind Energy*. He has co-authored eight patents on devices linked to the marine renewable energy and offshore aquaculture sector.

**Wei He** obtained her PhD at the Department of Mechanical Engineering, Delft University of Technology, and MBA from European University in Paris. She has worked in wind energy for more than 25 years, including design institute in China, DTU in Denmark, DNV GL (KEMA) in the Netherlands and Statoil in Norway. She is currently a principal engineer at Statoil, Norway, where she has worked for 18 years. She worked for offshore oil/gas platforms for 10 years and is applying her offshore oil/gas platform experiences to offshore wind and aquaculture technology developments. She is currently leading several EU collaborative H2020 and FP7 wind energy research projects at Statoil.

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**Sedat Kabdasali** has been active in hydraulics/coastal engineering since his PhD (awarded 1982, Istanbul Technical University). He has served as the head of hydraulics division for many years and has been involved in many international and national research projects. He has coordinated several research projects, total budget of which sums up to some €500,000. He has published more than 72 journal and 70 conference papers. He has supervised 31 MSc and 9 PhD theses, many of which were collaborated with industrial projects.

**Phoebe Koundouri** is the founder and scientific director of ICRE8 (www.icre8.eu) and professor at the Athens University of Economics and Business. She is also founder and scientific director of the Research Laboratory ReSEES (Research tEam on Socio-Economic and Environmental Sustainability) at the same university. Since 2013 she has also been a visiting senior research fellow at the Grantham Research Institute on Climate Change and the Environment, London School of Economics in the UK. She has published 15 edited books and monographs and more than 250 articles in academic journals and edited volumes. She is a highly cited academic author ranked in the top 1.5% of all female economists in the world. She has held academic positions at the University of Cambridge, University College London, University of Reading and many visiting positions around the world. She has been acting as an advisor, consultant and research evaluator for the European Commission, the World Bank, OECD, UN, NATO, WHO and various foundations and governments.

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# Abbreviations

| | |
|---|---|
| AOC | Annual operating costs |
| CAPEX | Capital expenditure |
| CBA | Cost-benefit analysis |
| CCS | Carbon capture and storage |
| CE | Choice experiment |
| CEA | Cost-effectiveness analysis |
| $CO_2$ | Carbon dioxide |
| $CO_2eq$ | Carbon dioxide equivalent |
| COS | Cantabria offshore site |
| CVM | Contingent valuation method |
| DDR | Declining discount rate |
| DM | Dry matter |
| EC | European Commission |
| EEZ | Exclusive economic zone |
| EIA | Environmental impact assessment |
| EMF | Electromagnetic fields |
| EPCI | Engineering, procurement, construction and installation |
| ESA | Ecosystem services approach |
| FDR | Financial discount rate |
| FNPV | Financial net present value |
| FRR | Financial rate of return |
| GW | Gigawatt |
| GWP | Global warming potential |
| IRR | Internal rate of return |
| kg | Kilogram |
| $km^2$ | Square kilometre |
| kt | Kiloton (1000 metric tons) |
| kWh | Kilowatt hour |
| kV | Kilovolt |
| LCA | Life cycle assessment |
| LCoP | Levelized cost of production |

| | |
|---|---|
| m | Metre |
| MCDA | Multi-criteria decision analysis |
| MISEA | Methodology for integrated socio-economic assessment |
| MSFD | Marine Strategy Framework Directive |
| MSP | Marine spatial planning |
| MUOPs | Multi-use offshore platforms |
| NGOs | Non-governmental organizations |
| NIS | Non-indigenous species |
| NPV | Net present value |
| NUTS | Nomenclature of units for territorial statistics |
| O&M | Operation and maintenance |
| OPEX | Operating expense |
| OWC | Oscillating water column technology |
| PER | Renewable energies plan of Spain |
| PESTEL | Policy, economic, social, technical, environmental and legal factors |
| PSU | Practical salinity unit |
| R&D | Research and development |
| SCBA | Social cost-benefit analysis |
| SD | Standard deviation |
| SEIA | Socio-economic impact assessment |
| SMEs | Small and medium enterprises |
| TEV | Total economic value |
| TRL | Technology readiness level |
| UNEP | United Nations Environment Programme |
| UNCLOS | United Nations Convention on the Law of the Sea |
| VAT | Value-added tax |
| WTA | Willingness to accept |
| WTP | Willingness to pay |
| WW | Wet weight |

# Chapter 1
# Introduction to the MERMAID Project

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**Abstract** This chapter provides an introduction to the MERMAID project. MERMAID focused on developing concepts for offshore platforms which can be used for multiple purposes, such as energy and aquaculture production. These concepts were developed with input from experts as well as societal stakeholders. MERMAID consortium comprised of 28 partner institutes, including Universities, Research institutes, Industries and Small and Medium Enterprises from several EU countries. Consortium members brought a range of expertise in hydraulics, wind engineering, aquaculture, renewable energy, marine environment, project management, as well as socioeconomics and governance. Within the scope of MERMAID it has been developed and applied an Integrated Socio-Economic Assessment of the

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sustainability of Multi-Use Offshore Platforms, using the results from the natural and engineering sciences as inputs, boundaries and constraints to the analysis.

**Keywords** Mermaid • Marine spatial planning • Multi use offshore platforms • Socio-economic assessment • Marine infrastructure • EU • Energy • Aquaculture

During the next decades, there will be a substantial development of offshore marine structures in the European seas, such as offshore wind farms, constructions for marine aquaculture and the exploitation of wave and tidal energy. Offshore platforms that combine multiple functions, such as energy and aquaculture production, offer significant economic and environmental benefits. However their installation and maintenance, and the transport of materials and products to and from these structures, will unavoidably exert environmental pressures on the marine ecosystems. It is therefore crucial that the economic costs, the use of marine space and the environmental impacts of these activities to be appropriately captured and explored and to remain within acceptable limits.

A key initiative in this context has been the launch of *The Ocean of Tomorrow* cross-thematic calls in FP7 (FP7-OCEAN). The initiative aimed to foster multidisciplinary approaches and cross-fertilisation between various scientific disciplines and economic sectors on key cross-cutting marine and maritime challenges such as reduction of fossil-based energy and promotion of sustainable aquaculture. A key feature of the initiative has been the participation of business partners, in particular Small and Medium Enterprises (SMEs), in the funded research projects.

MERMAID (http://www.mermaidproject.eu/) is an EU-FP7 project selected for funding in response to OCEAN.2011 call on multi-use offshore platforms (FP7-OCEAN.2011–1 “Multi-use offshore platforms”). MERMAID had a cost of 7.4 million Euro and comprised of 28 partner institutes, including Universities (11), Research institutes (8), Industries (5) and Small and Medium Enterprises (4 SME’s), from several regions of the European Union (EU). The group represented a broad range of expertise in hydraulics, wind engineering, aquaculture, renewable energy, marine environment, project management, as well as expertise in socio-economics and governance (MERMAID Project 2015). MERMAID focused on developing concepts for the next generation of offshore platforms which can be used for multiple purposes, including energy production, aquaculture and platform related transport. The project did not envisage building new platforms, but examined new concepts, such as combining functions and building new structures on representative sites under different conditions. These concepts were developed with the input from experts as well as societal stakeholders (MERMAID Project 2014).

MERMAID designed concepts of Multi-use Offshore Platforms (herafter MUOPs) that addressed different physical conditions in order to make the best use of the ocean space. Going from deep water (north of Spain) to shallow water with high morphodynamic activity (north of the Wadden Sea) and further to inner waters like the inner Danish/Baltic areas and the Adriatic sea changes the focus from a

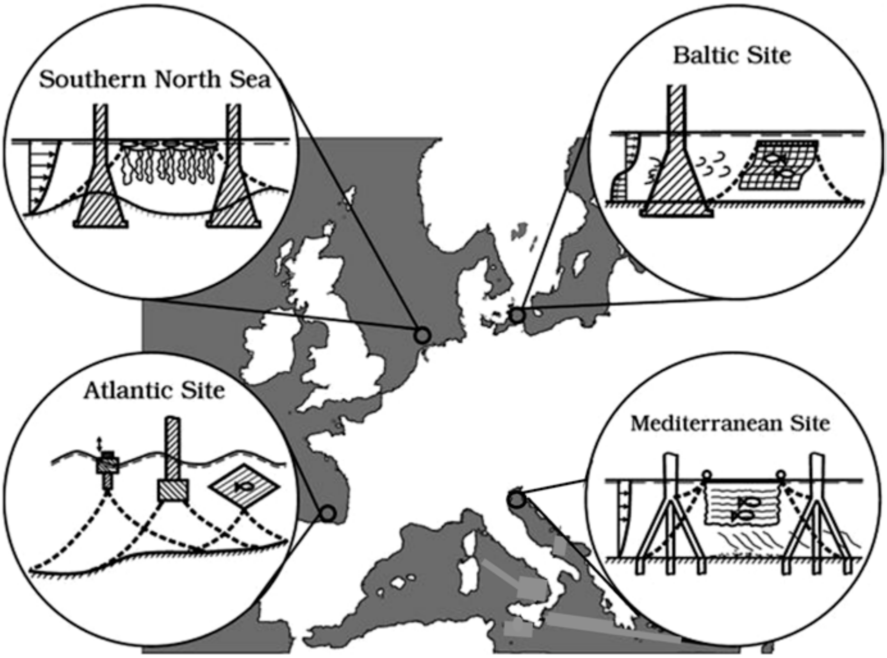

**Fig. 1.1** Map of Europe with close-up at the four sites, with focus on local challenges (MERMAID Project)

strong to low physical control of the environment. That made it possible to develop, assess and integrate different technologies but also to address site specific challenges concerning social, ecological and economic issues (Fig. 1.1).

Shared use of marine space implies shared environmental effects due to reduction of human activity in many different places. This is in line with the EU Directive on Maritime Spatial Planning (Directive 2014/89/EU) which is dedicated to establish efficient and sustainable planning of human activities that take place at sea. To ensure the sustainable development of MUOPs, the following need to be addressed: economic efficiency, social equity and environmental and ecological sustainability:

**Economic Efficiency** Economic efficiency satisfies the condition that the marginal (social) cost of each production activity under consideration equals the respective marginal (social) benefit. In this framework costs and benefits are considered in order to provide a holistic economic assessment in terms of efficiency. Production activities are considered sustainable, when the economic efficiency condition is satisfied over time and over space.

**Social Equity** Social equity requires that the social effects of the production activities are acceptable and affordable by the different social groups in the region. These affordability and acceptability conditions should be assessed spatially (intra-generational effects) but also dynamically (inter-generational effects).

**Environmental and Ecological Sustainability** Environmental and Ecological Sustainability ensures that the environmental and ecological effects of the activities under consideration are compatible with the persistence of vital ecosystems and their associated services over space (in the region under consideration) and time.

For the MERMAID project assessing the sustainability of MUOPs required the identification of the key impacts depending on the nature of the designs (floating, offshore, large size, combined activities). Their identification is important since they are expected to be financially and socially related to both the business/industry under consideration and to the wider local or regional community. Tables 1.1 and 1.2 present the potential socio-economic and environmental impacts, as well as activities affected due to MUOPs, respectively, without being exclusive (MERMAID Project 2012).

While aiming to develop MUOPs, specific policy, economic, social, technical, environmental, and legal (PESTEL) factors will become influential in some way. Recognizing these external factors to a business environment can assist in understanding the "big picture" in which businesses need to operate (Issa et al. 2010). For example: It is relevant to assure protection of the marine ecosystem by licensing procedures based on site-specific environmental studies and to guarantee the implementation of an environmental monitoring system in the designated marine areas for MUOPs development.

**Table 1.1** Activities affected

| |
|---|
| Commercial fishing |
| Recreational fishing |
| Commercial shipping |
| Yachting and recreational boating |
| Other water-based activities |
| Land-based activities |
| Regional tourism |

**Table 1.2** Socio-economic and environmental factors potentially impacted

| |
|---|
| Regional employment (direct and indirect) and training opportunities |
| Cultural and natural heritage |
| Access to local seafood and energy |
| Sustainable food and energy production |
| Risk potentially affecting the seabed and associated ecosystems |
| Risk associated with the characteristics of the water column and associated species |
| Risk to fish, mammals, turtles and birds |
| Risks related to the spread of invasive species and/or diseases |
| Environmental aesthetics |

The construction of MUOPs might cause a variety of different changes to the environment and human health. Since the first installation of offshore wind farms, these effects have been studied in increasing detail, and numerous publications have appeared on the subject (Degraer and Brabant 2009; Lindeboom et al. 2011; Bergström et al. 2013). The modification of the natural environment, i.e. the replacement of natural substrata with harder surfaces of stone, concrete, asphalt, metal or other artificial material can enhance the distribution of a number of species typical of hard substrata, some of which can thrive on these anthropogenic surfaces. Because of this, marine infrastructures are sometimes perceived as an opportunity for habitat enhancement, providing local benefits associated to hard substrata where none previously existed, or potential refuge for rare or threatened native rocky species. Also, there is evidence that marine infrastructures can offer particularly favourable substrata to many non-indigenous species (NIS). NIS may colonize from nearby natural rocky habitats or could spread out of ports, harbours, marinas, or other sources of introduction, especially when multiple artificial structures are built relatively close to one another. Furthermore, offshore structures provide some degree of refuge from trawling activities since for safety reasons it is forbidden to navigate closer than a distance of between 200 m and 1000 m from offshore platforms.

On the other hand, marine structures can seriously affect the genetic and species diversity (Fauvelot et al. 2009, 2012), the biological resources and the water quality because of the high levels of disturbance in the marine environment. The epifauna on the hard structures may compete for food with zooplankton or planktivorous fish, and create limiting amounts of food for these faunal groups, especially in accumulation when aggregations of offshore wind farms are placed within a larger area (which will be the case in the southern North Sea) (Maar et al. 2009).

Other disturbances may include possible increased noise, light and electromagnetic fields. The installation of offshore wind farms is commonly carried out by piling. This creates a large acoustic underwater disturbance that affects the distribution and possibly migration and feeding of marine mammals in a radius of some tens of kilometers around the pile for the period of windfarm construction, ca. a half year. Relevant for MERMAID is the possible interaction between marine mammals and the offshore constructions through the observed aggregation of fish, that may attract mammals instead of repelling them. Due to the foreseen installation of tens of GW of offshore windfarm capacity in various coastal areas, it is assumed that the accumulative effect of the installation and operation of offshore constructions such as wind farms could create longer-lasting impacts on marine mammals, both negative (piling) and positive (aggregation and added production of fish). The same holds for birds and bats that use the marine space for feeding, migration and resting. The offshore constructions create a behavioural change in birds using the marine surface as a resting and feeding area (Lindeboom et al. 2011), next to the possibility of mortal collisions with rotors. The increased availability of fish and shellfish within offshore constructions may influence (both in negative and in positive terms) the distribution and fitness of birds. Last, electromagnetic fields (EMF) from cables running over the seafloor may impede foraging and migration of rays and sharks, due to interaction of the EMF with the electrosensory organis of these animals used for foraging (Gill 2005).

MUOPs can interfere or interact with several of these wind farm effects. Seaweed aquaculture may use nutrients that cannot be used by phytoplankton and cause nutrient depletion that may have effects on higher trophic levels (zooplankton, fish). Shellfish aquaculture such as for blue mussels may have a comparable effect, but then filtering algal biomass that will not be available to zooplankton and/or fish. Structures supporting such aquaculture may add to the amount of hard substrate and strengthen their effects. There is a lack of knowledge on the possible environmental and ecological interactions of MUOPs when based on offshore wind farms platforms.

In order to understand if and how the environment is being affected by the projects, and to avoid, minimize and eventually offset the adverse significant negative impacts, an environmental monitoring program is necessary that the business can use to guide their operations. Depending on the specific uses within the MUOPs, the environmental monitoring system could focus on issues such as e.g. spreading of invasive species, biodiversity, underwater noise and electromagnetic radiation, water pollution, along the lifetime of the project, preceded by environmental baseline studies. In some countries such as the Netherlands, it is currently forbidden to navigate within offshore wind farms at all. This creates the possibility for the benthic assemblage to recover from repeated and long-term trawling, although the anticipated positive effects seem to be time and substrate dependent (Bergman et al. 2014; Duineveld et al. 2007).

There is a call for clear policy frameworks at all levels to offshore multi-use platform development to make developers more willing to invest in MUOPs. This policy framework should adhere to the principles of Marine Spatial Planning (MSP) to foster sustainable use of marine space and it should also include permits and licensing procedures. At the moment it appears that the start-up of MUOPs comes with substantially higher investment costs and risks as compared to business-as-usual projects. Therefore mechanisms of financial support are needed to enhance the first stages of the development of MUOPs and make the investment more attractive.

Research in MERMAID has been conducted with the aim to involve various stakeholders of relevance. Involving different stakeholders has shared and increased knowledge on the difficulties with regards to the development and implementation of MUOPs. It is recommended to get familiar with this knowledge. This helps taking into account a variety of institutional, technical, environmental, financial and socio-economic aspects in MSP and for developing policy instruments that can support the development, implementation and running of MUOPs.

The recommendation is to engage different stakeholders in spatial planning and when developing policy instruments for offshore MUOPs. Important stakeholders are business partners and the potential future developers, environmental authorities, local and/or regional administration, relevant professional associations, local Non-Governmental Organisations (NGOs), and research institutes. The most valuable lesson derived from Van den Burg is that stakeholder involvement is indeed very valuable for the development and acceptance of the designs. However, the involvement can differ for each site and that consequently the selected approach should be tailored to the situation. During the MERMAID project, at the Baltic site, a clear selected group of stakeholders examined the feasibility of realizing a MUOP at a specific location, whereas at the Atlantic and Mediterranean sites, the idea of MUOPs was unclear and the process brought together stakeholders to explore the wider issue and potential of MUOPs at these locations.

This book derives from the interdisciplinary research within MERMAID in developing and applying an Integrated Socio-Economic Assessment of the sustainability of Multi-Use Offshore Platforms, using the results from the natural and engineering sciences as inputs, boundaries and constraints to the socioeconomic analysis. In this framework the economic, social and environment impacts of the proposed MUOPs, are identified, quantified and expressed in monetary terms, as detailed in the following chapters. The analysis concludes with a discussion on the challenges and obstacles to the MUOPs development and recommendations to consider.

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# Part I
# Socio-economic Assessment of Multi-use Offshore Platforms

## Chapter 2
# Methodology for Integrated Socio-economic Assessment of Multi-use Offshore Platforms

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**Abstract** This chapter presents the methodology employed for the Integrated Socio-Economic Assessment (MISEA) of different designs of Multi-Use Offshore Platforms (MUOPs). The methodology allows for the identification, the valuation and the assessment of the potential impacts and their magnitude. The analysis considers a number of feasible designs of MUOP investments, and the likely responses of those impacted by the investment project. The approach provides decision-makers with a valuable tool to assess whether a MUOP project increases the overall social welfare and hence should be undertaken. This is performed under alternative specifications regarding platform design, the discount rate and the stream of net benefits, if a Cost-Benefit Analysis (CBA) is to be followed or a sensitivity analysis of selected criteria in a Multi-Criteria Decision Analysis (MCDA) framework. The

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methodology can support the implementation of policies aiming at achieving a good environmental status of the EU's marine waters and the protection of the resource base upon which marine-related economic and social activities depend.

**Keywords** Marine spatial planning • Multi use offshore platforms • Socio-economic assessment • Environment • Ecosystem services • Cost-benefit analysis • Multi-criteria decision analysis • Life cycle assessment • Risk analysis • Monte Carlo

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## 2.1 Introduction

MERMAID project developed concepts for a next generation offshore platforms for multi-use of ocean space for energy production, aquaculture and platform related transport. The project examined different concepts in design, such as a combination of structures or different uses on representative sites under different conditions. Under this scope the project combined, integrated and improved available technology in a way that it enhances economic feasibility, it reduces the environmental impact and it increases the optimal use of the available ocean space at specific sites.

Within this framework, an integrated socio-economic analysis has been performed with the aim to identify and quantify the impact of the related activities on human welfare. The analysis focusses on financial feasibility and also looks into the social and ecological aspects, including consideration of the distribution of all impacts across the different stakeholders. In this manner it is provided a comprehensive socio-economic analysis that adds in a useful manner by taking into consideration the social and cultural values within the ecosystem services frameworks.

The methodology can be used to facilitate the implementation of the EU water framework directive as defined in the guidance document of the Marine Strategy Framework Directive (MSFD-Directive 2008/56/EC). The MSFD was adopted in June 2008 and it aims at achieving good environmental status of the EU's marine waters by 2020 and at protecting the resource base upon which marine-related economic and social activities depend. In the MSFD, a thematic strategy for the protection and the conservation of the marine environment has been developed with the aim of promoting the sustainable use of the seas while protecting marine ecosystems.

In terms of energy, the European Commission's Renewable Energy Roadmap states a mandatory target of 20% share of renewable energy in the EU's energy mix by 2020. In relation to aquaculture, the Commission published in 2009 a communication to give new impetus to the sustainable development of European aquaculture sector. This strategy has three key elements: (a) help the sector become more competitive through strong support for research and development and better spatial planning in open sea areas and river basins, (b) ensure it remains sustainable by maintaining environmentally-friendly production methods and high standards of animal health and welfare and consumer protection and, (c) improve governance and ensure there is a business-friendly environment in place at all levels – local, national and EU – so the sector can accomplish its full potential.

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This chapter presents the methodology employed for the assessment of MUOPs in accordance to the MSFD. The methodology develops in steps as follows: First, it is undertaken the socio-economic characterization of the selected MERMAID sites (North Sea, Mediterranean Sea, Baltic Sea and the Atlantic Coast). Second, the production and demand structures of the proposed MUOPs are investigated. This is done by the identification and the quantification of the costs and the benefits of suggested MUOPs by using market and non-market methods in order to capture private, social/public and ecological effects. At a final stage, policy recommendations are based on economic tools such as Cost-Effectiveness Analysis (CEA), Cost-Benefit Analysis (CBA) and other approaches to socio-economic analysis such as Multi-Criteria Decision Analysis (MCDA).

The remainder of the chapter develops as follows: Sect. 2.2 discusses the assessment scooping. Baseline profiling and characterization of production and demand of MUOPs is presented in Sect. 2.3. Section 2.4 presents the data requirements and availability and Sect. 2.5 discusses the different tools and methodologies that can be used to assess the socio-economic impact of MUOPs. Section 2.6 discusses the risk analysis approaches employed. Section 2.7 discusses the life cycle assessment approach of MUOPs. Last section concludes.

## 2.2 Scoping the Assessment

The ‘scoping’ phase of the socio economic impact assessment (SEIA) establishes the goals and boundaries of the assessment and focuses the SEIA on key impacts. In this context, it is important to focus on the significant impacts in order of priority and to identify all the significant effects on all impacted groups.

### *2.2.1 Key Impacts of MUOPs*

The key impacts of the MUOPs are dependent on the nature of the designs (floating, offshore, large size, combined activities, etc.). Considering that the suggested methodology extends financial analysis to consider also social and ecological parameters, it is foreseen that impacts are related not only to private agents, firms and individuals but also to the society as a whole and to the environment.

The following potential risks associated with MUOPs have been identified:

- effects on the seabed
- properties of the water column
- faunal composition
- spread of invasive species and/or diseases

It is considered that the MUOPs have socio-economic and environmental impacts on commercial shipping and fishing, recreational fishing, yachting and boating and other water-based activities. They also have an impact on land-based activities, regional tourism, processing transport, regional employment (direct and indirect) and training opportunities (Social Sciences Program et al. 2005).

### *2.2.2 Impacts on Environment and Ecosystem Services*

The ecosystem services approach (ESA) can be employed in order to perform the socio- economic analysis and to integrate environmental impacts. Ecosystem services are defined as services provided by the natural environment that benefit human welfare. As defined in the Guidance document of the MSFD the ESA starts by identifying the ecosystem service of the marine area, link them with human welfare and elicit their value. The ESA establishes an environmental baseline, identifies and provides a qualitative assessment of the potential impacts of policy options on ecosystem services and quantifies the impacts of policy options on specific ecosystem services. Finally, the ESA assesses the effects on human welfare and values the changes in ecosystem services (DEFRA 2007). When assessing the impact of ecosystem services on human welfare, it is critical to focus on the benefits generated by these services, as this is what affects human welfare directly. It is, therefore, the benefits rather than the services per se that are valued.

### *2.2.3 Extent of Appropriate Information for Undertaking the Assessment*

Due to the multidimensional character of the impacts leading to welfare gains and sometimes losses, a range of different information is needed in order to assess them. Thus, market data, secondary data for the performance of simulations, survey based primary data, data provided from literature review, consultation with experts and stakeholders and information coming from environmental impact assessments are all deemed as important in the framework of integrated environmental and socio-economic assessment. The MISEA of the viability/sustainability of MUOPs is developed using a general framework of analysis and a method of analysis depending on whether the data is available or not. Under sufficient data availability all steps of MISEA can be fully applied. Under limited data availability a parsimonious, generic approach to multi-dimensional impact assessment can be employed.

## 2.3 Profiling Baseline Conditions and Characterization of Production and Demand of MUOPs

This part of the framework focuses on gathering information about the socio-economic environment and context of the proposed development with regard to energy production, aquaculture and maritime services. Hence, before achieving the evaluation of the socio- economic impact it is necessary to start with the baseline profiling of the case study areas in order to identify who is going to be impacted. Thus, this approach enables the identification of the production and demand functions of the MUOPs.

### *2.3.1 Description of Case Studies and Socio-economic Characterization*

The MERMAID project looked into four case studies, in four different natural environments, from deep water (north of Spain), to shallow water with high morphological activity (the Wadden/North Sea), and further to inner waters like the inner Danish/Baltic areas and the Mediterranean. The activities related to the socio-economic characterization regard gathering information on baseline conditions of the wind power production, aquaculture, transport maritime services and wave energy activities.

In order to assess the indirect and the induced impacts a regional profiling is necessary. The information typically gathered as part of a regional profile includes the population characteristics, the political and social resources, a description of historical factors, identification of the relationships with the biophysical environment, culture, attitudes and social-psychological conditions, the current status of operations (aquaculture, energy production, maritime services) and the identification of the people who will be impacted by the project (Social Sciences Program et al. 2005).

The initial (baseline) assessment includes economic and social analysis of the use of those waters under current use and future autonomous developments. This baseline assessment should include both market and non-market costs and benefits (Eftec and Enveco 2010). The scope is the profiling of all current uses and identifying businesses, households and individuals that may be impacted by the future installation of MUOPs. In addition, broader social and environmental issues related to current and future operations should be highlighted.

## *2.3.2 Production and Demand Structures of the Proposed MUOPs*

In this step are identified the economic, environmental and social issues with regards to the level of employment, regional development and overall attitude of the population towards the technologies and specific options proposed. The production and demand analysis is based on economic data, environmental valuation surveys (if deemed necessary) and Benefit Transfer (BT) techniques. The production side analysis of the proposed MUOPs is based on the proposed financial costs of offshore structures as well as on the social and environmental costs.

### 2.3.2.1 Identification of Private/Financial Costs of Suggested MUOPs

The identification of the private costs of the suggested offshore structures with regard to aquaculture, energy and maritime services is the first step of the production-side analysis. This step considers the capital costs which are the upfront costs to construct, install the project hardware and major maintenance work that needs to be carried out during the lifetime of the platform beyond typical operating expenses.

Platform development costs may include: technical, legal and planning consultants' fees, and the developer's own time, in negotiations with legal and statutory bodies, financing and legal costs, including the costs of arranging finance and others. Running and operation and maintenance costs per year may include: fuel costs, if applicable, direct costs, staff costs, insurance fees, transport costs, annual fees for licenses and pollution control measures, general maintenance and operating costs, equipment, site, etc. Finally, training costs are expected to cover the training of people who will run the platforms with regard to the safety, financial and environmental implications of the project.

### 2.3.2.2 Identification of the Social and Environmental Costs of Suggested MUOPs

Since the scope of the developed methodology is to integrate private and social/environmental costs of the suggested MUOPs it is equally important to consider the latter in the suggested framework of analysis. It is considered that offshore renewable energy installations (e.g., wind farms, energy wave devices) all have local environmental impacts (e.g., to local submarine habitats and seabird populations). Especially in the case of wind farms a regional scale 'displacement' impact e.g., displacement of fishing by marine protected areas around wind turbine sites and consequent increase on the fishing pressure in 'unprotected' areas or a boost in jelly fish populations may be expected. Aquaculture is associated with local environmental consequences and potential impacts on the marine food web via fish food provision and accidental releases of fish with a low genetic diversity (Turner et al. 2010).

#### 2.3.2.3 Demand-Side Analysis of Potential Production of Goods and Services of Proposed MUOPs

The analysis here focuses on the estimated financial and social/environment benefits of the offshore structures. Private and financial benefits of the suggested MUOPs could result from the sale of energy, aquaculture products and maritime services. Additional benefits could be derived from saving in fuel consumption and reduction of energy expenditure or by product sales (or displaced costs), greater productivity (macro scale) and higher real disposable income (at a macro level). Direct and indirect employment is also part of the social benefits resulting from MUOPs.

Environmental benefits include: mitigated global warming, avoided emissions-compared to non-existent wind farms of current status, improved water quality near the coast or seabed life through less use of pharmaceuticals. The marine and coastal zone interventions and their benefits can be linked to four environmental impacts/effects categories (relevant for human welfare): direct and indirect productivity effects, human health effects, amenity effects (congestion), and existence effects such as loss of marine biodiversity and/or cultural assets.

## 2.4 Data Availability and Approaches for Socio-economic Impact Assessment of MUOPs

In order to proceed to the socio-economic impact of MUOPs it is important to construct a list of impact indicators as discussed above. The economic figures can be more easily identified while this is not the case with the information on the social and environmental impacts. Social and environmental indicators are associated to hidden impacts and may be viewed as positive or negative externalities. Table 2.1 summarizes the suggested impact indicators and relevant data that can be employed in the analysis.

## 2.5 Methods for the Quantification of the Costs and the Benefits

Considering the complex nature of the socio-economic and environmental impacts, different approaches are needed in order to quantify them. One theoretical approach of capturing and describing the benefits derived from the different ecosystem services is the Total Economic Value (TEV) framework. It provides a systematic tool for considering the full range of impacts the marine environment has on human welfare. TEV can be derived from the preferences of individuals.

For ecosystem services, preferences can be studied by stated preference methods and revealed preference methods (see Eftec 1999). Revealed preference methods rely on data regarding the preferences of individuals for a marketable good and

**Table 2.1** Indicative impact indicators

| Impact | Indicator |
|---|---|
| Financial | Capital cost |
| | Project development costs |
| | Running and operation and maintenance costs/Training costs |
| | Income |
| Social | Employment |
| | Education |
| | Self-reliance (energy and food security) |
| | Community benefits |
| | Financial return – this can be for the individual but also for the community for community based schemes |
| | Diversification of rural incomes |
| | Local employment |
| | Contribution towards environmental sustainability and potential for combining with Green Tourism |
| | Some degree of control over the scheme for the community (for community based schemes) |
| | Local hydrology |
| | Sense of satisfaction for those involved and building capacity |
| | Health hazards related to the operation of the platform and associated equipment |
| | Other interrelated factors, such as air quality |
| Environmental | Emissions-climate change |
| | Noise (compared to inshore constructions) |
| | Visual (compared to inshore constructions) |
| | Recreation |
| | Risk abatement |
| | Transport of fuel |
| | Local and global issues |
| | Navigation routes |
| | Decommissioning |
| | Product/by product disposal |
| | Effect on the marine ecosystem, erosion, local hydrology |

could be divided in market-based and surrogate markets related. Surrogate market related methods include travel cost method and hedonic pricing. Stated preference methods use structured questionnaires to elicit individuals' preferences for a given change in a natural resource or environmental attribute.

In this category, the contingent valuation method (CVM) and choice experiment (CE) are included. The CVM is based on the development of a hypothetical market or scenario in which the respondents to a survey are given the opportunity to state their Willingness-to-Pay (WTP) or Willingness-to-Accept (WTA). Different elicitation methods are used to derive the WTP/WTA amounts and because these values are contingent on the hypothetical market the method is called CVM.

CE is another stated preference method. In a CE framework, the good in question is broken down into its component attributes, which are presented to respondents normally as a set of combinations of the attributes. Respondents are then presented with a sequence of choice sets differentiated by attributes and levels (Bennett and Adamowicz 2001; Birol and Koundouri 2008).

The fact that gathering primary site-specific data is costly has made the Benefit Transfer (BT) method a popular alternative for the valuation of ecosystem goods and services. BT is about applying existing economic value estimates from one location where data are collected to another similar site in another location with little or no data (Rosenberger and Loomis 2000). Bergland et al. (1995) discuss three main approaches to BT: (i) the transfer of the mean household WTP, (ii) the transfer of an adjusted mean household WTP, (iii) the transfer of the demand function.

### *2.5.1 A Maximum Data Approach for Socio-economic Impact Assessment*

An important goal of the SEIA is to identify the socio-economic impact of MUOPs by adopting an integrated approach. In the framework of a maximum data approach the CBA, CEA as well as MCDA emerge as useful means to achieve the goals of SEIA. While the CBA evaluates the social profitability of the relevant programs, CEA evaluates the programs against predetermined objectives.

MCDA takes into account project impacts that are not easily given monetary values. It involves a structured approach to differentiating between a range of options, based on a set of objectives or criteria, against which each option is assessed. As argued in Turner et al. (2010, p.33): "*The choice between CBA and CEA is determined by the nature of the policy problem under scrutiny. If the problem is one of meeting some environmental standard, complying with a law or achieving a target then finding the least cost way of achieving this by completing a CEA is the appropriate action. If the problem is one of choosing between a number of different possible policy or project options which do not involve compliance with standards or targets then CBA is the most appropriate assessment tool. If the situation is one where monetary valuation is not possible then CEA and CBA should be replaced with a multi-criteria assessment process.*" The following subsections present the different versions (CEA, CBA, and MCDA) of the full data approach which depends on specific data availability.

### 2.5.2 *Cost-Effectiveness Analysis (CEA)*

CEA is a type of economic evaluation that compares the cost of the investment to its effectiveness. Hence, CEA is a form of economic analysis that enables comparison between different kinds of interventions with similar effects (outcomes) on the basis of the cost per unit achieved. CEA is distinct from CBA, which assigns a monetary value to the measure of effect. Hence, this approach may be deemed more practical for selecting between investment options when the budgets are fixed and/or the benefits are hard to monetize while it only requires marginal economic data on costs.

### 2.5.3 *Cost-Benefit Analysis (CBA)*

CBA is a technique that assesses the monetary social costs and benefits of an investment project over a time period as compared to a well-defined baseline alternative. In this way, the costs and the benefits of MUOPs are evaluated and compared and the long-run economic efficiency of implementing the project of MUOPs is assessed. In a CBA framework, the estimated economic values accrued by the involved stakeholder groups are aggregated over their relevant populations and added to capture the TEV generated by the investment project. A project is deemed to be profitable if the total benefits exceed total costs. Due to the project's expected long-run impacts on the local economy and ecology, its sustainability is to be tested using a long-run CBA, and the net present value (NPV) of the project is to be estimated with the use of different discount rate schemes (Birol et al. 2010).

The NPV results reveal whether the net benefit generated by the investment project of MUOPs is positive and significant well into the future. A general calculation of the NPV is formulated as follows:

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

where $K_t$ is the construction cost, $B_t$ is the stream of benefits, $C_t$ is the stream of maintenance costs and r is the discount rate.

The Internal Rate of Return (IRR) is another important aspect of a CBA. It is the discount rate for which the NPV is zero. Since a CBA of long-term investments is enormously sensitive to the discount rate, the use of the classical NPV in the long term is problematic. Recent economic literature (Koundouri 2009; Gollier et al. 2008) proposes the use of a Declining Discount Rate (DDR). The use of DDR in long–run cost–benefit analysis can replace traditionally employed constant discount rates. The policy implications aligned with the project's nature and EU's policy aspirations, are that it implies that the policy-maker will put relatively more effort into improving social welfare in the far distant future than in the short term.

### *2.5.4 Multi-Criteria Decision Analysis (MCDA)*

MCDA is a method for preparing structured and transparent support to decisions, when there is a large amount of complex information. MCDA can be used for different purposes, e.g.: (1) to identify a most preferred alternative, (2) to rank alternatives against each other, (3) to short-list a set of alternatives or (4) to distinguish the acceptable alternative from the unacceptable. A full MCDA includes, apart from identifying the decision alternatives and the relevant criteria to be assessed, scoring, weighting and finally the combination of these into an overall value for each alternative (Communities and Local Government 2009).

In order to apply an MCDA for a sustainability evaluation of MUOPs it is necessary to define a set of economic, social and ecological criteria which focus on the nature of MUOPs. However, it should be clear that as a method for economic analysis, MCDA is considered inadequate to deliver information required by the MSFD when it "does not present comparisons of costs and benefits that provides a CBA of potential measures or informs whether their costs are disproportionate, and therefore would not comply with the minimum requirements of the Directive" (Eftec and Enveco 2010, p.33).

### *2.5.5 A Limited Data Approach for Socio-economic Impact Assessment*

The "minimum-data Trade-off Analysis" (TOA-MD) is well-suited to address the uncertainty in impact assessments. This approach relies on a form of a generic TOA-MD model that can be employed to assess impacts in agricultural, social and economic data populations (Antle and Valdivia 2010). The TOA-MD model is a prominent simulation tool that employs a statistical description of a heterogeneous population of decision making units (DMUs) to simulate the proportion of DMUs that utilizes a baseline system and the proportion of DMUs that would adopt an alternative system within defined strata of the population. The critical decision for adopting limiting data approach is made in terms of acquiring the most robust and informative results under the constraint of available list of data for each case study.

## 2.6 Risk Analysis Approach

It should be clear that all results should be subjected to a rigorous uncertainty/sensitivity analysis since uncertainty is present at all stages of the assessment process. A way to explore uncertainty is through sensitivity analysis. This approach can be used to identify the parameters of the system which are particularly subject to uncertainty and have a significant impact on the outcome of the assessment. A sensitivity analysis can be included in the CBA, to assess the impact on the benefit cost ratio and/or net present value of changes in the values of central parameters (Turner et al. 2010). In a CBA framework it may be relevant to perform an uncertainty analysis rather than just sensitivity analysis, e.g. by assigning parameter uncertainty in the CBA and performing Monte Carlo simulations as described next.

### Risk Analysis

Risk analysis or risk assessment aims to address uncertainty associated with the future cash flows of a project. For the specific project that analyses the viability/sustainability of MUOPs, costs and benefits associated with offshore wind farms and aquaculture are expected to embody considerable uncertainties. The risks associated with the project could be classified as: (i) economic, (ii) natural – environmental, and (iii) technological. These risks affect the cash flows of the project and consequently the net present value (NPV), the IRR, and the benefit cost ratio (B/C) of the project. The NPV, IRR or B/C are the main objects in carrying out risk analysis. Within the context of the project, two types of risk assessment are studied: (i) Sensitivity analysis, and (ii) Monte Carlo simulations.

### Sensitivity Analysis

Sensitivity analysis is a technique that determines the values for the NPV or the IRR which correspond to proportional deviations of variables that affect the cash flow of the project from a base case.

Sensitivity analysis involves the following steps:

1. Definition of a base-case or benchmark estimation of the NPV and the IRR, which is developed using the expected values for each variable involved in the cash flow.
2. Identification of sensitive or critical variables. These are cash flow variables (e.g., unit labour cost, average wind velocity, fish output, fish price) with the property that a small deviation of their values from the benchmark value will change the NPV or the IRR a lot.
3. Construction of a sensitivity diagram that relates proportional changes in the critical variable to NPV or IRR values.
4. Identification of switching values for important cash flow variables. A switching value is the value of the variable at which the NPV becomes zero or falls below a cut-off level.

### Monte Carlo Method

The Monte Carlo method is a computational algorithm which is based on random sampling. To use the method the analyst needs to assign specific subjective probability distributions to important cash flow variables. The method proceeds in the following steps:

1. A value for a variable of interest is selected from its assumed distribution using a random number generator.
2. A vector of specific values is defined for these variables (e.g. unit labour cost, average wind velocity, fish output, fish price), and these values are used to calculate an NPV and an IRR.

3. After a large number of replications a frequency distribution is estimated for the NPV and/or the IRR.
4. Making the normality assumption the estimated distribution can be used to construct confidence intervals and perform hypothesis testing. The purpose of performing a Monte Carlo simulation of the uncertainty in a NPV of a CBA is to see how big the uncertainty in the NPV is.

**Application**

The purpose of risk analysis for the specific project is to apply sensitivity analysis – and potentially, depending on the availability of disaggregated data that will allow the meaningful approximation of probability distributions for important variables, Monte Carlo simulations in order to assess the stand alone risk of the project. The methodology is applied to provide a risk assessment of the economic viability/sustainability of MUOPs in the specific areas. To perform an adequate risk analysis the cash flow of the project should be provided in a suitably disaggregated form so that critical variables and their uncertainty in terms of probability distributions can be determined.

## 2.7 Life Cycle Assessment of Multi-use Offshore Platforms

Life Cycle Assessment (LCA) aims at determining the environmental effects of a product/function of a product based on a “from cradle to grave” view. LCA can be used to make a “strengths and weaknesses” analysis, product improvement and product comparison. It may contribute to remedies in design stage and provide environmental and economic benefits. LCA developed in the stages that include: (i) identifying and quantifying the environmental loads involved (energy and raw materials used, emissions, wastes), (ii) assessing and evaluating potential environmental impacts of the loads, and (iii) assessing the opportunities available to bring about environmental improvements (UNEP 1996). This stage continues to the end of the study because LCA is an iterative process. In the assessment of the MUOPs LCA will be used as a comparison tool between single use and multi-use so as to evaluate the feasibility of MUOPs by means of environmental impacts.

## 2.8 Concluding Remarks

The methodological approach discussed here can provide decision-makers with valuable alternatives and insights regarding different aspects of the recommended novel constructions. The results from the adoption of this methodology as discussed in the following chapters, suggest whether the projects in question should be undertaken under alternative specifications regarding the discount rate, and the stream of benefits if a CBA is to be followed or sensitivity analysis of selected criteria in an MCDA framework.

The outcome of these efforts provides support to policy makers for the project appraisal and evidence on whether MUOPs will result in an increase of the overall social welfare. In addition, the SEIA provides insight on the determinants of the public attitudes toward MUOPs that national and European policy makers should take into consideration when selecting policy responses for efficient energy management.

Another important contribution of the MISEA derives from the increase in the transparency of decisions that emerges from a visible analysis of benefits gained by some agents; costs borne by others and the limits on transfers justified by the projects.

Overall results assess the viability of the novel constructions that optimize marine space allocation for different marine activities and provide evidence of their potential to provide us with environmentally–friendly and cost–efficient energy, food supply and maritime services. In a European context, the results of the MISEA directly contribute to the adopted EU Green Paper on Energy (COM 2006) which develops a European strategy to ensure energy security, stable economic conditions and effective action against climate change. They also ensure accordance with the EU Marine Strategy Framework Directive demonstrating in this way a sustainable use of the marine environment.

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# Chapter 3
# Socio-economic Analysis of a Selected Multi-use Offshore Site in the Baltic Sea

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**Abstract** Denmark has designated the area of the Kriegers Flak to install an offshore wind farm of 600 MW, which is planned to be fully operational in 2022. This chapter investigates the combination of wind turbines and offshore aquaculture. The fish farming is planned as two separate facilities located between the two groups of turbines and 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. Although the Social Cost Benefit Analysis of the multi-use platform scenario was not completed due

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to lack of information, the scenario is expected to be sustainable considering the current policy and institutional framework, as well as the environmental and socio-economic effects.

**Keywords** Multi-use offshore platforms • Marine infrastructure • Socio-economic analysis • Environmental analysis • Marine spatial planning • Baltic Sea

## 3.1 Introduction

The Baltic Sea is the world's largest estuary, comprising salty North Sea water mixed with freshwater from rivers from Russia, Scandinavia, the Baltic countries, and a large part of Northern Europe. The specific location selected for the MERMAID Project is called Kriegers Flak, which is a shallow ground (25 m) within the Danish Exclusive Economic Zone (EEZ) in the estuary of the Baltic Sea, approximately 15 km from Danish and Swedish coasts. The Kriegers Flak is a large sandy shoal with a sand layer thickness of up to 8 m located in the Western Baltic Sea between Denmark, Sweden and Germany. The site is characterized by medium, but high quality, wind resource, moderate exposure to waves, and currents and salinities and temperature, being close to optimal for salmon aquaculture (Fig. 3.1, Table 3.1).

Denmark has designated the area of the Kriegers Flak to install an offshore wind farm of 600 MW, which is planned to be fully operational in 2022. Since Kriegers Flak has good conditions for fish farm activities, the ultimate objective is to combine wind turbines and offshore aquaculture. The wind farm is estimated to consist of two areas with a total of 8 MW turbines. The seabed conditions are good, thus foundations may be of gravity-base type or driven monopiles. In addition to the turbines, two 220 kV substations and necessary submarine cables to onshore connections are planned.

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

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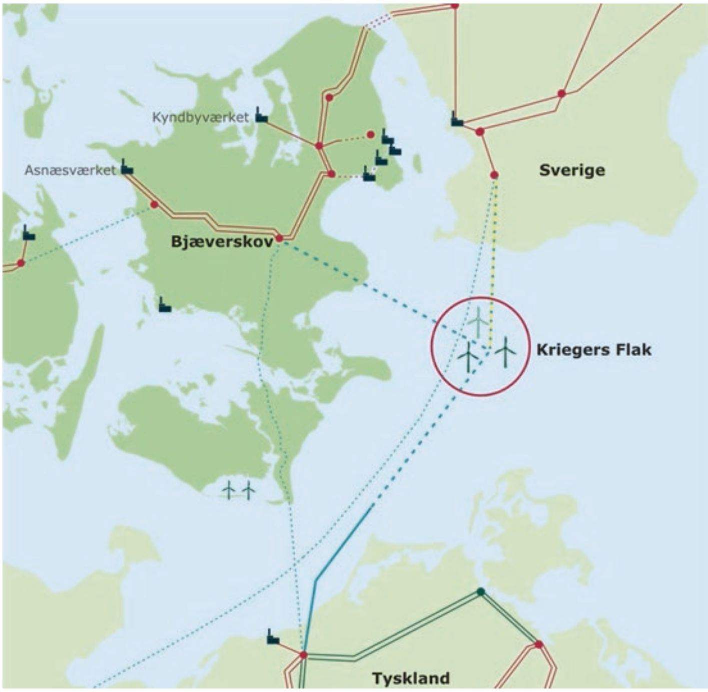

**Fig. 3.1** Location of Kriegers Flak

**Table 3.1** Basic facts about the Kriegers Flak

| Geographical location | Kriegers Flak, Western Baltic Sea (site) |
|---|---|
| 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 | Variable currents driven by wind, gradients & differences in sea level |
| Mean tidal range | No tides present |
| Wave height | Mostly moderate (1–1.5 m) |

Source: http://www.vliz.be/projects/mermaidproject/docmanager/public/index.php?dir=Outreach_Material%2F&download=MERMAID_Booklet.pdf

cages might be either floating or submersible. The conditions at the site are favourable in terms of dilution of waste from the farm and optimal conditions for fish growth and quality. (MERMAID project 2015, 2016).

The socio-economic analysis of the multi-use design for the Kriegers Flak site is applied as follows: The case study is put into a socio-economic context in Sect. 3.2 through identifying and describing actors, economic sectors and institutions. In Sect. 3.3, the environmental impact of the multi-use is analysed, and the potential of valuing these impacts in monetary terms is assessed. An initial financial and economic assessment of the multi-use design is found in Sect. 3.4, which is followed by an attempt to apply a social cost-benefit analysis in Sect. 3.5. Given that data for both functions were not available; a Social Cost-Benefit Analysis (SCBA) was applied to the single use scenario aiming to support the importance of considering possible externalities, i.e. non-market economic impact, into the analysis. Section 3.6 concludes.

## 3.2 The Case Study in a Socio-economic Context

This section aims at contributing to an improved understanding of the effects of the multi-use design by providing a brief description of the case study profile. Demographic and socio-economic facts are provided, stakeholders are identified, and relevant institutional and policy settings are described.

### *3.2.1 Demographics and Economic Activities*

The land area of the study site amounts to 7273 km$^2$. The population accounted for 816,172 inhabitants in 2012 with density of 112 inhabitants per km$^2$. The population of the study site exhibits a rather balanced distribution between male (49.6%) and female (50.4%), while the average household size is around 1.8 persons per household. The qualitative aspects of human resources in the study site can be revealed through the educational level of the population. The educational attainment indicates a rather high share of population with elementary education (34%), and a low share of population with higher education (22%), while almost 44% of population has secondary education.

Total employment in the Baltic site amounts to 370,000 persons (2013). The employment synthesis is rather balanced since male employment amounts to 51% and female employment accounts for 49%. Unemployment rate in the region amounts to 7.4% (30,000 persons). The structure and organization of the regional economy can be studied through the analysis of the sectorial employment. The analysis of employment by branch of economic activity portrays that the major sectors offering employment in the region are the public administration, education and health sector (35%) and the trade and transport sector (21%). Overall, regional economy is highly services-oriented since the tertiary sector accounts for 77% of total employment, while the secondary sector contributes by 21%. The contribution of the primary sector to total employment has been contracted to 2%.

The total value of regional production in the study site amounts to 432,125 million DKK (2011). In terms of the sectoral shares of regional production, the tertiary sector contributes about 62% to the regional product generation, the secondary sector contributes by 36%, and the primary sector by only 2%. In particular, the manufacturing industry contributes by 30% in the regional product formation, the wholesale trade sector by 27% and the transportation sector by 12%.

The planned windmill park is expected to create 10,000 jobs during the construction phase. The operational and maintenance needs of the MUOP will secure jobs and will act as an international window for Danish know-how. Both aquaculture and wind energy extraction will benefit from sharing seabed area in terms of sharing transportation costs, housing etc.

### *3.2.2 Stakeholders*

The most vulnerable groups to wind power production in the study site are: (a) energy suppliers; (b) persons involved in equipment and machinery sector; (c) energy consumers; (d) persons involved in transport constructing and letting activities. The most vulnerable groups to aquaculture in the study site are: (a) fishermen; (b) persons involved in transport constructing and letting activities; (c) persons involved in tourism activities; (d) persons involved in transport and storage activities. The most vulnerable groups to transport maritime services in the study site are: (a) fishermen; (b) persons involved in tourism activities; (c) persons involved in transport and storage activities. The most vulnerable groups to wind energy production in the study site are: (a) energy suppliers; (b) persons involved in equipment and machinery sector; (c) energy consumers; (d) persons involved in transport constructing and letting activities. In all four cases the geographic location of stakeholders who may be impacted by the proposed changes is within the Danish economic zone at the Kriegers Flak in the Baltic Sea (van den Burg et al. 2016; MERMAID project 2013).

Aquaculture has great opportunities in remote areas of Denmark in terms of growth and jobs. However, NGOs are opposed to aquaculture because of the emission of nutrients and the interaction with habitats and species. NGOs primarily focus on the discharge of nutrients and the use of antifouling to the nets. In general, fish farms and aquaculture at sea are less accepted by the public compared to wind farms. However, all these public images can change. There is currently a debate that argues that aquaculture is not polluting and produces healthy food in an environmentally efficient and correct way. Furthermore, it is likely that the pylons and foundations of turbines would 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 environmental impact of the fish production. Finally, the development of a MUOP can create opposition for developing more intensive economic activities at sea (van den Burg et al. 2016; MERMAID project 2013).

## *3.2.3 Institutional and Policy Framework*

### 3.2.3.1 Policies Related to Offshore Wind Energy

The Danish Government provides the main conditions for offshore wind parks in the Promotion of Renewable Energy Act (Act no 1392 27th December 2008), and the Danish Electricity Act (Danish Energy Policy 2012). Chapter 3 is mainly relevant for off-shore wind parks. This chapter regulates the access to exploiting energy from water and wind offshore. Most important condition is that the right to exploit energy from water and wind within the territorial waters and the exclusive economic zone (up to 200 nautical miles) around Denmark belongs to the Danish State. The act also lays down the procedures for the approval of electricity production from water and wind and pre-investigation.

Some of the most important sections of the Renewable Energy act (2008) are: (a) approval for preliminary investigations shall be granted either after an invitation for applications in a tendering procedure or after receipt of an application; (b) approval for preliminary investigations shall be granted for areas in which the Minister for Climate and Energy considers energy exploitation may be relevant; (c) the Minister for Climate and Energy may stipulate terms for the approval, including on the conditions to be investigated, on reporting, on the performance and results of the preliminary investigation, on the access of the Minister to utilise the results of the preliminary investigation, cf. and on compliance with environmental and safety requirements and similar.

In general, the establishment of offshore wind turbines can follow two different procedures: a government tender procedure run by the Danish Energy Agency; or an open-door procedure. For both procedures, the project developer requires all three licenses. All licenses are granted by the Danish Energy Agency: (a) license to carry out preliminary investigations; (b) license to establish the offshore wind turbines; (c) license to exploit wind power for a given number of years, and – in the case of wind farms of more than 25 MW – an approval for electricity production.

In the open-door procedure, the project developer takes the initiative to establish an offshore wind farm of a chosen size in a specific area. In an open-door project, the developer pays for the transmission of the produced electricity to land. An open-door project cannot expect to obtain approval in the areas that are designated for offshore wind farms in the report Future Offshore Wind Power Sites - 2025 from April 2007 and the follow-up to this from September 2008. There are three examples of the open-door procedure. It was followed for the DONG Energy off-shore wind farm at Avedøre and Frederikshavn – and for the Sund & Bælt project at Sprogø.

#### 3.2.3.2 Policies Related to Fish Farming

The management, control and development of fisheries and aquatic resources, like aquaculture, in Denmark are regulated by the Fisheries Act (2004) under the Ministry of Food, Agriculture and Fisheries. In particular, Chap. 13 of this act addresses offshore ocean farming and establishes licensing system governing mariculture facilities. Besides the fisheries Act, the regulation on the establishment and operation of ocean farms contains more detailed rules on the licensing system of mariculture facilities. There is no general definition of aquaculture in the Fisheries Act (2004). The Regulation relative to the establishment and operation of ocean farms (1991), adopted under the Act, has, however, the following definition of ocean farming: “With ocean farming is understood fish farms consisting of cages and the like, placed in marine waters which requires the use of feed for its operation”.

According to the Danish Aquaculture Organisation, the environmental legislation on aquaculture exists on two levels: (a) general legal acts that all types of economic activity have to comply with, and (b) legal acts for various forms of aquaculture. However, there is no specific law on aquaculture in Denmark. All Danish fish farms have to be officially approved in accordance with the Danish Environmental Protection Act Ord. No. 122 of March 1st 1991. A fixed feed quota is assigned to each individual farm in addition to specific requirements including feed conversion ratios, water use and treatment, effluents, removal of waste, etc.

The overarching legal framework for marine farming is the environmental frame directive, implemented in Danish legislation as consolidated Act. No.932. Marine farming is only partly covered by this directive. The ecological status applies for coastal waters up to 1 nautical mile whereas the chemical status applies for coastal waters up to 12 nautical miles. The most critical issue in this directive is the discharge of nitrogen. In the programme of measures for marine farming stands that there must be no overall reduction in the current discharge of nitrogen approved marine farms, but also that new permits must not lead to increased discharge. It is impossible for farms to increase the production without an increase of nitrogen load. On the longer term farms could possibly compensate for such increase. If marine farms want to increase their production it can apply for a part of the total nitrogen quota. But the permit is only granted under the condition that the increase in the discharge of nitrogen is eliminated by compensatory farming.

For aquaculture facilities that are placed on land taking in marine water and for farming of mussels, oysters etc. no regulations have been issued pursuant to the Fisheries Act (2004). For fish farming that requires feed an approval according to the Environmental Act is required. All marine farms must have an environmental permit no later than 2014. The Environmental Protection Act (No. 1757 issued December 22th 2006) sets the overall framework for issuing such permits. At this time most marine farms have obtained permits under this act. Marine farms also have to comply with the requirements for discharge of residues of medicines (Order No. 1022 issues August 25th 2010) and protected habitats (Protection of Nature Act No. 933 issued September 24th 2009).

#### 3.2.3.3 Policies Related to Environmental Concerns

When the project can be expected to have an environmental impact, an Environmental Impact Assessment (EIA) must be carried out. The specific procedure for the EIA regarding offshore electricity producing installations is described in Executive Order No. 684 of 23rd June 2011 on EIA. That also includes sections that implement the EU EIA directive (PM).

Any party applying to establish an offshore wind farm must prepare an environmental report in order to ensure: (a) that the environmental conditions within the defined installation are described; (b) that impact and reference areas are studied and described; (c) that all known environmental impacts in connection with the establishment and operation of the wind turbine installation have been previously considered and assessed; (d) that the authorities and the general public have a basis for assessing and making a decision regarding the project.

An EIA is necessary for developing aquaculture activities. This can be found in the Planning act (order No 1510 issued December 15th 2010). For marine farms situated up to one nautical mile for the coast will require a full EIA. This is a general rule. To some extent it is decided by the local government in the area and they can administer this rule in different ways. For existing farms outside the nautical mile zone only a screening is required. This has been done as a result of a political compromise between government, farmers and environmental organizations. The regulation on supplementary rules contains requirements regarding the contents of the EIA. The regulation provide that when establishing a new marine water fish farm outside a zone designated for aquaculture in the Regional Plan, or when changing such a facility considerably, an EIA shall be worked out. If the aquaculture facility in question is designated for intensive fish farming or has an intake of fresh water, an EIA shall be worked out as far as the facility it is likely to have a considerable impact on the environment, even when it is to be established in an aquaculture zone.

The Regulation lists the different criteria that shall be used when considering whether a facility is likely to have such an impact, i.e. the size of the facility, waste production, the vulnerability of the surrounding environment etc. When it comes to the contents of the EIA, the Regulation states that the EIA shall include a description of the planned facility, a summary of the most important alternative sites that have been examined, the reasons for the choice of alternatives, a description of the environment that can be considerably influenced by facility, as well as an account of the short term and long term influence on the environment. As to ocean farms outside the County Council planning area, the Coastal Directorate decides whether an EIA shall be carried out in relation with an application for the setting up of a facility.

## 3.3 Monetization of Environmental Impact

### *3.3.1 Impact on Ecosystem Services*

The selected multi-use design for the Kriegers Flak site might influence a number of the marine ecosystem services supplied by the Baltic Sea. These are summarized in Table 3.2.

It was decided under project to apply an adjusted Benefit Transfer method to account for potential environmental and socio-economic impacts. The referred adjustments considered income changes, price changes over time and purchasing power differences. The adjustments were based on UNEPs manual on valuing transferred values of ecosystem services (2013).

In order to choose the relevant studies, common socio-economic and geographical characteristics are considered between the policy site and the study sites of each examined paper. Since it was hard to find studies related to offshore multi-use platforms, research had 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 was 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 MERMAID site managers and biologists, habitat services with regards to increased diversity caused by the reef effect were given monetary values. However, economic values for all the possible effects on ecosystem services were not given due to lack of data. In order to do so, we approximated the positive effect on biodiversity and increase of marine biomass by the effect on algae and invertebrates (31.44 € per person, one-time payment). Hence, based on the regional profiling,[1] we estimated economic benefit due to environmental effect to be 25,750,259 Euro (2013). Ressurreição et al. (2012) paper was used for the purpose of benefit transfer (Table 3.3).

**Table 3.2** Ecosystem services probably affected by the multi-use design

| Category of ecosystem services | Provisioning services | Supporting/regulating services | Cultural services | Habitat services |
|---|---|---|---|---|
| Ecosystem services | Food and raw materials | Nutrient cycling | Cognitive development | Diversity |
| Period of the effect | Constrution and operation phase | Operation phase | Not relevant | Construction and operation phase |

*Source: Communication with Site Managers and Biologists*

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[1] We estimated the average population growth rate between Sweden, Denmark, Germany and Poland to be 0.35%. These are the countries possibly affected by the platform.

**Table 3.3** Benefit transfer application for the Kriegers Flak Site

| Description | Algae and Marine Invertebrates (Biomass) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ressurreição, A. et al. (2012) This study uses a contingent valuation method to estimate the public's willingness to pay (WTP) to avoid loss in the number of marine species. One-time payment. | *Country* | *Value of Algae* **(€) (2007)** | | *Value of Inverts* **(€) (2007)** | | *Average* | Weights | **Benefit Transfer Value (€) (2013)** |
| | | *Visitors* | *Residents* | *Visitors* | *Residents* | | | |
| | Gulf of Gdansk, Poland | 14 | 20 | 14 | 21 | 17.25 | 0.75 | 17.36 |
| | Isles of Scilly, UK | 66 | 75 | 52 | 59 | 63 | 0.25 | 14.08 |
| **Weighted Average Value to avoid Algae and Marine Invertebrates Loss (€)** | | | | | | | | **31.44** |

***Notes:*** *Mean WTP is more appropriate for cost benefit analysis* (Loomis and White 1996)
*Values were expressed as one-time payment per individual*

**Table 3.4** Unit amount of $CO_2$ emissions per function and the compared production technologies

| Function | Parameter | Amount | Unit |
|---|---|---|---|
| Electricity production | Amount of $CO_2$eq production per 1 kWh | 9.32 | g $CO_2$eq |
| Coal based electricity production | Amount of $CO_2$eq saved through electricity production per 1 kWh | 810.68 | g $CO_2$eq |
| ENTSO-E electricity production | Amount of $CO_2$eq saved through electricity production per 1 kWh | 452.6 | g $CO_2$eq |
| Fish production | Total amount of $CO_2$eq production per 1 t fish produced | 3.6 | t $CO_2$eq |

**Table 3.5** Total amount of $CO_2$ emissions per function and the compared production technologies

| Function | Parameter | Amount |
|---|---|---|
| Electricity production | Amount of $CO_2$eq production (assuming 1317.6 GWh/year) | 9.32g$CO_2$eq/kWh*1317.6 GWh/year*25 years=307,000.8ton $CO_2$-eq |
| Coal based electricity production | Amount of $CO_2$eq saved (assuming 1317.6 GWh/year) | 810.68g$CO_2$eq /kWh*1317.6 GWh/year *25 years=26,703,799.2ton $CO_2$-eq |
| ENTSO-E electricity production | Amount of $CO_2$eq saved (assuming 2196 GWh/year) | 452.6g$CO_2$eq /kWh *2196 GWh/year*25 years=24,847,740 ton $CO_2$-eq |
| Salmon production | Total amount of $CO_2$eq production (assuming 6000 t/year) | 3.6t$CO_2$-eq *6000 t/year*15 years=324,000 ton $CO_2$-eq |

### *3.3.2 Impact on $CO_2$ Emissions*

Another environmental effect associated with the Kriegers Flak site is emissions of carbon dioxide ($CO_2$). Those emissions were possible to estimate through applying a Life Cycle Assessment (LCA) for evaluating the Global Warming Potential (GWP) associated with the multi-use for the Kriegers Flak site.[2] Resulting quantity of emitted $CO_2$ equivalents ($CO_2$-eq) for each of the uses, and total amounts of emissions are presented in Tables 3.4 and 3.5; details about the estimations are found next.

**Wind Farm** The design for Baltic Case includes a wind farm with installed capacity of 600 MW (Energinet.Dk 2013). 8 MW turbines with monopile foundations were chosen among these turbine and foundation types for the LCA study. This choice considers a wind farm consisting of 75 wind turbines. The systems studied

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[2] An 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.

included production and installation of structures (wind turbine components), electricity transmission system (offshore substation and submarine cables), operation and maintenance activities, disposal of multi-use farm as well as transportation of materials during the life cycles of the MUOPs. Electricity distribution that is located onshore was excluded from the system studied. Functional unit was selected as 1 kWh electricity produced. Obtained Global Warming Potential (GWP) impact category result for energy production function of the MUOP is 9.32 g $CO_2$-eq. This result was then compared with values for producing electricity based on coal. The results showed that producing 1 kWh energy in this farm cause a decrease from 820 to 9.32 g $CO_2$ equivalents ($CO_2$eq) which corresponds to a difference of 810.68 g $CO_2$eq based on average $CO_2$eq value for electricity production via coal burners (Schlömer et al. 2014). When the European electricity mix value (ENTSO-E network), which corresponds to 462 g $CO_2$eq/kWh (Itten et al. 2014), was chosen as the comparison parameter, the difference is 452.68 g $CO_2$ equivalents.

**Fish Farm** The design for Baltic Case includes a fish farm with a capacity of 10,000 ton salmon production. An offshore salmon farm is designed for Baltic Sea Case by Musholm and DHI in the context of the project. Total capacity of the designed marine net-pen system fish farm is 10,000 tons harvested fish per year, and the fish cages are designed to resist offshore conditions. The systems studied included production and installation of aquaculture structures, operation and maintenance activities, disposal of structures as well as transportation of materials during the life cycles of the MUOPs. Functional unit was selected as one tonne of salmon harvested. The result of LCA study of Salmon fish farm in terms of GWP is 3.6 tonnes $CO_2$eq per ton of harvested fish.

The emission estimates were monetized by applying the social cost of carbon. This refers to the shadow price of world-wide damage caused by anthropogenic $CO_2$ emissions (Pearce 2003). According to Arrow et al. (2014), the social cost of carbon is \$19.50 per ton of $CO_2$ 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 monetization was based on the estimate from the state-space model, which correspond to 22.50 € per ton[3] (2013).

## 3.4 Financial and Economic Assessment

For the Kriegers Flak site, the wind-salmon farm efficiency gains for maintenance, salaries and mortality were expected to be 3%, 2% and 1%, respectively, from the combined use (i.e. 4% total efficiency gains).

The total price of the wind farm is expected to be between 2.0 and 2.7 billion Euro, whereof the grid connection is budgeted at 0.47 billion Euro. With regards to

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[3] Exchange rate 0.83 \$/€.

salmon farming, in existing 3000 tons farms, production costs are 2.85 Euro per kg and it is expected to have slightly lower production costs in a larger farm, but also slightly higher cost of insurance. Salmon farming costs cover operation, maintenance and depreciation of freshwater and marine activities and the expected revenues for salmon farming are 36 million Euro per year. Seaweed farming is also a future option that requires future testing and market analysis.

## 3.5 Social Cost-Benefit Analysis

The Social Cost-Benefit Analysis (SCBA) applied in this case study revealed whether the net benefit generated by the multi-use investment project is positive in a temporal perspective, conditional on the utilized discount rate scheme. The Net Present Value (NPV) criterion was applied.

A general expression for NPV is the following:

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

where $K_t$ is investment costs, $B_t$ is the stream of benefits, $C_t$ is the stream of costs and $r$ is the discount rate. Monetized values of externalities, i.e. the benefits derived by the $CO_2$ emissions reduction and artificial reefs effect due to wind energy production, were also included in the benefits or costs terms, which is one major feature that distinguishes a SCBA from a typical financial assessment.

However, only the single-use scenario of energy production was examined since there was incomplete information about the costs and benefits of salmon production. A 22-year time horizon was selected for the SCBA.

A triangular distribution was used in energy investment and maintenance. Since there were no information regarding the stochastic factors affecting wind investment, the triangular distribution was considered reasonable, with central value the given investment cost and boundaries at ±15% of the central value.

Furthermore, normal distribution was used in Energy output and artificial reefs. Again, since there was no information about the specific distributions and only a central value for each of the items, a normal distribution was assumed with mean the given central value. 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 $\gamma$ was consistent with the data of the specific case. That is $\mu \pm 2\sigma = \mu \pm \gamma\mu$.

Two alternative values were used for the social discount rate: 3% and 4%. These values are consistent with values obtained from the Ramsey formula for long-lived projects (Dasgupta 2008): $r = \rho + \eta g$, where $\rho = L + \delta$ is the rate at which individuals discount future utilities, L is catastrophe risk, i.e. the likelihood that there will be some event so devastating that all returns from policies, programs or projects are

**Table 3.6** Net present value estimations for energy production

| | Mean NPV(3%) | St. dev. NPV(3%) | Mean NPV(4%) | St. dev. NPV(4%) |
|---|---|---|---|---|
| **Single-use:** Wind function operation compared to coal energy production | 1283.97 | 115.22 | 1018.85 | 110.61 |
| **Single-use:** Wind function operation compared to ENTSO-E energy production | 1062.20 | 112.29 | 823.60 | 107.31 |

All values in million Euro. Monte Carlo simulations involving 1000 repetitions were applied for taking uncertainty into account

**Table 3.7** Annual equivalent operating cost

| | AOC (3%) | AOC (4%) |
|---|---|---|
| **Single-use:** Wind function operation compared to coal energy production | 102.01 | 90.53 |
| **Single-use:** Wind function operation compared to ENTSO-E energy production | 84.39 | 73.18 |

All values in million Euro

eliminated, or at least radically and unpredictably altered, δ is the rate of pure time preference, which reflects individuals' impatience and preference for utility now, rather than later, g is annual growth in per capita consumption, and η is the elasticity of the marginal utility of consumption. These numerical values are within the limits of typical values for the discount rate 3–4% appearing in the literature (Table 3.6).

The important issue in this site was that there was no information regarding operating cost. To obtain insights into the profitability of the project we worked as follows. The single-use scenario of wind energy production will be profitable if the NPV of the operating costs, NPV(OC), is less than the mean NPV under the corresponding alternative assumptions regarding the discount rate and savings related to the reduction of $CO_2$ emissions. This NPV(OC) can be transformed to annual equivalent operating costs (AOC) using the relationship:

$$NPV\left(OC\right)=\sum_{t=4}^{22}\frac{AOC}{\left(1+r\right)^{t}}$$

Thus if annual operating costs are below the above values for each discount rate and savings related to the reduction of $CO_2$ emissions, the project will pass the SCBA test (Table 3.7).

## 3.6 Concluding Remarks

Lack of data has rendered difficult the complete production of the Social Cost Benefit Analysis for the multi-use scenario of the MERMAID site in the Baltic Sea. However, communications with the economists of the Baltic site revealed that the multi-use platform scenario is expected to be economically viable in the future. An additional point to consider is associated to the time horion considered. A longer time horizon in the SCBA, extending beyond 22 years could change the outcomes. This can be associated to possible differences in energy prices and long run environmental effects, for example changes in the level of eutrophication.

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# Chapter 4
# Socio-economic Analysis of a Selected Multi-use Offshore Site in the North Sea

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**Abstract** A 600 MW offshore wind farm is under construction in the Netherlands Exclusive Economic Zone at a site called Gemini situated 55 km north of the Wadden Sea island of Schiermonnikoog and 85 km from the nearest Dutch port of Eemshaven. This chapter investigates the option of introducing a multi-use design for the Gemini site by adding mussel cultivation (48 kt wet weight per year) and seaweed cultivation (480 kt wet weight per year) to the wind farm. An institutional analysis indicates a political will in the Netherlands to support the development of adding uses to offshore wind farms, but a number of implementation obstacles are also identified. Those obstacles include an absence of licences for multi-use production and legal restrictions against third-party access to wind farms. There is therefore a need for a regulatory framework for multi-use and trust-building among actors involved in multi-use installations. A financial and economic assessment,

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and a cost-benefit analysis also taking into account monetized changes in $CO_2$ emissions, indicate that adding mussel cultivation to the wind farm is likely to be both financially and socio-economically viable. Including a seaweed cultivation function is probably not financially and socio-economically viable under current technical and economic conditions. Knowledge gaps and uncertainties in these assessments with respect to, for example, missing site-specific data and non-monetized externalities suggest further research, also including pilot cultivations of mussels and seaweed in planned single-use or multi-use installations.

**Keywords** Multi-use offshore platforms • Marine infrastructure • Socio-economic analysis • Environmental analysis • Marine Spatial Planning • North Sea

## 4.1 Introduction

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 Dutch North Sea waters contain relatively high concentrations of nutrients, calling for the combination of different types of aquaculture with offshore wind farms as a promising multi-use concept.

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**Table 4.1** Basic facts about the North Sea site

| Characteristic | North Sea site (Gemini site) |
|---|---|
| Geographical location | The Netherlands Exclusive Economic Zone |
| 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 | 10 m/s |

Source: http://www.vliz.be/projects/mermaidproject/docmanager/public/index.php?dir=Outreach_Material%2F&download=MERMAID_Booklet.pdf

The MERMAID project focused specifically on a case study area located in the Netherlands Exclusive Economic Zone, 55 km north of the Wadden Sea island of Schiermonnikoog and 85 km from the nearest Dutch port of Eemshaven. At this location, an offshore wind energy farm called Gemini is at present under construction and is planned to be fully operational by 2017 (www.geminiwindpark.nl). Table 4.1 presents some basic facts about the Gemini site and Fig. 4.1 shows the location of the site. As indicated in Fig. 4.1, the Gemini site consists of two areas with a total capacity of 600 MW. An annual production of 2600 GWh is expected from a total of 150 4-MW turbines. The seabed conditions are excellent and monopiles have been selected as foundations. In addition to the turbines, an offshore hotel and support centre, two 220 kV substations and two required submarine cables to the onshore connection at Eemshaven are to be developed.

Although an offshore wind farm such as Gemini only has licenses for single use, more stakeholders in the Netherlands – as well as in other countries developing offshore wind – are starting to discuss multi-use possibilities, such as regional fishermen and entrepreneurs for aquaculture and tourism. Through the participatory approach applied in MERMAID (for details, see van den Burg et al. 2016), stakeholders and the MERMAID project team identified mussel and seaweed aquaculture as the most promising uses to be combined with the Gemini offshore wind farm. The conceptual design is shown in Fig. 4.2.[1]

As will be further investigated in this chapter, a multi-use design has the potential of creating synergies related to operation and maintenance, logistics and design. For example, the presence of seaweed causes wave attenuation, which in turn can result in less harsh offshore (wave) conditions for the wind farm through reduced fatigue loads and subsequently also improving the longevity of the applied material. Furthermore, less wave energy inside the wind farm extends the weather windows

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[1] See Table 4.2 for basic facts of the production capacity of this design and MERMAID project (2016) for further design details.

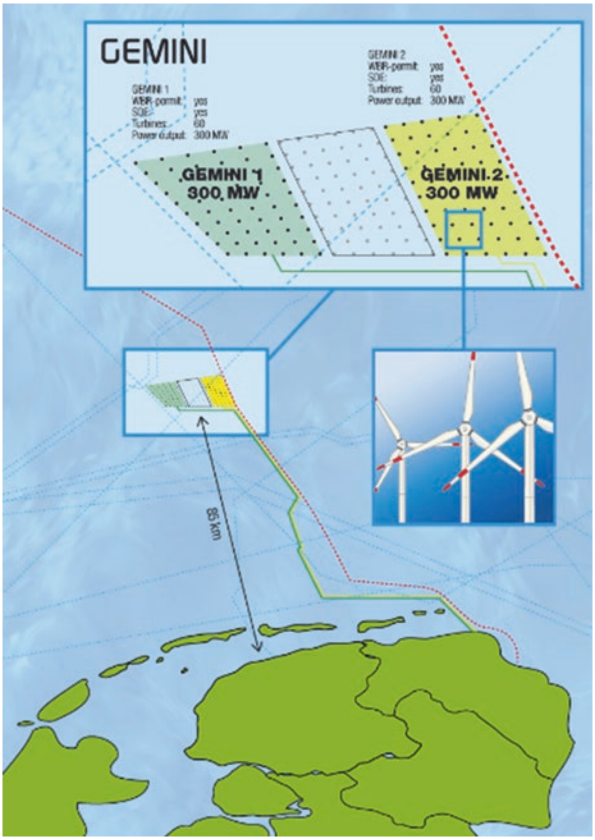

**Fig. 4.1** Location of the North Sea site (Gemini site)
Note: The *arrow* shows the shortest distance to the Dutch coast and "85 km" refers to the shortest distance of navigation between the site and the nearest Dutch port of Eemshaven

for operation and maintenance activities. See Hadadpour et al. (2016) for experimental results on wave attenuation by seaweed.

Driving forces for such a potential multi-use design include the fact that the Dutch offshore aquaculture sector is at the beginning of a new development (Stuiver et al. 2016). While the Dutch blue mussel cultivation is to a large extent likely to remain inshore in the Wadden Sea and Eastern Scheldt because mussel farmers are hesitant to go offshore (Verhaeghe et al. 2011), a transition phase to more offshore cultures has started (MERMAID Project 2013). This shift is probably triggered by indications that the market potential for mussels might be twice the current market (van den Burg et al. 2013; Klijnstra et al. 2016). Regarding the potential for seaweed cultivation, the most immediate opportunity is to offer wet seaweed on the local market. However, the use of seaweed not only for food but as a raw material for health care and plastic products indicates an increasing need for larger quantities (Klijnstra et al. 2016).

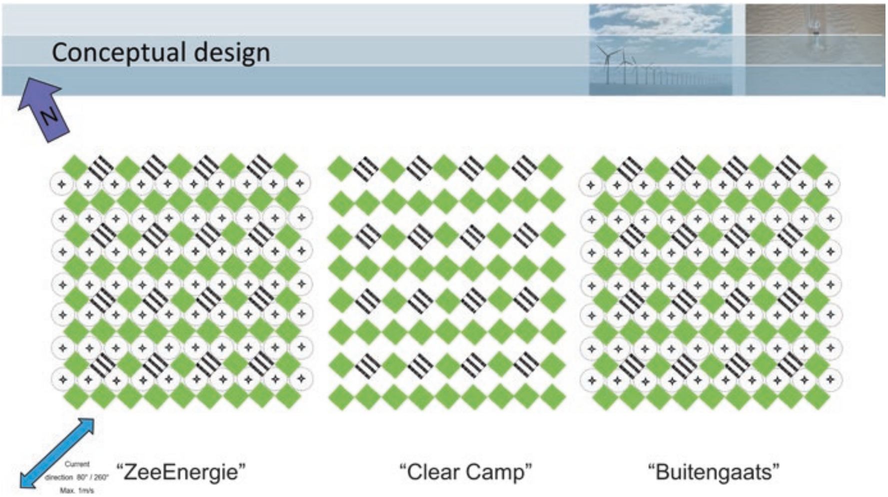

**Fig. 4.2** Conceptual multi-use design for the North Sea site. *Green* diamonds illustrates seaweed, *round circles* are the offshore wind turbines in the two wind farm areas of ZeeEnergie and Buitengaats included in the Gemini site, and *black* and *white* diamonds are the areas with mussel aquaculture

**Table 4.2** Estimated production for the conceptual multi-use design

| Function | Capacity | Annual total production |
|---|---|---|
| Wind energy | 600 MW | 2600 GWh |
| Mussel cultivation | 3 kg WW/m$^2$ | 48 kt WW |
| Seaweed cultivation | 10 kg WW/m$^2$ | 480 kt WW |

Source: MERMAID project (2016)

In an early stage of the design process, fish aquaculture and wave energy were also considered as potential multi-use components at the site. However, fish farming was excluded from the design due to relatively high water temperature peaks exceeding 18 °C during the summer. Currently, no native species are expected to have an adequate economic return on investment under the conditions present at the current location in the North Sea. Wave energy convertors were also judged to not be feasible because of the low efficiency in combination with limited availability of wave energy in the North Sea (MERMAID Project 2015).

The focus of the analysis summarized in this chapter is to evaluate the consequences of changing the single-use of wind energy at the Gemini site to a multi-use site including also mussel cultivation and seaweed cultivation. These consequences are evaluated in comparison to a single-use reference alternative where the Gemini site is only used for the already decided wind farm, excluding any other use. It is also assumed that the added functions of mussel cultivation and seaweed cultivation would not replace any other site for mussel cultivation and/or seaweed cultivation. In principle, this means that environmental and socio-economic impacts of the wind farm are held constant in the analysis as long as those impacts are not influenced by adding the new functions of mussel cultivation and seaweed cultivation to the site. Nevertheless, some major impacts of the wind farm are also described in the chapter in order to provide an enriched context for the analysis.

The remainder of the chapter develops as follows: The case study is put into a socio-economic context in Sect. 4.2 through identifying and describing actors, economic sectors and institutions. In Sect. 4.3, the environmental impact of the multi-use is analysed, and the potential of valuing these impacts in monetary terms is assessed. A financial and economic assessment of the multi-use design is found in Sect. 4.4, which is followed by a social cost-benefit analysis in Sect. 4.5. One major difference between the social cost-benefit analysis in Sect. 4.5 and the financial and economic assessment in Sect. 4.4 is that the former also takes externalities into account, i.e. non-market economic impact. The chapter is concluded with a discussion and recommendations in Sect. 4.6.

## 4.2 The Case Study in a Socio-economic Context

This section aims at contributing to an improved understanding of the effects of the multi-use design by providing a broader context to the case study. Demographic and socio-economic facts are provided, stakeholders are identified, and relevant institutional and policy settings are described. In the last sub-section, some important probable obstacles to implementation of multi-use designs are identified.

### *4.2.1 Demographics and Economic Activities*

With reference to the EU nomenclature of units for territorial statistics (NUTS), the Gemini site is administratively associated with the NUTS 1 region of Noord Nederland, more specifically the two NUTS 2 regions of Groningen and Friesland, and the three NUTS 3 regions of Delfzijl and surroundings (Delfzijl en omgeving), Other Groningen (Overig Groningen) and North Friesland (Noord-Friesland). The socio-economic profile for the case study is therefore described for those NUTS 2 and NUTS 3 regions. As a comparison, socio-economic facts for the Netherlands as a whole are also provided.

The population of the Netherlands in 2012 was about 16.7 million inhabitants, of which residents in Groningen and Friesland account for 3.5 and 3.9%, respectively, see Table 4.3. The table also shows that the population is rather balanced between males and females, and the range of the average household size varies from 2.0 to 2.3 persons per household.

**Table 4.3** Demographic data for 2012 at national level, and also for regional and local levels relevant for the case study

| | The Netherlands | Groningen (NUTS 2) | Friesland (NUTS 2) | Delfzijl and surroundings (NUTS 3) | Other Groningen (NUTS 3) | North Friesland (NUTS 3) |
|---|---|---|---|---|---|---|
| Population | 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 |
| Per cent males | 49.5 | 49.7 | 50.0 | 49.8 | 49.7 | 50.1 |
| Per cent females | 50.5 | 50.3 | 50.0 | 50.2 | 50.3 | 49.9 |

Source: Statistics Netherlands, www.cbs.nl

The population at national level is characterized by a favourable educational attainment level. In particular, 64% of the population has higher education (baccalaureate, graduate and postgraduate studies), while 6% of the population has elementary education only. 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% are males and 46% are females. The Groningen region exhibits the highest unemployment rate (7.5%) of the Netherlands. At the national level, 35% of the employees has attained graduate and postgraduate studies, 43% holds baccalaureate and 22% has elementary and secondary education. The highest percent of employees with graduate and postgraduate studies (43%) is observed in the Other Groningen, while the highest percent of employees with elementary and secondary education is found the Delfzijl and surroundings region.

The national Dutch economy is to a very large extent service-oriented since the tertiary (service) sector accounts for more than 80% of total employment. The health and community services sector, property and business services sector and trade sector are the major sectors offering employment at the national and regional levels. The highest contribution of the secondary (transformation of raw material into goods) sector to total employment takes place in the Delfzijl and surroundings region (26%), while the primary (raw material extraction) sector contributes by only 1% to total employment at the national, regional and local levels. With regards to the value of regional production, the manufacturing and energy sector contribute by 68% and 56% in the Delfzijl and surroundings and Other Groningen regions, respectively, while the service sector contributes by 60% in the Friesland region.

### *4.2.2 Stakeholders*

Main stakeholder groups in wind power production and maritime logistic services include competent authorities, energy companies, construction companies, investment and development companies, consultancies, fisheries, shipping and non-governmental organisations (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 utilities), Van Oord, 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. Also individuals and organizations associated with tourism and recreational boating can be identified as stakeholders.

Based on this general identification, stakeholder groups were contacted and invited to participate in the MERMAID participatory design process (see MERMAID Project 2015 for details). Their participation contributed to knowledge about controversies about multi-use of marine areas, which is further described below.

## *4.2.3 Institutional and Policy Framework*

### 4.2.3.1 Policies Related to Offshore Wind Energy

In the current Dutch energy policy, a clear policy for offshore wind energy is available. In the 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 subsidies. 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+ programme, because wind energy was considered to be 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, this law is not yet approved. Another 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 Euro (excluding maintenance and financing costs).

An offshore wind energy park requires a permit, based on the Water Management Act (Wet Beheer Rijkswaterstaatwerken, 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 an Environmental Impact Assessment (EIA) report (milieueffectrapportage, MER), which assesses the environmental impact of their envisioned project. If a project developer has gone through the procedures for the MER and permitting successfully, a 20-year concession is granted to build and operate a wind energy farm. The system of concessions stems from the Mining Act and grants the developer the possibility to build permanent structures and extract resources. In the concession, additional requirements can be included.

#### 4.2.3.2 Policies Related to Multi-use of Marine Areas

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 Water Plan, the options for multiple uses of space are explicitly mentioned.

North Sea policies are further elaborated in the Policy Document 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.

The co-use issue is also considered in the Integrated Management Plan for the North Sea 2015, which mentions aquaculture inside offshore wind energy parks as a potentially smart use of space, providing opportunities for clever entrepreneurship (IDON 2011). However, no space is allocated to offshore aquaculture for the Dutch part of the North Sea in this plan. This means that aquaculture activities in wind energy parks need to be applied for through permits.

As is indicated by these plans and policies, the Dutch government has the ambition to realize multi-use of offshore wind farms. This political will is manifested by recent stakeholder meetings, processes and projects initiated as well as facilitated by the Ministry of Economic Affairs and the Ministry of Infrastructure and the Environment (Stuiver et al. 2016). However, this has not yet resulted in establishing a regulatory framework for multi-use.

### *4.2.4 Controversies and Implementation Obstacles*

Stuiver et al. (2016) identify a number of obstacles to the implementation of multi-use options of marine areas, dividing them into policy, economic, social, technical, environmental and legal obstacles. We give a few examples of these obstacles here and refer to Stuiver et al. (2016) for further details.

**Policy Obstacles** Already awarded permits for offshore wind farms such as the Gemini site are only for single-use. The absence of licences for multi-use production is a major obstacle. Also, as was mentioned above, there are no areas designated for offshore aquaculture in the Dutch spatial plans for the North Sea.

**Economic Obstacles** There is scepticism among stakeholders on the existence of a viable business case for combining offshore wind farms with aquaculture (MERMAID Project 2013, 2015) not least because the current practice for offshore wind parks to prohibit other vessels to enter the designated parks in order to avoid issues on risks and responsibilities. As a result, risks associated with third-party access are difficult to assess, which means that the impact on insurance premiums of allowing multi-use is unclear.

**Social Obstacles** Lack of trust among potential users might be a considerable obstacle. Offshore wind power has earlier been subject to many discussions between fisheries organizations and wind power companies. In general, any new fishing restriction because of offshore installations is a major issue for fishermen. To counterbalance such restrictions, fisheries organizations have argued for the need for compensation fees and/or additional activities for fishing vessels, e.g., fishing with static gears, organizing sightseeing trips to wind farms for tourists, and providing service and maintenance work in wind farms. This illustrates that controversies could also be a source of opportunities on potential synergies across various uses.

**Technical Obstacles** Adding additional uses to a wind farm give rise to technical challenges such as finding a design which makes wind turbines and cables satisfactorily accessible for maintenance. Also, Dutch offshore aquaculture is generally in its infancy, which means that there is at present very limited experience of what technical design is suitable for aquaculture installations.

**Environmental Obstacles** One reason for the fact that there is at present no areas designed for offshore aquaculture in Dutch spatial plans for the North Sea is potential negative environmental impacts of offshore fish farming. While those impacts might not at all be present for other types of offshore aquaculture, uncertainties about environmental risks might still be a general obstacle.

**Legal Obstacles** For Dutch wind energy parks, restrictions for multi-use stem from the concession agreements in which the competent authorities have included “restricted areas” surrounding wind energy constructions where no ships are allowed. For offshore wind energy parks there is a safety zone of 500 meter around static objects such as turbines. This means that no shipping activities can take place within 500 meter of the turbine, which affects the opportunities to combine aquaculture with wind power. However, exemptions on this rule could be made through permit applications.

Stuiver et al. (2016) conclude that the presence of obstacles such as those mentioned above suggests that there is a need for developing a regulatory framework for multi-use that, for example, help establishing a licensing procedure for multi-use. Furthermore, trust-building and close collaboration among actors directly or indirectly involved in multi-use installations are likely to be of great importance. Such trust-building is likely to be facilitated by the Dutch “poldering tradition” of involving stakeholders (MERMAID Project 2015).

## 4.3 Monetization of Environmental Impact

### *4.3.1 Impact on Ecosystem Services*

Adding the functions of mussel cultivation and seaweed cultivation to the wind farm at the Gemini site might influence a number of the marine ecosystem services supplied by the North Sea:

- Production of food and raw material: Mussels and seaweed are products that can be used as food or as inputs in other types of production. In addition, marine food sources such as mussels and seaweed are generally seen as healthy food, the consumption of which might imply positive externalities in terms of improved public health. However, it is unknown to what extent the mussels and seaweed produced at the Gemini site would contribute to a changed public diet.
- Water quality: Mussel cultivation and seaweed farming might improve water quality through its need for nutrients. However, the relatively low concentration of nutrients at the offshore location of the Gemini site implies that the general impact of this improvement is likely to be negligible.

- Habitats: Locally at the Gemini site, mussels' and seaweed's consumption of nutrients might contribute to increase the transparency in the water column, which could improve light conditions for benthic vegetation. However, the turbidity caused by tidal forces might still override this effect. The increased nutrient consumption could also cause negative ecosystem effects through less nutrients being available for single-cell algae (MERMAID Project 2015). The net effect on biodiversity is therefore difficult to establish.
- Cognitive development: The multi-use might give rise to scientific and educational benefits by being examples of innovative engineering with aquaculture providing food and other products.

There are also environmental impacts of a single-use wind farm that are not likely to be influenced by an addition of new functions. For example, trawling is prohibited in the wind farm, and wind turbine foundations and associated scour protection installations become an artificial reef providing a new habitat for marine life. This generally increases the abundance of fish and other species (Krone et al. 2013; Reubens et al. 2014). On the other hand, a potential problem is that hard structures in an otherwise soft sediment environment might form "stepping stones" for invasive species, which might have negative effects on the ecosystem, such as reduced overall biodiversity (Glasby et al. 2007). Which net effect on biodiversity would prevail is, again, difficult to establish.

None of the potential effects on ecosystem services of adding mussel cultivation and seaweed cultivation to the wind energy park were monetized due to lack of data in combination with the negligible or uncertain nature of potential effects. However, the potentially positive effect on health might be reflected by the demand for mussels and seaweed and would in such a case at least partially be taken into account through the market price of mussels and seaweed. To establish the total economic value of health improvements would require a study of non-market values, which should be an objective of future research.

### *4.3.2 Impact on $CO_2$ Emissions*

Another environmental effect associated with the Gemini site is emissions of carbon dioxide ($CO_2$). Those emissions were possible to estimate through applying a life cycle assessment (LCA) for evaluating the Global Warming Potential (GWP) associated with the multi-use for the Gemini site.[2] Resulting quantity of emitted $CO_2$ equivalents ($CO_2$eq) for each of the uses, and total amounts of emissions are pre-

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[2] An 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.

**Table 4.4** Unit amount of $CO_2$ emissions per function and the compared production technologies

| Function | Parameter | Amount | Unit |
|---|---|---|---|
| Wind farm 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 wind farm electricity production per 1 kWh | 810 | g $CO_2$eq |
| ENTSO-E electricity production | Amount of $CO_2$eq saved through wind farm electricity production per 1 kWh | 452 | g $CO_2$eq |
| Mussel cultivation | Total amount of $CO_2$eq production per 1 kg | 0.622 | kg $CO_2$eq |
| Seaweed cultivation | Total amount of $CO_2$eq production per 1 kg | 0.0192 | kg $CO_2$eq |

**Table 4.5** Total amount of $CO_2$ emissions per function and the compared production technologies

| Function | Parameter | Amount |
|---|---|---|
| Wind farm electricity production | Amount of $CO_2$eq production (assuming 2600 GWh/year) | 10 g $CO_2$eq/kWh * 2600 GWh/year * 20 years =520,000 ton $CO_2$-eq |
| Coal based electricity production | Amount of $CO_2$eq saved (assuming 2600 GWh/year) | 810 g $CO_2$eq/kWh * 2600 GWh/year * 20 years = 42,120,000 ton $CO_2$-eq |
| ENTSO-E electricity production | Amount of $CO_2$eq saved (assuming 2600 GWh/year) | 452 g $CO_2$eq/kWh * 2600 GWh/year * 20 years =23,504,000 ton $CO_2$-eq |
| Mussel cultivation | Total amount of $CO_2$eq production (assuming 48,000 t WW/year) | 0.622 ton $CO_2$eq/ton * 48,000 ton mussel/year * 20 years =597,120 ton $CO_2$-eq |
| Seaweed cultivation | Total amount of $CO_2$eq production (assuming 480,000 t WW/year) | 0.0192 ton $CO_2$eq/ton * 480,000 ton seaweed/year * 20 years =184,320 ton $CO_2$-eq |

sented in Tables 4.4 and 4.5; details about the estimations are found in the paragraphs below.

**Wind Farm** As mentioned in Sect. 4.1, the wind farm will consist of 150 Siemens SWT 4.0 wind turbines, giving a total capacity of 600 MW.[3] The Environmental Product Declaration (EPD) of Siemens SWT 4.0 declares that for 1 kWh energy produced, the greenhouse gas (GHG) emissions are 10 g $CO_2$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 potential of coal based electricity production (820 g $CO_2$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 810 g $CO_2$eq and 452 g $CO_2$eq/kWh, respectively. The wind farm can thus help reducing $CO_2$ emis-

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[3] The capacity factor (average generated power divided by its peak power) varies between 25 and 50% roughly for Danish wind farms. For the Gemini wind farm web site this value is given as 2600 GWH/year (capacity factor of 49.5%).

sions, given an assumption that a change towards non-fossil fuel energy sources such as wind power would facilitate a reduced cap in the EU emissions trading system.

**Mussel Cultivation** An LCA in line with ISO 14040 and 14,044 standards was carried out for mussel production using Ecoinvent integrated GaBi software to determine environmental impacts of a mussel farm for its life cycle (ISO 2006a, b). 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 (Dreyer et al. 2003). 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. The selected functional unit was kg of mussel harvested. With regards to GWP, the information about the mussel farm is limited to capacity and technique (long-line mussel farming) of the proposed farm. There are two studies for calculating the carbon footprint of blue mussel farming 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) reported 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 seafood products, taking into account material and energy consumption data for 1 kg of edible mussels as well as transportation to the wholesaler. Both studies were about blue mussels farmed by long-line techniques in North Sea coastal countries and it is therefore assumed the same amount of inputs can be applied to the Gemini site. This results in an estimate of 0.622 kg CO2eq per kg mussels in terms of GWP, assuming that the mussel production at the Gemini site would not replace any other production elsewhere.

**Seaweed Cultivation** The total capacity of the seaweed farm is 480,000 ton wet weight (WW) per year, and the seaweeds will be grown using textile cable structure with buoys and metal spreader bars. Lack of data precluded the use of LCA of the seaweed farm, but instead the results of Fry et al. (2012) are used as an example of GWP of seaweed production on a cradle-to-gate basis. These results indicate emissions amounting to 0.0192 kg CO2eq per kg harvested seaweed, again assuming that the seaweed production at the Gemini site would not replace any other production elsewhere.

Finally, the emission estimates were monetized by applying the social cost of carbon. This refers to the shadow price of world-wide damage caused by anthropogenic $CO_2$ emissions (Pearce 2003). According to Arrow et al. (2014), the social cost of carbon is \$19.50 per ton of $CO_2$ 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 monetization was based on the estimate from the state-space model, which correspond to 22.50 Euro per ton.[4]

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[4] Exchange rate 0.83 $/ €.

## 4.4 Financial and Economic Assessment

The financial and economic assessment benefited from data available about the ongoing Gemini offshore wind farm project 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). Below we go through the financial assessment for each of the functions in the multi-use design. Results are summarized in Table 4.6.

**Wind Farm** Specific data for the Gemini wind farm, market analysis and literature suggest that 2800 million Euro are invested for the first year, while an additional investment of 1800 million Euro is required to replace the wind turbines that are assumed to have a design life time of 15 years. As to operation and maintenance (O&M) costs, results related to hypothetic or real offshore wind farms indicate a cost interval of 60–140 million Euro per year. Different O&M costs per energy produced yearly in MWh (Bartelings et al. 2014; Næss-Schmidt and Møller 2011; IEA 2013; DECC 2013), or per capacity installed in MW (DECC 2011, 2013) are suggested. The O&M cost interval excludes estimates from the literature that were not considered as representative for the Gemini site, e.g. because they are based on sites located much closer to the coastline than the Gemini site, which is likely to have a strong impact on costs for transports. The O&M cost interval might still be an overestimation, because details of the wind farm investment agreement are not fully known, which means that at least some O&M costs might be included in the investment costs. The costs associated with the offshore hotel and support centre at the Gemini site are assumed to be included in the investment cost and the O&M cost interval mentioned above. With regard to revenues, 442 million Euro per year are estimated for the first 15 years. Later on, the estimated revenues decrease to 112 million Euro per year, as the project is only entitled to subsidies during the first 15 years. This means that subsidies amount to 330 million Euro per year during the first 15 years. These revenues are based on a production of 2600,000 MWh per year and an electricity price of 170 Euro per MWh (including subsidies) or 43 Euro per MWh (excluding subsidies). That is, the subsidy during the first 15 years amount to 127 Euro per MWh.

**Mussel Cultivation** 7–11 million Euro are assumed to be required to invest every 5 years, which is based on assumptions and on unit costs of components in a mussel plot (Buck et al. 2010) applied to the conceptual multi-use design. The higher value of the range takes into account the eventual need of investing in a new vessel (Buck et al. 2010). A range of 8.5–57 million Euro per year is estimated for O&M costs. This interval 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. A mussel production of 48,000 ton WW (wet weight) per year is assumed to result in revenues amounting to 45 million Euro per year, given a price of 940 Euro per ton WW (based on Bartelings et al. 2014).

**Table 4.6** Summary of the financial characteristics for the Gemini site

| | Wind farm | Mussel cultivation | Seaweed cultivation |
|---|---|---|---|
| Investment costs | 2800 (year 1)<br>1800 (year 16) | 7–11 (every 5 years) | 21–400 (year 1)<br>10 (every 5 years)-400 (every 10 years) |
| Operation and maintenance costs | 60–140 per year | 8.5–57 per year | 47–68 per year |
| Revenues | 442 per year (first 15 years)<br>112 per year (year 16 and following years) | 45 per year | 17–48 per 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. |

All amounts in million Euro

**Seaweed Cultivation** Initial investment costs can be estimated to 21–400 million Euro. According to assumptions provided by Schipper (2015), a relatively low investment cost of 21 million Euro for the production capacity installed would be succeeded by reinvestments of around 10 million Euro every 5 years. The considerably higher estimates of 40 million Euro (based on Burg et al. 2013) and of 400 million Euro (based on Burg et al. 2013; and on Bartelings et al. 2014) would apply both for the initial investment and for reinvestments every 10 years. The former estimate is based on unit costs per production capacity installed (Burg et al. 2013), and the latter on unit costs per area for a specific production installed (Burg et al. 2013; Bartelings et al. 2014). Expected O&M costs amount to 47–68 million Euro per year, based on unit costs and sub-costs per area for a specific production capacity (Schipper 2015; Bartelings et al. 2014). Revenues for seaweed farming are very uncertain, but can be expected to be within the range of 17–40 million Euro, depending on estimated prices of 210 Euro per ton DM (Dry Matter) (Bartelings et al. 2014) or of 600 Euro per ton DM (Schipper 2015). A production of 80,000 ton DM of seaweed, corresponding approximately to 480,000 ton WW of seaweed, was used in the calculations (Bridoux 2008).

Table 4.6 provides a summary of the financial characteristics. Note that future revenues and 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). All values are associated with a considerable uncertainty because some data is missing – either not made available or unknown – and therefore estimations had partly to rely on not site-specific data and expert judgement. The lack of site-specific data also made it difficult to estimate what cost reductions could be expected because of efficiency gains from multi-use synergies. However, based on Bartelings et al. (2014), a 10% efficiency gain can be expected due to savings on operation and maintenance costs. On the other hand, the multi-use design might give rise to increased insurance costs. On the whole, those considerations are not likely to influence the main conclusions about financial profitability in Table 4.6, i.e. that there is probably a business case for adding mussel cultivation to the wind farm, but it is very uncertain whether there is also a business case for adding seaweed cultivation. The wind farm that is already under construction is likely to be financially profitable, at least as long the production is subsidized.

The possibility of a business case for mussel cultivation and/or seaweed cultivation is further illustrated by two extreme scenarios taking into account the rather wide cost and revenue intervals estimated for some of the functions. The first scenario gives a maximum profitability by combining the lowest estimates of investment and O&M costs with the highest estimates of revenues, and the second one gives a minimum profitability by combining the highest estimates of investment and O&M costs with the lowest estimates of revenues, see Tables 4.7 and 4.8 for results. Again, seaweed cultivation shows a negative financial profitability, also in the maximum profitability scenario. However, the future development of the market price of seaweed products is highly uncertain. As an illustration of what market price is required for making offshore seaweed farming to a business case, a break-even price was estimated to approximately 620 euro per ton DM of seaweed for the maximum profitability scenario and to about 1400 Euro per ton DM of seaweed for the minimum profitability scenario.

Finally, some economic considerations in terms of job creation opportunities are added to the financial assessment above. The wind park that is under construction is expected to create around 500 full-time jobs during the construction and installation phase and another 120 full-time jobs during the operational phase (Van Oord n.d.). The local tourist industry might also benefit from sightseeing trips to wind farms. The employment impacts of the maritime logistic services are mainly concentrated on the redesign of fishing vessels towards multipurpose vessels, which may give fishermen the opportunity to carry out maintenance works and logistic activities. Adding the functions of mussel and seaweed cultivation to the wind farm can be expected to produce approximately an additional 60 full-time or seasonal jobs (based on Buck et al. 2010; Burg et al. 2013).

**Table 4.7** A maximum profitability scenario for the Gemini site (lowest estimates of investment and O&M costs combined with highest estimates of revenues)

| | Wind farm | Mussel cultivation | Seaweed cultivation |
|---|---|---|---|
| Investment costs | 2800 (year 1) | 7 (every 5 years) | 21 (year 1) |
| | 1800 (year 16) | | 10 (every 5 years) |
| Operation and maintenance costs | 60 per year | 8.5 per year | 47 per year |
| Revenues | 442 per year (first 15 years) | 45 per year | 48 per year |
| | 112 per year (year 16 and following years) | | |
| Financial profitability | Yes, as long as there are subsidies. | Yes. | No. |

All amounts in million Euro

**Table 4.8** A minimum profitability scenario for the Gemini site (highest estimates of investment and O&M costs combined with lowest estimates of revenues)

| | Wind farm | Mussel cultivation | Seaweed cultivation |
|---|---|---|---|
| Investment costs | 2800 (year 1) | 11 (every 5 years) | 400 (year 1) |
| | 1800 (year 16) | | 400 (every 10 years) |
| Operation and maintenance costs | 140 per year | 57 per year | 68 per year |
| Revenues | 442 per year (first 15 years) | 45 per year | 17 per year |
| | 112 per year (year 16 and following years) | | |
| Financial profitability | Yes, as long as there are subsidies. | No. | No. |

All amounts in million Euro

## 4.5 Social Cost-Benefit Analysis

As a rule, a project is deemed to be socially profitable if total discounted benefits exceed total discounted costs, i.e. a positive net present value (NPV). Monetized values of externalities are included in the benefits or costs, which is one major feature that distinguishes a SCBA from a financial assessment. Also the internal rate of return (IRR), i.e. the discount rate that makes the NPV equal to zero, can give useful information: The higher a project's IRR, the more desirable is the undertaking of the project. Any project with an IRR greater than the discount rate used for the project is a profitable one.

For the Gemini site the financial costs and revenues reported in Sect. 4.4, together with the benefits (costs) associated with reduced (increased) $CO_2$ emissions (see Sect. 4.3.2), were included in the SCBA. For the case of wind energy production, both the case of coal based electricity production and the case of European electricity mix value (ENTSO-E) was used in the analysis (see Sect. 4.3.2).

Two alternative values for the social discount rate were used in the SCBA: 3% and 4%, which are values often obtained when applying the Ramsey equation for long-lived projects for example (Arrow et al. 2014). Further, 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 reinvestments in installations because of wear and tear is not synchronized across the three multi-use functions of wind energy, mussel cultivation and seaweed cultivation. This issue was handled by adapting the reinvestment 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 are assumed to last for 15 years. However, reinvestments 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 was 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 years 16–19.

- For mussel cultivation and seaweed cultivation, decommissioning is assumed to take place in year 20, instead of having an otherwise necessary reinvestment in this last year.

Monte Carlo simulations involving 1000 repetitions were performed for taking uncertainty into account. Triangular distributions were applied for the investment costs of mussel cultivation and seaweed cultivation, respectively, for O&M costs of wind energy, mussel cultivation and seaweed cultivation, respectively, and also for the price of seaweed. The triangular distribution was regarded as the best choice because it made it possible to apply the maximum and minimum profitability scenarios described by Tables 4.7 and 4.8. It was assumed that the estimates associated with the maximum and the minimum profitability, respectively, are associated with the lowest probabilities of occurrence in the triangular distribution, and the average of those estimates with the highest probability of occurrence in the triangular distribution.

The normal distribution was used in the simulation for all other variables. Since there was no information about the specific distributions and only a central value for each of the items, a normal distribution with mean equal to 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 deviations from the mean has boundaries at a distance of $\pm \gamma$ per cent of the mean. The choice of $\gamma$ was consistent with the data of the specific case. That is, $\mu \pm 2\sigma = \mu \pm \gamma\mu$.

The SCBA results for the case when the functions of mussel cultivation and seaweed cultivation are added to the single-use of wind energy is shown in Table 4.9. Adding only mussel cultivation entails a positive NPV (117 million Euro as an average for the two discount rate alternatives), but adding both mussel cultivation and seaweed cultivation results in a negative NPV (−474 million Euro as an average for the two discount rate alternatives). This is explained by the considerably negative NPV of seaweed cultivation (−594 million as an average for the two discount rate alternatives). These results are not surprising, given the findings in the financial assessment in Sect. 4.4.

The results in Table 4.9 are valid when having the single-use wind farm at the Gemini site as a reference alternative, which is reasonable because it is under construction. If the reference alternative is instead an unused space at the Gemini site, it would make sense to investigate the NPV of constructing a multi-use site with wind energy and mussel cultivation and/or seaweed cultivation. The NPV for this case is reported in Table 4.10 in a situation where subsidies are not deducted from the price of electricity produced by the wind farm at the Gemini site. All combinations are now associated with a positive NPV. The considerable profitability of the wind farm compensates for the losses entailed with the seaweed cultivation. Not surprisingly, the most profitable design is the combination of wind energy with mussel cultivation only.

**Table 4.9** Estimated NPV in million Euro (mean and standard deviation) for making the single-use Gemini wind farm to a multi-use design with either mussel cultivation or seaweed cultivation, or both

| | 3% discount rate | | 4% discount rate | |
|---|---|---|---|---|
| Design | Mean NPV | St. dev. of NPV | Mean NPV | St. dev. of NPV |
| Adding mussel cultivation only | 122.47 | 32.94 | 110.95 | 29.47 |
| Adding seaweed cultivation only | −617.67 | 113.10 | −570.99 | 104.24 |
| Adding both mussel cultivation and seaweed cultivation | −492.82 | 118.74 | −456.15 | 106.69 |

Not deducting the subsidies to wind power in the SCBA can be motivated by an assumption that those subsidies serve as a proxy for positive externalities from wind power other than reduced greenhouse gas emissions. Examples of such possible additional externalities from a renewable energy source such as wind power might be positive network externalities that promote technological improvements and support the transition to a low carbon economy. However, an assumption that there are no such additional externalities would imply that the subsidies should be deducted in the SCBA. In such a case, the NPV of wind energy is reduced substantially, which is illustrated in Table 4.11 for the deterministic maximum profitability scenario. Given this scenario, the NPV ranges from −282 million Euro to 46 million Euro, depending on the choice of discount rate and comparison to type of alternative electricity production. However, this suggests that constructing a multi-use site by adding the profitable mussel cultivation to the wind farm can be crucial for increasing the chances of having a positive NPV also in a case when wind energy is assumed to have no other positive externalities than greenhouse gas reduction. The probability for a positive NPV would be further increased if the potential efficiency gains due to multi-use of about 10% can be realized, cf. Sect 4.4.

## 4.6 Discussion and Recommendations

A main conclusion that follows from the assessment is that adding mussel cultivation to the single-use wind farm at the Gemini site is likely to be both financially and socio-economically viable. While this supports a multi-use design at the site, this does not mean that the site is an optimal multi-use location. From a mussel farming perspective, sites situated closer to the Dutch shore are likely to provide conditions that entail an improved financial and socio-economic performance. Another main conclusion is that including a seaweed cultivation function is not likely to be financially and socio-economically viable under current technical (investment costs and O&M costs) and economic (market prices) conditions.

There are some limitations in the assessments that should be taken into account when interpreting these conclusions. For example, the monetization of environmental externalities in Sect. 4.3 included $CO_2$ emissions, but no other potential externalities such as improved public health and water quality became part of the

**Table 4.10** Estimated NPV in million Euro (mean and standard deviation) for constructing a Gemini site with wind energy, mussel cultivation and/or seaweed cultivation, given a reference situation with an unused site

| | 3% discount rate | | 4% discount rate | |
|---|---|---|---|---|
| Design | Mean NPV | St. dev. of NPV | Mean NPV | St. dev. of NPV |
| Wind energy only (coal) | 1252.50 | 98.08 | 1009.27 | 90.96 |
| Wind energy only (ENTSO-E) | 1020.93 | 95.92 | 799.64 | 91.46 |
| Wind energy (coal) and mussel cultivation | 1369.55 | 105.73 | 1123.43 | 96.44 |
| Wind energy (ENTSO-E) and mussel cultivation | 1140.58 | 105.49 | 904.54 | 94.57 |
| Wind energy (coal) and seaweed cultivation | 630.74 | 150.25 | 448.93 | 143.55 |
| Wind energy (ENTSO-E) and seaweed cultivation | 397.88 | 149.39 | 225.82 | 138.95 |
| Wind energy (coal) and mussel cultivation and seaweed cultivation | 755.90 | 153.43 | 541.05 | 147.82 |
| Wind energy (ENTSO-E) and mussel cultivation and seaweed cultivation | 520.32 | 153.23 | 328.12 | 147.00 |

*coal* Wind energy compared to coal energy production
*ENTSO-E* Wind energy compared to European electricity mix production

**Table 4.11** Estimated NPV in million Euro for the Gemini wind farm for the deterministic maximum profitability scenario in a case when subsidies are deducted. (Monetized positive externalities due to $CO_2$ emission reduction are still included)

| Design | NPV (3% discount rate) | NPV (4% discount rate) | IRR (percent) |
|---|---|---|---|
| Wind energy only (coal) | 45.76 | −68.81 | 3 |
| Wind energy only (ENTSO-E) | −183.93 | −281.52 | 1 |

*coal* Wind energy compared to coal energy production
*ENTSO-E* Wind energy compared to European electricity mix production

quantitative assessment. This might result in a bias of unknown magnitude and direction, which suggests a need for further research. Further, the financial and economic assessment in Sect. 4.4 was mainly supported by data from a literature review and expert judgments, because site-specific data was available only to a limited extent. There is thus a risk for inconsistencies because of different sources and different assumptions. There are also considerable uncertainties associated with the choice of statistical distributions and some of the estimated values, which is evident from the quite substantial intervals for some costs and revenues. Missing site-specific data on sub-categories of costs made it also difficult to estimate site specific efficiency gains from the multi-use design. These limitations suggest that the SCBA results in Sect. 4.5 should be interpreted as preliminary. If additional information becomes available through, for instance, a wider monetization of externalities or a more precise investigation of synergy opportunities, this could potentially change some of the conclusions. For example, seaweed cultivation as a potentially profitable multi-use function in the future should not be ruled out, because knowledge gaps in the assessment are substantial and the market price development for seaweed products are highly uncertain.

These issues illustrate the difficult choice in a research project between either relying at least partly on data that are relevant though with high uncertainty (e.g., apply not site-specific data), or to only gathering 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 the following:

- Different design of the site in terms of, for example, capacity installed and size of the site.
- Comparison of the profitability of seaweed cultivation in an offshore single-use site, in an offshore multi-use site, in a coastal site close to the North Sea, or in the conventional markets such as Asia.
- Analysing offshore mussel cultivation in comparison to more near-shore mussel cultivation.
- Assessing differences in externalities associated with an offshore location in comparison to an on-shore location or a location closer to shore, taking into account that coastal areas are already subject to considerable environmental pressures.
- Different economic valuation methods.
- Longer time horizons in the SCBA than 20 years.

A particularly considerable uncertainty is related to the existence of potential synergies when combining uses. As mentioned in Sect 4.4, literature suggests that a 10% cost reduction is possible because of the possibility of efficiency gains in combining different functions in a multi-use site. This potential cost reduction was not taken into account in the financial assessment and in the SCBA. While such a reduction would not change the qualitative conclusions above about the financial and economic viability of adding mussel cultivation and seaweed cultivation to the wind farm, it should be emphasized that the extent of the potential 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.

It should also be emphasized that realizing multi-use sites in the future hinges crucially on a number of governance issues to be resolved, such as multi-use licensing and the possibility to obtain insurance for multi-use. Further, some additional key challenges that deserve further study include the design of mussel and seaweed cultivation systems within an 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). For the Gemini site, there are also considerable operational challenges related to the relatively long distance to the nearest main port (85 km) and the extreme wave heights that occur during storms.

The uncertainties and challenges suggest the need for further research on how multi-use sites should best be realized. For example, complementary research about seaweed cultivation in a multi-use site could be done by incorporating pilot cultivation in planned single-use or multi-use installations. This would increase know-how about such things as biomass production and costs, and therefore decrease uncertainty about this use. For example, this could clarify to what extent the presence of seaweed cultivation could protect wind farm installations and facilitate operation and maintenance activities through wave attenuation. Pilot installations entailing low investment costs might be easily accommodated within already subsidized projects with high investment costs such as wind farming. Introducing subsidies for "start-ups" for offshore mussel and seaweed production would improve its financial viability, although our results indicate that seaweed production would require a substantial subsidization. However, introducing subsidies might introduce a risk that investors are not making maximum efforts for discovering and implementing multi-use synergies, which suggests that a "start-up" subsidy system already from the beginning should entail a clear structure for phasing out the subsidies.

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# Chapter 5
# Socio-economic Assessment of a Selected Multi-use Offshore Site in the Atlantic

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**Abstract** This chapter presents the results obtained from the analysis of the multi-use design for the Cantabria Offshore site in the Atlantic coast. The analysis shows that the technology exists. Nevertheless at the present the profitability of potential business is still uncertain. The reliability of the activity as a self-sustained business relies on the existence of a stable regulatory framework, on the availability of financial support from the state and on the relaxation of the regulatory barriers existing in the industry. Likewise ocean energy industry is far from been socially accepted in the region. The socio-economic analysis suggests that the multi-use scenario can be profitable.

**Keywords** Multi-use offshore platforms • Marine infrastructure • Socio-economic analysis • Environmental analysis • Marine spatial planning • Atlantic

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## 5.1 Introduction

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 Atlantic-western storms lead to a severe ocean environment. The ocean conditions are severe and challenging. In the MERMAID project, the Cantabria Offshore Site (COS) was selected, given its deep sea and harsh ocean conditions. COS is situated 10 km Atlantic from the coast of Santander (Cantabria) and it covers up to 60 km$^2$ of sea. It 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/m$^2$. The 50 year return period significant wave high and average expected wind speed will be around 9 m and 27 m/s respectively (Table 5.1, Fig. 5.1).

The high energy content makes the site very attractive for developing wind and wave energy extraction. A number of 77 units of multi-use design that includes wave and wind energy 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.

The multi-use farm proposed will be integrated in a site characterized by a wide range of water depths comprehended between 40 and 200 m where floating structures are the most suitable technology for ocean energy harvesting. This multi-use design 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 center of the triangle. The three outer columns are equipped with the OWC technology, 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 the

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**Table 5.1** Basic facts about the Cantabria Offshore site

| 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 |

Source: http://www.vliz.be/projects/mermaidproject/docmanager/public/index.php?dir=Outreach_Material%2F&download=MERMAID_Booklet.pdf

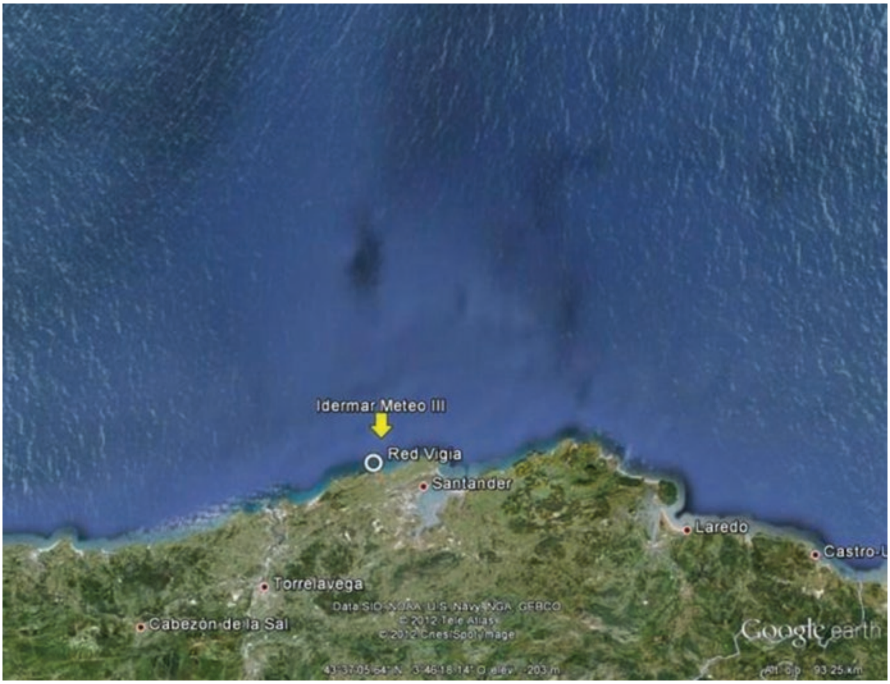

**Fig. 5.1** Location of the Cantabria Offshore site

costs (MERMAID Project 2015, 2016). The availability of natural port facilities constitutes an additional advantage for the deployment of the selected activities.

In this chapter we perform a socio-economic analysis of the multi-use design for the Cantabria Offshore site. For this the following steps are applied. The case study is put into a socio-economic context in the following section. For this are identified and described the actors, the economic sectors and the institutions of interest. Next the multi-use environmental impact is analyzed, and the potential of valuing these impacts in monetary terms is assessed. An initial financial and economic assessment of the multi-use design is also performed. This is followed by a social cost-benefit analysis.

## 5.2 The Case Study in a Socio-economic Context

### *5.2.1 Demographics and Economic Activities*

The land area of the study site accounts 5321 km$^2$. The population of the region amounts to 577,995 inhabitants with density of 109 inhabitants per km. The regional population synthesis is rather balanced between male (51%) and female (49%), while the average household size is around 3.1 persons per household. The qualitative aspects of human resources in the study site can be revealed through the educational level of the population. The educational attainment is rather balanced between primary, secondary and higher level. In particular, almost 32% of the population has elementary education that can be considered quite high and could impede the goal of economic development. Almost 36% of population has secondary education and 32% of population has higher education.

Total labor in the Atlantic site amounts to 277,100 persons. Male employment amounts to 55%, while female employment accounts for 45%. The unemployment rate in the region is around 20.5%. Sectoral employment is often considered an important indicator in analyzing the economic structure and organization. The analysis of sectoral employment indicates that the economy is more services-oriented, as the tertiary sector accounts for 73% of total employment. The contribution of agriculture to total employment has been contracted to 3%, while manufacturing and construction sectors contribute by 16% and 8%, respectively. With regards to the qualitative characteristics of the employees, 56% of the labor force has higher education (26% of the population holds baccalaureate and 30% has attained graduate studies), while 34% of the labor force has education.

The total value of regional production in the study site amounts to 12.8 million Euro. In terms of the sectoral shares of regional production, the tertiary sector contributes by 60% to the regional production generation, the secondary sector contributes by 37%, and the primary sector by only 3%. In particular, manufacturing industry contributes by 17% in the regional product formation, construction sector by 12%, and the trade sector by 10%.

The MUOP selected design is expected to have an increase in temporary employment. It is also expected to accrue benefits for the industry and benefits for existing businesses. In particular, it has been estimated that during the construction phase of the proposed platform 1000 persons can be employed over a three-year period, while 500 persons can be employed for O&M activities during the operation phase. This will enrich the available expertise for the companies and other stakeholders involved in the Industrial Cluster organized around local University and Regional Government.

### 5.2.2 Stakeholders, and Implementation Barriers

A group of stakeholders was interviewed in November 2012 in order to understand their views and perceptions about MUOPs in Cantabria. Three alternative MUOP designs were presented to local stakeholders, namely, the wave energy generation in combination with aquaculture, the wind energy generation in combination with aquaculture, and the wind and wave energy generation in combination with aquaculture. With regards the technical feasibility of the proposed schemes, the stakeholders referred that in general there is a high risk on geotechnical failure and failure with land connections. These risks are expected to be highest on the third alternative, i.e. wind and wave energy generation combined with aquaculture.

While there is a lot of research on offshore wind energy, local businesses and academia focus on developing wave energy and mooring systems. Consequently, the expected local benefits of wind energy are considered low, whereas wave energy development is believed to strengthen local businesses. Wave energy production is an emerging technology that can provide access to new markets, while wind power production can generate employment in affected activities, e.g. electrical maintenance and maritime services at local level.

The sensitivity of local society towards the aesthetic and functional impact of the proposed facilities is rather high and negative. Locals perceive coastal sea areas as free access areas and hence any restriction, actual or presumed, is traditionally considered as a private appropriation of public areas receiving thus heavy public opposition. This attitude is applied to coastal facilities on both ground and sea. Previous proposals developed in the area involving ground facilities have been abandoned or restricted due to this attitude (e.g. fracking, oil drilling and land windmills). The lack of local energy availability and the strong energy dependence of the country do not guarantee public interest and support of the activity. Furthermore, uncertainty over future impacts is also an important source of rejection of private settlements on public areas.

There is also great uncertainty on the regulatory conditions for the affected sectors. The majority of proposals made for the Atlantic site are oriented to energy production. Thus, costs cannot be shared among sectors, while the financial conditions of the business operation depend critically on policy regulations determined by the public sector. There is also uncertainty on spatial planning regulations. Past experience has shown that the needed guarantees for long term investments are never provided and initial approvals can easily be rejected. There is also uncertainty in the availability of funding that may have a great impact on the potential development of the infrastructure. Furthermore, the uncertain character of the proposed activities represents a significant restriction for financial agents that want financial guarantees to assume their participation in the funding scheme.

The local society is nowadays concerned about different emerging new technologies. The government of Cantabria between 2008 and 2011 promoted the onshore wind development in the region. Several social initiatives led by political parties and other civil associations revealed a negative perception of the initiative that was deeply reflected on the Cantabrian society. Due to the negative social perception the government of Cantabria decided to reduce the onshore wind development by 2012. In 2012 a new emerging technology associated to shale gas extraction, emerged as a very promising source of income. Nevertheless social perception in this case as well has been highly negative. Social and political initiatives led by different organizations are highlighting the negative impacts of these technologies and as a result significant social barriers to this technology have been set. These examples show how social perception in Cantabria can setup barriers that can impede different kind of initiatives.

The potential barriers in the implementation of the project can be identified at international, national and regional level. These barriers include:

(a) Lack of social consensus
(b) Need for consistent time scheduling for decisions and intermediate steps
(c) Regulatory risks connected with energy policy in Spain and Europe
(d) Current controversies on external energy dependence may promote marine energy production in future.

Past experiences in energy production industries have showed that strategic options have been the subject of never ending discussions. The complex bureaucratic procedure to obtain permissions is one of the major institutional and administrative obstacles. There is also insufficient coordination between ministries that further impede the offshore grid development. With regards to environmental legislation, the existing one does not explicitly exclude offshore renewable energy installations and infrastructure. However, it may slow down or hamper in some specific cases the deployment of offshore renewable energy installations/infrastructure.

## *5.2.3 Institutional and Policy Framework*

### 5.2.3.1 Policies Related to Offshore Renewable Energy

The regulatory framework for the development of marine energy in Spain includes:

(a) the Renewable Energies Plan 2011–2020 (PER)
(b) the Royal Decree No. 661/2007
(c) the Royal Decree No. 1028/2007
(d) Administrative procedures

The Renewable Energies Plan (PER) of Spain was approved in November 2011. The main objective of this plan is to establish a set of guidelines and policies to meet European objectives by 2020 given by the EU Directive 2009/28/CE. The plan promotes the production of renewable energies according to the Royal Decree 661/207 and the Sustainable Economy Law 2/2011. Furthermore, it establishes the available power of each marine energy. By 2020, the offshore wind energy goal is 750 MW, while the wave energy power goal is 100 MW.

The Royal Decree 661/2007 establishes a regular and legal framework in order to give stability and certainty and a sufficient return to the society. It aims at promoting an efficient operation of the electrical system, while it integrates and maximizes renewable energies in the electrical system. Finally, it establishes some mechanisms and incentives for market participation.

The renewable installations are classified in the following groups:

- Category A: cogeneration and residual energy installations
- Category B: renewables (solar; wind; geothermal, hot rock, wave, tide, ocean-thermal; mini-hydro, power < 10 MW; hydro, power > 10 MW; biomass; biogas and others; industrial biomass);
- Category C: energy recovery from waste (SUW; waste not previously considered; waste accounting for at least 50% of primary energy used; plants pursuant to Royal Decree No. 2366/1994 of waste from mining operations).

Marine energies, including wind and waves, are included in the second category and they are considered special regime energy resources. The Directorate-General of Energy Policy and Mines is the competent authority for the inclusion in the special regime when the installation is located in territorial waters. The mechanisms for remunerating the energy produced in the special regime includes a single regulated list of charges for all programming periods and a market sale through the system of bids managed by the market operator, the bilateral contracting system or by installment, or a combination of all these.

#### 5.2.3.2 Administrative Procedures Related to Offshore Renewable Energy

The administrative procedures include the following processes: (a) administrative authorization which is set by the Royal Decree No. 1955/2000; (b) environmental impact assessment of the project; (c) environmental impact study (available Environmental Impact Assessment (EIA) for similar project in the region: Plan Eólico de Cantabria); (d) identification and justification of the sea-land public domain to be occupied; (e) approval of the construction project; (f) start-up certificate.

The administrative authorization body of installations is the Directorate-General of Energy Policy and Mines of the Ministry of Industry, Energy and Tourism. The grants authorizations and concessions to occupy the sea-land public domain are provided by the Ministry of Agriculture, Food, and the Environment (Directorate-General of Coast and Sea Sustainability). The Directorate- General of Environmental Quality and Assessment and Natural Affairs of the Ministry of Agriculture, Food, and the Environment is the competent environmental body, while the Secretariat-General for the Sea passes measures to protect and regenerate fishery resources. The Ministry of Development (Directorate-General of the Merchant Marine) is responsible for passing measures for maritime security, navigation and human life at sea, while port authorities are responsible for grants authorizations and concessions to occupy the port public domain.

#### 5.2.3.3 Policy Obstacles and Regulatory Uncertainty

The majority of proposals made for the Spanish Coast site are oriented to energy production. Thus, costs cannot be shared among sectors, while the financial conditions of the business operation depend critically on policy regulations determined by the public sector. However, there is uncertainty on spatial planning regulations. Past experience has shown that the needed guarantees for long term investments are never provided and initial approvals can easily be rejected. There is also uncertainty in the availability of funding that may have a great impact on the potential development of the infrastructure. Furthermore, the uncertain character of the proposed activities represents a significant restriction for financial agents that want financial guarantees to assume their participation in the funding scheme.

The complex bureaucratic procedure to obtain permissions is one of the major institutional and administrative obstacles. There is also insufficient coordination between ministries that further impede the offshore grid development. With regards to environmental legislation, the existing one does not explicitly exclude offshore renewable energy installations/infrastructure. However, it may slow down or hamper in some specific cases the deployment of offshore renewable energy installations/infrastructure.

Other legislative obstacles include the following:

(a) the international marine spatial planning (MSP) instruments set up provisions influencing the legislative and procedural requirements for offshore renewable energy and the related grid infrastructure
(b) the maritime spatial planning is closely related to a legal framework
(c) the priority principle for navigation has been firmly anchored in the United Nations Convention on the Law of the Sea (UNCLOS) and is reflected in the dominant position of the shipping sector
(d) the fundamental right to lay submarine cables is firmly anchored in the UNCLOS
(e) lack of clarity of information, specific uncertainty related to grid capacity reinforcements.

## 5.3 Monetization of Environmental Impact

### *5.3.1 Impact on Ecosystem Services*

The selected multi-use design for the Cantabria Offshore site might influence a number of the marine ecosystem services supplied by the Atlantic Coast. These include provision of food and raw materials, supporting services, cultural and habitat services (Table 5.2).

**Table 5.2** Ecosystem services probably affected by the multi-use design

| Category of ecosystem services | Provisioning services | Supporting/regulating services | Cultural services | Habitat services |
|---|---|---|---|---|
| Ecosystem services | Food and raw materials | Nutrient cycling | Cognitive development: research and education | Diversity |
| Period of the effect | Constrution and operation phase | Not relevant | Construction and operation phase | Operation phase |

Source: Communication with Site Managers and Biologists

Under MERMAID Project it was decided to apply an adjusted Benefit Transfer method to account for potential environmental and socio-economic impacts. The referred adjustments considered income changes, price changes over time and purchasing power differences. The adjustments were based on UNEPs manual on valuing transferred values of ecosystem services (2013).

In order to choose the relevant studies, common socio-economic and geographical characteristics are considered between the policy site and the study sites of each examined paper. Since it was hard to find studies related to offshore multi-use platforms, research had to be expanded on case studies that include similar environmental and social effects in the marine area without explicitly referring to offshore platforms. The aim was 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 MERMAID site managers and biologists, cultural services with regards to cognitive development were given monetary values. However, economic values for all the possible effects on ecosystem services were not given due to lack of data. The positive benefit during the construction and operation period produced from R&D and education was estimated to be 1.2 euros per person per year (2013). Assuming that the affected population is 577,995 based on the regional profiling, the economic revenues amounts to 695,727.13 (2013) euros per year (Table 5.3).[1]

### 5.3.2 Impact on $CO_2$ Emissions

Energy Farm MUOP designed by University of Cantabria comprises oscillating column type wave energy devices and 5 MW NREL wind turbine that are installed on a triangular semisubmersible concrete platform. In the energy farm, 77 energy platforms are planned to produce energy. Transmission of produced electricity is realized through submarine cables which are gathered at one offshore substation. After this, electricity is transmitted to an onshore substation where it is connected to main transmission lines. The systems studied in LCA study included production and

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[1] Pugh and Skinner (2002) paper was used for the purpose of benefit transfer.

**Table 5.3** Benefit Transfer Application for the Cantabria Offshore Site.

| Description | Research and Education | | | |
|---|---|---|---|---|
| Pugh and Skinner (2002) | Total Value (£)/year (2004) | UK Population (2004) | Value (£)/ person (2004) | Benefit transfer value (Euro) (2013) |
| This study estimated the value added for research and development in the marine sector, including education and training during the period of 1994–2000. | 292,000,000/6 = 48,666,667(£) | 59,990,000 | 0.81(£) | 1.20 (Euro) |

Exchange rate 2004, £/$ used: 1.77

installation of MUOP components (wind turbine, wave energy converter, floating platform) and electricity transmission system (offshore substation and submarine cables), operation and maintenance activities, disposal of MUOP farm as well as transportation of materials during the life cycles of the MUOPs. Electricity distribution that is located onshore was excluded from the system studied. Functional unit was selected as 2 kWh electricity produced by the system.

Wind and wave according to the characterization results, obtained GWP impact category result is 20.4 g $CO_2$-eq for the site. To give the decrease in the amount of greenhouse gases due to renewable energy sources, the comparison is made with conventional electricity production techniques and European electricity mixes, respectively. If this comparison is made for Atlantic Case design, the result is the difference between 820 and 20.4 g $CO_2$ equivalents by taking the average value for electricity production via coal burners for 1 kWh electricity produced (Schlömer et al., 2014). Therefore, it is claimed that if 1kWh energy is produced by the designed MUOP, GHG emissions are decreased for 799.6 g $CO_2$-eq compared to electricity production by coal usage. In the case of considering European electricity mix (ENTSO-E network) which corresponds to 462 g $CO_2$-eq/kWh (Itten et al. 2014), the difference is 441.6 g $CO_2$-eq (Tables 5.4 and 5.5).

The emission estimates were monetized by applying the social cost of carbon. This refers to the shadow price of world-wide damage caused by anthropogenic $CO_2$ emissions (Pearce 2003). According to Arrow et al. (2014), the social cost of carbon is $19.50 per ton of $CO_2$ 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 monetization was based on the estimate from the state-space model, which correspond to 22.50 Euro per ton (Exchange rate 0.83 $/Euro).

**Table 5.4** 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 | 20.4 | g $CO_2$-eq |
| Coal Based Electricity Production | Amount of $CO_2$-eq saved through MUOP electricity production per 1 kWh | 799.6 | g $CO_2$-eq |
| ENTSO-E Electricity Production | Amount of $CO_2$-eq saved through MUOP electricity production per 1 kWh | 441.6 | g $CO_2$-eq |

**Table 5.5** Total amount of $CO_2$ emissions per function of MUOP and the compared production technologies

| Function | Parameter | Amount |
|---|---|---|
| MUOP Electricity Production (WIND + WAVE) | Amount of $CO_2$-eq production (assuming 778.53GWh/year) | 20.4 g$CO_2$-eq/kWh *778.53GWh/year*25 years = 397050.3ton $CO_2$-eq |
| WIND: Coal Based Electricity Production | Amount of $CO_2$-eq saved (assuming 777.25 GWh/year) | 799.6 g$CO_2$/kWh *777.25GWh/year*25 years = 15537227.5ton $CO_2$ |
| WIND: ENTSO-E Electricity Production | Amount of $CO_2$-eq saved (assuming 777.25 GWh/year) | 441.6 g$CO_2$/kWh *777.25 GWh/year*25 years =8580840ton$CO_2$ |
| WAVE: Coal Based Electricity Production | Amount of $CO_2$-eq saved (assuming 1.2 GWh/year) | 799.6 g$CO_2$/kWh *1.2GWh/year*25 years =23,988 ton $CO_2$ |
| WAVE: ENTSO-E Electricity Production | Amount of $CO_2$-eq saved (assuming 1.2 GWh/year) | 441.6g$CO_2$/kWh *1.2GWh/year*25 years =13,248 ton $CO_2$ |

## 5.4 Financial and Economic Assessment

The financial data for the Atlantic MUOP derived from the final design after considering stakeholders feedback and tests. They are based on the design itself, the construction procedure estimates, the expected location and size of the project and the best available estimates for unit construction costs. First, the resource availability from the re-analysis of spatial database was estimated. From this, the resource availability from wind and wave was obtained. Then the efficiency factor was estimated for the device based on laboratory tests in the tank. Combining both sources, we got the energy produced, which was related to the energy price. Furthermore, the final series of the tests obtained for available resource showed a typical deviation from the mean for wind energy production equal to 0.59 and 0.55 for wave energy production.

The Cantabrian Offshore site MUOP's was composed of 77 units of 8Mw floating devices with mixed technology: windmills and oscillating water column farm,

**Table 5.6** Estimates on annual energy production per function of the platform on the Atlantic site

| | Resource | Power | Capacity factor | Energy | Sigma(Resource)/ Mean(Resource) |
|---|---|---|---|---|---|
| Wind | 450 w/m$^2$ | 5 Mw | 0.2304 | 10.09 Gwh | 59% |
| Wave | 28 kw/m | 3 Mw | 0.0544 | 1.43 Gwh | 55% |

total power 616Mw. Total manufacturing cost is estimated to be 2.7 million Euro/ Mw, whereas total capital expenses reach 3.66 Euro/KW. The capacity factor for the installation reaches 0.20 for windmills and 0.05 for waves consistent with other experiences. An estimate for operational cost reaches 2.189 million Euro/kw and the average cost of energy reaches 0.167 Euro/kwh. The energy price starts with 0.15 euros/kwh and jumps to 0.17 in 8 years from the operation of the platform. The energy operation costs, were estimated based on a 20% of revenues as standard in the literature. Working on a high scale simulation project initially did not show contradiction with this standard (Table 5.6).[2]

By making use of these figures, we have obtained the expected business revenues and costs of the project. In joint graphs the EPCI budget, CAPEX, OPEX and Project budget are summarized next. The total project budget is up to 3,739,899,031 Euro with 60% of it being is related to CAPEX. It is important to notice the 23% of financing project cost considered are due to the total investment required to develop the MUOP farm. The main part of the budget is allocated to the power take-off (wind turbine and OWC) and the marine structure (72% of the EPCI budget and 53% of the CAPEX) (Fig. 5.2).

In this case, the power take-off devices as well as, the marine structures are not replaced. Consequently, the OPEX budget is spread into operation and maintenance costs and insurance cost. They are almost equal (54%–46%) (Fig. 5.3).

## 5.5 Social Cost-Benefit Analysis

The Social Cost-Benefit Analysis (SCBA) applied in this case study revealed whether the net benefit generated by the multi-use investment project is positive in a temporal perspective, conditional on the utilized discount rate scheme. The Net Present Value (NPV) criterion was applied. For this the general expression for NPV is employed as follows:

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

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[2] It should be noted that the device is still under a process of refining and improving the capacity factor (ratio of energy captured over nominal capacity of the device). The final figures are expected to improve in the near future.

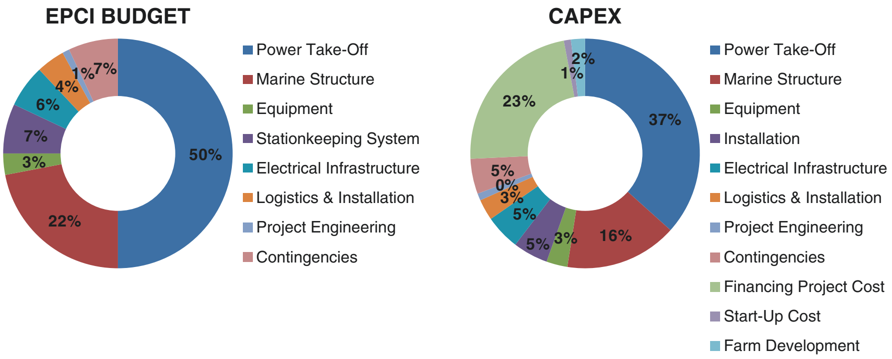

**Fig. 5.2** EPCI budget and CAPEX

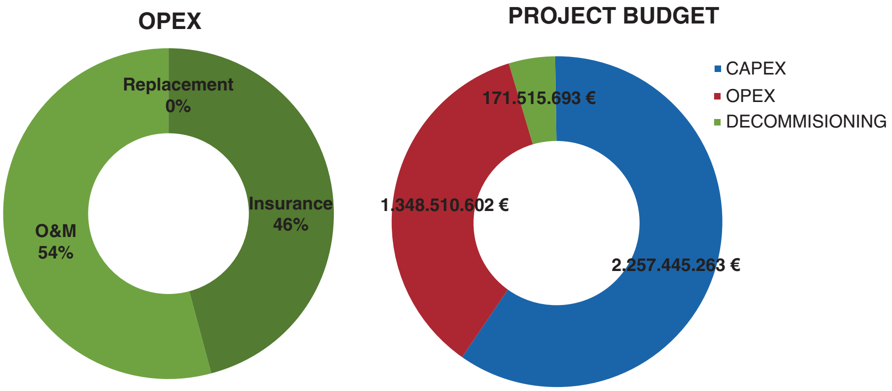

**Fig. 5.3** OPEX and project budget

where $K_t$ is investment costs, $B_t$ is the stream of benefits, $C_t$ is the stream of costs and $r$ is the discount rate. Monetized values of externalities, i.e. the benefits derived by the $CO_2$ emissions reduction and research and education effect due to wind and wave energy production, were also included in the benefits or costs terms, which is one major feature that distinguishes a SCBA from a typical financial assessment. For this case the financial costs and revenues, together with the benefits derived by the reduction of $CO_2$ emissions and research and education were included in the SCBA. For the case of $CO_2$ emissions both comparisons were used in the analysis, i.e. reduction of $CO_2$ emissions compared to coal energy production and ENTSO-E production.

For the wind energy production, the triangular distribution was considered. Since, there was no information regarding the stochastic factors affecting wind investment, the triangular distribution was considered as a reasonable assumption,

**Table 5.7** 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 | 706,564,380.13 | 41,298,125.64 |
| Single-use: Wind function operation compared to ENTSO-E energy production | 623,877,389.65 | 40,965,292.18 |
| Single-use: Wave function operation compared to coal energy production | −389,440,742.43 | 16,787,778.68 |
| Single-use: Wave function operation compared to ENTSO-E energy production | −390,505,552.28 | 16,750,771.88 |
| Multi-use: Wind & Wave scenario operation compared to coal energy production | 305,730,883.29 | 55,184,066.20 |
| Multi-use: Wind & Wave scenario operation compared to ENTSO-E energy production | 225,915,262.55 | 54,937,265.13 |

All values in euros

with central value the given investment cost and boundaries at 15% of the central value.

In the case of wind energy production and wave energy output production, normal distribution was used. Since no information about the specific distributions was available and there was only a central value for each of the items, a normal distribution was assumed with mean the given central value. The structure of the normal distribution was determined such that the mass included in the interval of ±2 standard deviation from the mean (μ) has boundaries at a distance of γ % of the mean (μ) the choice of γ was consistent with the data of the specific case.

Two alternative values were used for the social discount rate: 3% and 4%. These values are consistent with values obtained from the Ramsey formula for long-lived projects (see Dasgupta, 2008) $r = \rho + \eta g$, where $\rho = L + \delta$ is the rate at which individuals discount future utilities, L is catastrophe risk, i.e. 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, $\delta$ is the rate of pure time preference, which reflects individuals' impatience and preference for utility now, rather than later, g is annual growth in per capita consumption, and $\eta$ is the elasticity of the marginal utility of consumption. These numerical values are within the limits of typical values for the discount rate 3–4% appearing in the literature (Tables 5.7 and 5.8).

The estimates of mean NPV and its standard deviation suggest that the multi-use scenario (Wind & Wave) passes the SCBA test in terms of NPV (positive NPV) under all alternative assumptions regarding the discount rate and savings related to the reduction of $CO_2$ emissions. The wave scenario by itself is highly unprofitable due to high investment cost and low revenues. Since the Wind & Wave scenario is highly profitable, the inclusion of the wave function might be desirable to capture benefits related to technological progress which are quantifiable at the current stage.

**Table 5.8** 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 | 849,470,474.47 | 44,430,442.61 |
| Single-use: Wind function operation compared to ENTSO-E energy production | 760,080,006.68 | 43,250,317.42 |
| Single-use: Wave function operation compared to coal energy production | −392,995,362.89 | 16,240,898.77 |
| Single-use: Wave function operation compared to ENTSO-E energy production | −392,762,115.79 | 16,668,616.53 |
| Multi-use: Wind & Wave scenario operation compared to coal energy production | 442,343,771.94 | 58,288,143.94 |
| Multi-use: Wind & Wave scenario operation compared to ENTSO-E energy production | 355,399,160.92 | 56,008,811.17 |

## 5.6 Concluding Remarks

The assessment of the Atlantic coast site reveals that the implementation might be subject to several barriers. These are associated to lack of social consensus, to the need for consistent time scheduling decisions and actions, to the regulatory risks with regards to energy policy in Spain and Europe. On the external effects, these are identified with regards to interference of the MUOP with the navigation routes. On the identified drivers of risk the analysis indicates looking at the resource spatial-temporal variability and the institutional risk derived from feed-in tariffs and project administrative delays. Uncertainty on the institutional framework and spatial-temporal viability of the resource are the main concerns with regards to the analysis.

In financial terms, the analysis indicates the importance but also the magnitude of the required capital investments. Significant upfront payments when combined with risk and uncertainty indicate the need for support means to such initiatives. In terms of SCBA results, although the wave function alone seems not to be economically viable, synergies between wind and wave energy could result in technological progress that produces further economic benefits, that may extend well beyond the reduction of $CO_2$ emissions.

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# Chapter 6
# Socio-economic Analysis of a Selected Multi-use Offshore Site in the Mediterranean Sea

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**Abstract** The area off-shore Venice is characterized by a relatively mild climate that allows in principle a safe installation of an off-shore platform, but at the same time strongly limits the benefits of a single–purpose installation, both because of the limited available energy and because of the high distance from the shore due to the flat sea-bottom. Therefore the site appeared to be suited for multi-purpose designs with fish farming and wind energy as potential activities. An Ecosystem Services Approach (ESA) is adopted to identify possible environmental effects and conflicts with other relevant uses. We deal with these potential impacts by choosing a suitable location of the platform. Limited financial data on wind energy suggested a negative Net Present Value (NPV), whereas proper financial data on fish farming produced a slightly positive NPV. A Life Cycle Assessment applied to wind energy and fish farming estimated a significantly positive effect from reduced $CO_2$-eq emissions

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expressed in euros. A Social Cost-Benefit Analysis (SCBA) applied only to fish farming (i.e., including financial and $CO_2$ results) due to lack of data and resulted on a positive NPV. However, a MUP is not recommended by SCBA, and more explicitly it is not supported by stakeholders in the short-run. Whereas, it might be suggested in the long-run, when, in a crowded sea, both economic and environmental reasons could suggest to move some activities off-shore.

**Keywords** Multi-use offshore platforms • Marine infrastructure • Socio-economic analysis • Environmental analysis • Marine spatial planning • Mediterranean

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## 6.1 Introduction

Within the purposes of the MERMAID a site off-shore Venice has been selected for analysis. The area is characterized by mild climate allowing in principle the safe installation of an off-shore platform. Several challenges characterize the area, including:

- mild slope of 0.35 m/km and the peculiar circulation patterns with a high seasonal variability;
- severe anthropogenic development and co-occurring impacts, which leads also to erosion and land subsidence;
- strategic area for marine fauna conservation, sheltering relevant marine ecosystems (coralligenous reefs), seabird populations and endangered marine mammals, turtles and elasmobranchs;
- vicinity of the city of Venice, with the associated high social sensitivity to the construction of new marine infrastructures.

Considering the numerous maritime uses in the area, one of the key challenges to be solved is the location of the platform, depending on the potential conflict of uses deriving from the harbors with their commercial and touristic maritime routes, the fisheries, the oil and gas platforms, the natural habitats and the restricted areas (see Fig. 6.1, right). The main environmental parameters of the site are summarized in Table 6.1.

The meteo-marine climate of the site can be characterized as mild (Fig. 6.2). The maximum measured wave height is slightly higher than 4 m and the calm period is close to 40% (i.e. conditions with a wave height < 0.25 m), resulting in a mean available annual wave power around 1.1 kW/m. The wind velocity is in the range 3–4 m/s at 25 m height, and therefore its estimation at 100 m height is around 4.7 m/s.

Both wind and waves show two main incoming directions: one from the North East (Bora, between 0°N and 85°N) and a second from the South East (Scirocco, between 105°N and 175°N), being the Bora direction dominant both in intensity and frequency. The Adriatic is a semi-closed basin, and it is characterized by a low tidal excursion (< 1 m), so the tidal energy resource can be excluded from the multi-use scenario.

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

Based on the existence of many near-shore aquaculture farms, the site could be suitable for aquaculture. Moreover, the increasing demand on the global market, combined with the numerous existing space conflicts in coastal areas, has stirred interest in moving aquaculture further off-shore.

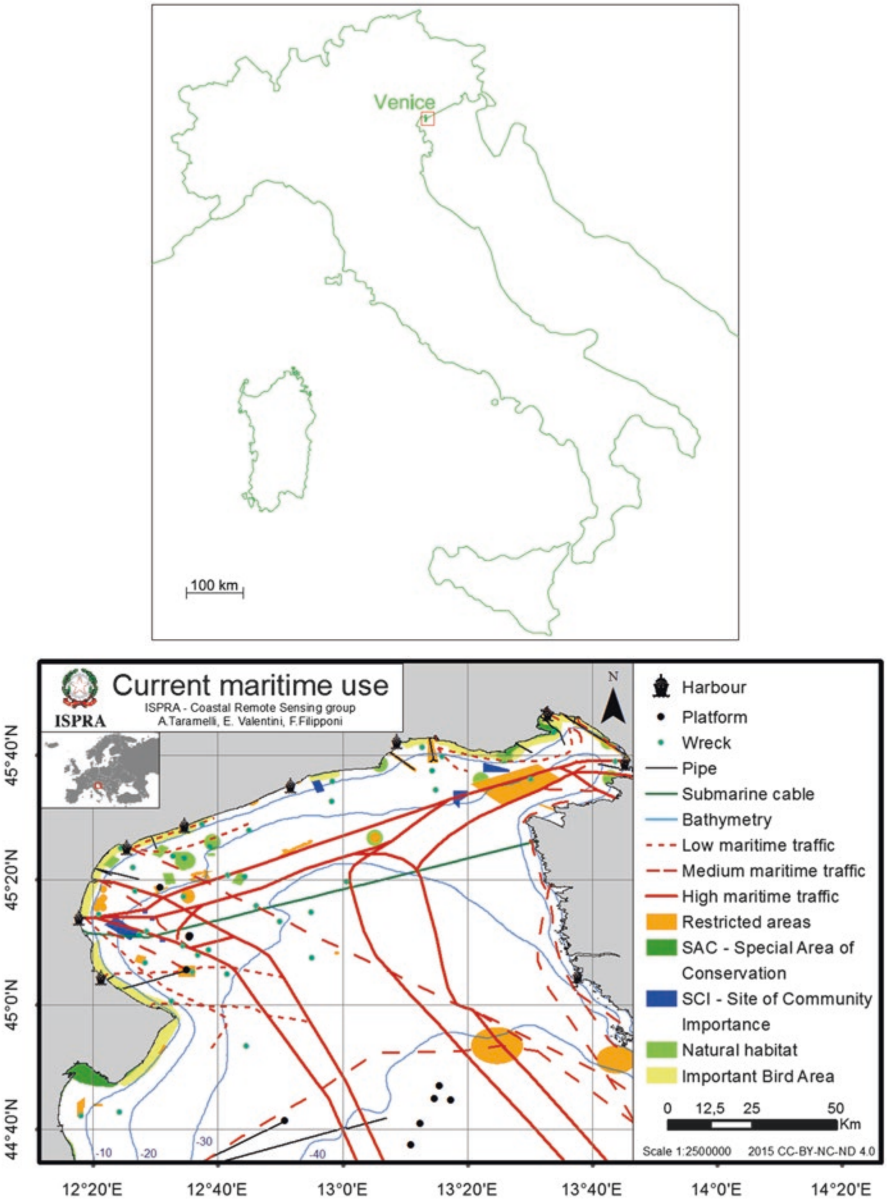

**Fig. 6.1** Location of the site highlighted with a *red square*; next are shown different existing uses in the selected area

**Table 6.1** Basic facts about the Mediterranean site

| Geographical location | Northern Adriatic Sea, off the coast of Venice (site) |
|---|---|
| Offshore distance | 16 km |
| Depth | 16 m, gentle slope towards south east |
| Substrate | A mixture of sand and mud |
| Average water temperature (+/− 1SD) | 14 °C (+/− 6 °C) |
| Average Salinity | 27.5 psu (+/− 1.5 psu) |
| Mean tidal range | 0.6 m (+/− 0.15 m) |
| Mean wave height | 1.25 m |
| Expected annual wave power | 3 kW/m |
| Average wind speed | 4.54 m/s |
| Expected annual wind power | Large turbines: 12.7 GWh/y/4 Vestas V112 turbines |

Source: MERMAID (2013). http://www.vliz.be/projects/mermaidproject/docmanager/public/index.php?dir=Outreach_Material%2F&download=MERMAID_Booklet.pdf

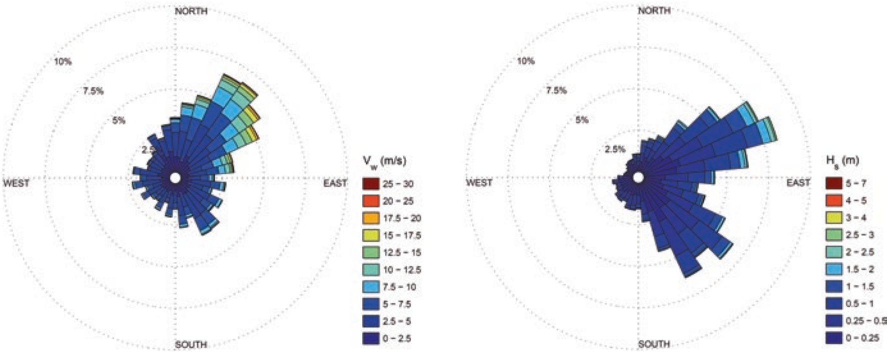

**Fig. 6.2** *Rose* diagram of the mean annual wind (to the *left*) and wave (to the *right*) regime at the Med site

According to the application of an original multi-criteria procedure and to the ranking of alternatives based on expert judgment (Zanuttigh et al. 2016), the selected multi-use design consists of wind turbines and fish farming (Fig. 6.3).[1]

The fish farm is designed to support annual production capacity of 2000 tons, equally divided between the gilthead sea bream (*Sparus aurata)* and European sea bass (*Dicentrarchus labrax*) species. It 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 three times the depth of the nets (9 m).

The wind farm consists of four VESTAS V112, each of which is characterized by a 112 m rotor diameter and by a rated power of 3.3 MW. The total production is of 12.7 GWh/y, with around 1000 equivalent hours. To reduce wake effects, a spacing

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[1] For details see: MERMAID (2016) and Zanuttigh et al. (2015)

**Fig. 6.3** Representation and layout of the selected multi-use platform in the Mediterranean Sea (Source: By courtesy of VLIZ)

of seven rotor diameters (distance of around 800 m) around each wind generator is assumed. The space occupied by the multi-use offshore platform (MUOP) is a square area of 0.64 km$^2$, 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 allows boat traffic to move between installations (MERMAID project 2015, 2016).

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.

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

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

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

In the following sections a socio-economic analysis of the multi-use design for the Mediterranean Sea site is applied as follows: The case study is put into a socio-economic context in Sect. 6.2 through identifying and describing actors, economic sectors and institutions. In Sect. 6.3, the environmental impact of the multi-use farm is analyzed, and the potential of valuing these impacts in monetary terms is assessed.

An initial financial and economic assessment of the multi-use design is found in Sect. 6.4, which is followed by an attempt to apply a social cost-benefit analysis in Sect. 6.5. Given that data for both functions were not available; a Social Cost-Benefit Analysis (SCBA) was applied to the single use scenario aiming to support the importance of considering possible externalities, i.e. non-market economic impact, into the analysis. The chapter is concluded with a discussion and recommendations in Sect. 6.6.

## 6.2 The Case Study in a Socio-economic Context

This section aims at contributing to an improved understanding of the effects of the multi-use design by providing a brief description of the case study profile. Demographic and socio-economic facts are provided, stakeholders are identified, and relevant institutional and policy settings are described. Environmental uncertainties and implementation obstacles are also discussed.

### *6.2.1 Demographics and Economic Activities*

The study site is in close proximity to the Veneto region of Italy. The land area of the study site amounts to 18,378 km$^2$. The population in that area accounts for 4,937,854 inhabitants with population density of 269 inhabitants per km$^2$ (2011). The population of the study site exhibits a rather balanced distribution between male (51%) and female (49%), while the average household size is around 2.4 persons per household. The qualitative aspects of human resources in the study site can be revealed through the educational level of the population. The population is characterized by a rather favourable educational attainment level, which constitutes an important asset for development prospects. More specifically, almost 46% of the population has completed graduate and postgraduate studies.

Total labour in the Mediterranean site amounts to 2,240,713 persons. Male employment amounts to 59%, while female employment accounts for 41%. Unemployment amounts to 128,612 persons (or 5.8%) of which 46% is male and 54% is female. Sectoral employment is often considered a crucial indicator in analysing economic structure and organization. The analysis of employment by branch of economic activity portrays that the major sectors offering employment in the region are the manufacturing sector (28%) and the trade sector (15%). The economy is service-orientated since tertiary sector (service sector) accounts for 60% of total employment, while the secondary sector (manufacturing sector) contributes by 37%. The contribution of agriculture (primary sector) to total employment is 3%. With regards to the qualitative characteristics of the employees, almost half of them hold baccalaureate, while 15% of labour force has attained graduate and postgraduate studies. The percentage of employees with primary education is only 4%.

The total value of regional production in the study site amounts to 130,634 million euros (2011). In terms of the sectoral shares of regional production, the tertiary sector contributes around 63% to the regional product generation, the secondary sector contributes by 35%, and the primary sector by only 2%. More specifically, the manufacturing industry contributes by 26% in the regional product formation, the property and business services sector by 14%, and the trade sector by 12%.

## *6.2.2 Stakeholders*

The stakeholders who may be affected by the multi-use designs are located in the coastal areas in Venetian Region. It should be noted that in the final design, no wave energy converters are considered. Nevertheless, information with regards to wave energy production is included in regional profiling for reference to future projects.

A thorough examination of the current political and social conditions in the Mediterranean site revealed that in terms of the aquaculture the most vulnerable groups and those impacted more are fishermen, persons involved in activities related to tourism and transport constructing and storage. With regards to wave energy production, the most vulnerable groups are mainly energy suppliers, the sector of equipment and machinery, the transport constructing activities and the consumers (van den Burg et al. 2016; MERMAID project 2013).

## *6.2.3 Institutional and Policy Framework*

### 6.2.3.1 Policies Related to Offshore Energy

Currently, no regional or national legislation regulating renewable offshore energy projects exists in the region. The Ministry of the Environment is responsible for safeguarding the environment. The Ministry of Infrastructures and Transport regulates issues of production of energy. The authorizations for the construction and operation of wind plants are issued by the Ministry of Infrastructures and Transport. The Ministry of Economic Development and the Ministry of the Environment are also consulted, while the peripheral offices of Genio Civile provide concessions of the maritime State property use. With regards to incentives for energy from marine renewable sources, the government ensures 0.34 € per kWh for all plants smaller than 5 MW. No national or regional legislation exists to regulate subsidies for such a project. Unlike other energy sectors, wind energy generation is at an early stage of development and there is no established industry consensus on codes and standards.

#### 6.2.3.2 Policies Related to Aquaculture

The Regional Government which is in charge of authorizing aquaculture activities can reimburse up to 50% of investment expenditures. The state refunds up to 80% of the insurance premium to create incentives for insurance that cover structural risks linked to natural events, climatic conditions and price fluctuations. Furthermore, the Region has set up local commissions to modernize the aquaculture sector.

It has to be stressed that aquaculture in the European Union (EU) is regulated by strict laws. A fish farm needs to fulfill an extensive list of requirements to get a permit of operation. This ensures that the operation will not have adverse impacts on the environment and that there is no clash with other activities. Once a permit is issued, which means an Environmental Impact Assessment (EIA) has been conducted in the area and all other requirements are met, then the company is obliged to conduct regular checks, which ensure the proper operation of the farm.

### *6.2.4 Environmental Uncertainty and Implementation Obstacles*

Controversies about aquaculture have arisen when clam producers imported a Philippine species (*Ruditapes philippinarum*) which is larger and grows faster than the native clam (*Ruditapes decussatus*). It was intentionally introduced in Northern Adriatic Sea coastal lagoons in 1983 to support a clam fishery suffering a crisis due to overexploitation of native clam *Ruditapes decussatus*. The Japanese kelp *Sargassum muticum*, the Asian kelp *Undaria pinnatifida* and the pacific oyster *Crassostrea gigas* have also been introduced by aquaculture and have rapidly spread in the Venice and Po Delta coastal lagoons. Overall the north Adriatic sea is a hotspot of species invasions (Occhipinti et al. 2011) As a result, concerns about the impacts of aquaculture on biodiversity and the current fishery sector were expressed.

Additionally to invasive species, eutrophication (related to both point-source discharges and non-point loadings of limiting nutrients, such as nitrogen and phosphorus), is another adverse impact of concern when aquaculture is considered. Karakassis et al. (2005) estimated that the overall N and P waste from fish farms in the Mediterranean represents less than 5% of the total annual anthropogenic discharge, while the overall annual increase in P and N pools in the Mediterranean, under a production rate of 150,000 tons, is less than 0.01%. In other words, Karakassis et al. (2005) results imply that “there is little risk of a noticeable increase in the nutrient concentration in the entire Mediterranean or even in the Eastern Basin as a result of fish farming”. Moreover, Pitta et al. (2009) found that grazing plays a key role in regulating phytoplankton biomass, keeping chlorophyll *a* at low levels and effectively transferring nutrients up the food web. Nonetheless, it is essential to tackle water eutrophication from fish production, also to allow current and future diving activities in this area.

In addition, the selected study site minimizes the controversies about energy production with regards to potential conflicts with other relevant environmental characteristics or uses of the marine environments, e.g., off-shore ports, naturalistic areas, fishery activities, tourism activities, and with the general conservation of the ecologically relevant species and habitats (see MERMAID Location Selection Tool).

Furthermore, fishery is a main income source in the region in both commercial and recreational terms. Significantly valuable biological seabed concretions (coralligenous type), which are called tegnue, exist in the region; these are protected areas and attract lots of divers. Thus, the selection of the location of the multi-use design was done specifically excluding those areas. However, the local stakeholders are very skeptical about the economic feasibility and success of aquaculture, while on the contrary are very optimistic for the economic potential of the wave energy production.

## 6.3 Monetization of Environmental Impact

### *6.3.1 Impact on Ecosystem Services*

The selected multi-use design for the Northern Adriatic Sea site might influence a number of the marine ecosystem services supplied by the Mediterranean. Aquaculture would increase the provisioning services through production of edible fish biomass. If the site is not carefully managed, the increase in fish biomass and resulting fish feces as well as fish feed may increase nutrient loading in the surrounding waters and sediments (Wu 1995; Pitta et al. 2005; Price et al. 2015). Such platforms could also be used to further cognitive development of visitors to the site if access is allowed for teaching purposes (Table 6.2).

Artificial structures favour non-indigenous species (NIS) as they have several advantages at colonising these compared to natives, leading to regional scale changes in their relative abundances (Airoldi et al. 2015). Artificial structures can also harbour polyps of cnidarians and dinoflagellates. When this happens, they may lead to increased numbers of, for example jellyfish (Duarte et al. 2013) or harmful algal blooms or damage fish if the polyps are attached to fish cages (Baxter et al. 2012). However, efforts have been made to identify solutions to reduce some of these risks. For example, the settlement and growth of NIS on artificial structures can be limited by using materials or coatings that prevent colonisation of any species including NIS. Ecologically informed repair schedules can limit the spread of NIS by favouring a quicker recovery of the native ones (Airoldi and Bulleri 2011). In the Adriatic sea, work within MERMAID has also shown that actively gardening ecologically relevant habitat-forming species could be a promising tool to contemporaneously enhance native species and deter NIS (Perkol-Finkel et al. 2012, Ferrario et al. 2016).

Based on the site characteristics and the information provided by the site manager and biologists, it was decided to estimate the economic value of the negative

**Table 6.2** Examples of ecosystem services potentially affected by the multi-use design and examples of these effects

| Category of ecosystem services | Provisioning services | Supporting/regulating services | Cultural services | Habitat services |
|---|---|---|---|---|
| Ecosystem services | Food and raw materials | Nutrient cycling | Cognitive development | Diversity |
| Effect | Positive due to increase in farmed fish biomass | Negative due to increased fish feces and fish feed from farm entering the water column leading to increased nutrient loads in the water column | Positive if site is used for education purposes (for example school trips) | Negative during construction, negative during operation unless ecological engineering is used to reduce chance of invasive species and support native species, particularly habitat forming species |
| Period of the effect | Operation Phase | Construction and operation phase | Not relevant | Construction and operation phase |

Source: Communication with Site Managers and Biologists

effects of the presence of Harmful Algal Blooms in Italian waters during operation of multi-use designs using the Benefit Transfer Method. Although such effects are currently rather small, they could be further enhanced by water quality issues related to aquaculture and by the introductions of additional artificial habitats related to the multi-use design's construction and operation. However, since these effects will not be crucial in the 30 years of expected operation duration and the location of the MUOP was chosen with the scope to minimize such negative environmental effects, it was chosen not to consider this value to the social cost benefit analysis.

### 6.3.2 *Impact on $CO_2$ Emissions*

Another environmental effect associated with the Northern Adriatic Sea site are carbon dioxide ($CO_2$) emissions. Those emissions were estimated through a Life Cycle Assessment (LCA) for evaluating the Global Warming Potential (GWP) associated with the multi-use for the Northern Adriatic Sea site.[2] Resulting quantity of

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[2] An 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.

**Table 6.3** Unit amount of $CO_2$ emissions per function and the compared production technologies

| Function | Parameter | Amount | Unit |
|---|---|---|---|
| Electricity production | Amount of $CO_2$-eq production per 1 kWh | 5.23 | g $CO_2$-eq |
| Coal based electricity production | Amount of $CO_2$-eq saved through electricity production per 1 kWh | 794.37 | g $CO_2$-eq |
| ENTSO-E electricity production | Amount of $CO_2$-eq saved through electricity production per 1 kWh | 456.77 | g $CO_2$-eq |
| Fish production | Total amount of $CO_2$-eq production per 1 t | 2.41 | t $CO_2$-eq |

**Table 6.4** Total amount of $CO_2$ emissions per function and the compared production technologies

| Function | Parameter | Amount |
|---|---|---|
| Electricity production | Amount of $CO_2$-eq production (assuming 20 GWh/year) | 5.23 g$CO_2$-eq/kWh *20 GWh/year*20 years = 2092 ton $CO_2$-eq |
| Coal based electricity production | Amount of $CO_2$-eq saved (assuming 20 GWh/year) | 794.37 g$CO_2$-eq/kWh *20 GWh/year*20 years = 317,748 ton $CO_2$-eq |
| ENTSO-E electricity production | Amount of $CO_2$-eq saved (assuming 20 GWh/year) | 456.77 g$CO_2$-eq/kWh *20 GWh/year*20 years = 182,708 ton $CO_2$-eq |
| Fish production | Total amount of $CO_2$-eq production (assuming 2000 t/year) | 2.41 t$CO_2$-eq*2000 t/year*30 = 144,000 ton $CO_2$-eq |

emitted $CO_2$ equivalents ($CO_2$-eq) for each of the uses, and total amounts of emissions are presented in Tables 6.3 and 6.4; details about the estimations are found in the paragraphs below.

### Wind Farm

The wind farm consists of four wind turbines. Wind turbines are 3.3 MW Vestas turbines and the total electricity generation is expected to be 20 GWh per year. In 2006, Vestas published a Life Cycle Assessment of offshore and onshore wind farms for 3.0 MW wind turbines. According to this report "1 kWh electricity generated by a V90-3.0 MW offshore turbine has an impact of 5.23 grams of $CO_2$ during the life cycle" (Vestas 2006). In absence of data for a 3.3 MW turbine this result can be used for the planned wind farm. When this value is compared to usage of coal for electricity production (799.6 g $CO_2$-eq, Schlömer et al. 2014), amount of produced $CO_2$eq gases is lower with a difference of 794.37 g$CO_2$-eq for 1 kWh electricity production. If the comparison is made according to European electricity mix (ENTSO-E network), which corresponds to 462 g $CO_2$-eq/kWh (Itten et al. 2014), the gain of environmental burden in the terms of $CO_2$-eq is 456.77 g/kWh.

### Fish Farm

In the system studied, production and installation of structures, operation and maintenance activities, and disposal of structures as well as transportation of materials during the life cycles were considered. In this study, fry production is excluded. One ton of harvested fish was selected as functional unit. In the fish farm, it is planned to farm European sea bass (*Dicentrarchus labrax*) and gilthead sea bream (*Sparus aurata)* and the capacity of the farm is 2000 tons per year. The results show that for each ton of harvested fish, 2.41 tons of $CO_2$-eq will be emitted during the life cycle stages of the fish farm.

The emission changes were expressed in monetary terms by applying the social cost of carbon. This refers to the shadow price of world-wide damage caused by anthropogenic $CO_2$ emissions (Pearce 2003). According to Arrow et al. (2014), the social cost of carbon is $19.50 per ton of $CO_2$ 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 monetization was based on the estimate from the state-space model, which correspond to 22.50 € per ton[3] in 2013 year values.

## 6.4 Financial and Economic Assessment

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

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

## 6.5 Social Cost-Benefit Analysis

The Social Cost-Benefit Analysis (SCBA) applied in this case study revealed whether the net benefit generated by the multi-use investment project is positive in a temporal perspective, conditional on the utilized discount rate scheme. The Net Present Value (NPV) criterion was applied.

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[3] Exchange rate 0.83 $/ €.

A general expression for NPV is the following:

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

where $K_t$ is investment costs, $B_t$ is the stream of benefits, $C_t$ is the stream of costs and $r$ is the discount rate. Monetized values of externalities, i.e. the benefits derived by the $CO_2$ emissions reduction, were also included in the benefits or costs terms, which is one major feature that distinguishes a SCBA from a typical financial assessment.

However, only the single-use scenario of energy production was examined since there was incomplete information about the costs and benefits of fish production. A Monte Carlo was applied (1000 simulations) and a 22-year time horizon was selected for this SCBA.

For the Monte Carlo, a triangular distribution was used in fish investment and fish revenue. In the absence of any information regarding the stochastic factors affecting wind investment, the triangular distribution was considered as a reasonable assumption, with central value the given investment cost and boundaries at ±15% of the central value.

Normal distribution was used in: fish labor, raw material, other, maintenance, operating costs and energy output. Since there was no information about the specific distributions and only a central value for each of the items was available, a normal distribution with mean the given central value was considered. 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 $\gamma$ was consistent with the data of the specific case. That is $\mu \pm 2\sigma = \mu \pm \gamma\mu$.

Two alternative values were used for the social discount rate instead of 6%: 3% and 4%. These values are consistent with values obtained from the Ramsey formula for long-lived projects (Dasgupta 2008): $r = \rho + \eta g$, where $\rho = L + \delta$ is the rate at which individuals discount future utilities, L is catastrophe risk, i.e. 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, $\delta$ is the rate of pure time preference, which reflects individuals' impatience and preference for utility now, rather than later, g is annual growth in per capita consumption, and $\eta$ is the elasticity of the marginal utility of consumption. These numerical values are within the limits of typical values for the discount rate 3–4% appearing in the literature (Table 6.5).

The estimates of mean NPV and its standard deviation suggest that the fish production scenario passes the CBA test in terms of NPV (positive NPV) under all alternative assumptions regarding the discount rate.

**Table 6.5** Net Present Value (in euros) estimations for fish production

| | Mean NPV(3%) | St. dev. NPV(3%) | Mean NPV(4%) | St. dev. NPV(4%) |
|---|---|---|---|---|
| Single-use: Fish production | 16,052,583 | 6,179,906 | 12,140,351 | 5,589,853 |

## 6.6 Discussion and Recommendations

There is no detailed data on financial costs and returns or on environmental, social and economic impacts for each single activity or all activities combined as suggested by the final design for the Mediterranean case study. Our preliminary, although tentative, analysis suggests that in the short term using a multi-use design with wind energy and fish production would be financially not sustainable, due to both low energy and fish production, and would bear high environmental risks. However, in the long-run, coastal and marine spaces might become more limited, and then going offshore will become more important to avoid unplanned and crowded uses in the future. More explicitly, for the case of aquaculture, going offshore provides better health of farmed fish, since it is supposed to provide better water quality to the farmed fish, lessen the possibility of infectious agents being transferred to them and provide a water current regime that will promote better water renewal and waste dispersal. Hence, considering and socio-economically analyzing the changes in the ecosystems and the value of ocean space could prove the sustainability of the multi-use design.

Indeed, in the Mediterranean case study, the economic internal rate of return for *all activities combined* is likely to be negative, if based on monetary analysis, and it is likely to be positive but very small, if some of the social and environmental benefits related to moving aquaculture offshore compared to inshore are taken into account. Even if currently there could be little arguments to develop multi-use farms in this area, long-term future benefits related to moving some fish and energy activities offshore would deserve careful consideration.

This decision is likely to be opposed by current stakeholders for two main reasons: (a) they might expect to bear costs today (e.g. larger fuel costs to reach an activity offshore or the risks of implementing an activity offshore) for benefits arising (for others) tomorrow; (b) they might not perceive the benefits of reduced environmental impacts from moving aquaculture offshore and increasing green energy production. A similar context was observed in urban land use planning in Italy in the 1950s, where many activities such as carpenters or smiths shops were inside villages, with benefits in terms of time saved on travelling and security for these shops, but costs in terms of noise and pollution. They were then moved to dedicated areas in the 1970–1980s.

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

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# Part II
# Risk Analysis

# Chapter 7
# Risk Analysis for the Selected MERMAID Final Designs

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**Abstract** This chapter presents the risk analysis results of the application of the Methodology for Integrated Socio-Economic Assessment (MISEA) which was developed in the MERMAID Project with regards to the different proposed designs of novel Multi-Use Offshore Platforms (MUOPs). For this purpose, sensitivity analysis of critical variables based on values given by experts and Monte Carlo simulation were undertaken to analyze the risk of developing these platforms. The approach integrates the results of the assessment discussed in the previous chapters. Both sensitivity analysis and Monte Carlo simulations approaches are compared.

**Keywords** Multi-use offshore platforms • Marine infrastructure • Risk analysis • Sensitivity analysis • Monte Carlo simulation

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## 7.1 Introduction of Risk Analysis

Risk analysis or risk assessment in cost benefit analysis aims at addressing uncertainty associated with the future cash flows of a project. In risk analysis the ‘stand alone’ risk for the project is analyzed. This type of risk represents measurable uncertainty which is the case where a known probability measure is associated with stochastic variables. Accounting for risk requires therefore an assessment of probability distributions indicating the likelihood of the realized value of a variable falling within stated limits.[1]

Risk assessment implies the estimation of the sensitivity of the project performance to stochastic effects and potentially the probability that a project will achieve a satisfactory performance, where performance is measured in terms of some threshold value of the Net Present Value (NPV). Probability should here be understood as an index that takes the value of 1 under full certainty that a prediction will be confirmed, a 0 value for certainty that the prediction will not be confirmed, and intermediate values for anything in between the two extremes. In this context, risk assessment can be used to make inference and test hypothesis in the statistical sense. Thus with an appropriate risk assessment an analyst can estimate the probability that the NPV of a project will be between pre-specified limits (confidence interval estimation), or that will be above or below some acceptable cut-off level.

Uncertainty of future cash flows is a natural consequence of the fact that these cash flows represent forecasts based on current knowledge and future expectations. Similarly, the capital outlays associated with a new product are generally obtained from the engineering and product development staffs, while operating costs are estimated by cost accountants, production experts, personnel specialists, purchasing agents, and so forth.

For the specific project that performs Cost Benefit Analysis (CBA) of MUOPs, costs and benefits associated with offshore wind/wave farms and aquaculture are expected to embody considerable uncertainties. These uncertainties affect not just the economic part of the project, that is prices and unit costs, but also the natural and the technological part that affect quantities of inputs and outputs and environmental impacts. In particular, variables associated with power production (wind and wave), aquaculture (mussels, seaweed and fish), revenues and costs, under the proposed multi-functional structures determine the future cash flows of the MUOPs. These cash flows are affected by strong stochastic factors. Furthermore, the project addresses different natural environments from deep water, to shallow water with high morphological activity, and further to inner waters like the inner Danish/Baltic areas and the Adriatic Sea. This spatial differentiation implies strong and spatially non-homogeneous physical and environmental risks.

Risk assessment can be carried out at two different but interconnected levels namely (i) Sensitivity analysis, and (ii) Monte Carlo Simulations:

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[1] In contrast in the case of pure uncertainty specific probabilities cannot be assigned to random events.

**Sensitivity Analysis** is a technique that indicates how much the NPV will change in response to a given change in variables that affects the cash flow of the project, other things held constant.

Sensitivity analysis involves the following steps:

1. Define a **base-case or benchmark** estimation of the NPV, which is developed using the ***expected values*** for each variable involved in the cash flow.
2. Define a **maximum and minimum** value for each of the variables relative to the benchmark estimation. Calculate the NPV for the range of values from maximum to minimum by a predetermined step (10% in our case), for each variable of step 1 by keeping the rest of the variables fixed.
3. Identify **sensitive or critical variables**. These are cash flow variables (e.g. equipment, wind power, costs) with the property that small deviations of their values from the benchmark value will change the NPV or the IRR a lot.
4. Construct a **sensitivity diagram or spider graph** that relates proportional changes in the critical variable to proportional changes in the NPV or IRR. A variable is sensitive or critical if it has a steep slope on the spider graph.
5. Identify **switching values** for important cash flow variables. A switching value is the value of the variable at which the NPV switches from positive to negative.

Sensitivity analysis can be regarded as analyzing specific scenarios for the evolution of variables affecting the NPV of the project. In fact, the base-case, the minimum and the maximum can be regarded as three alternative scenarios. However, although sensitivity analysis provides very useful descriptive results about the sensitivity of NPV to changes that affect cash flows, it does not allow for statistical inference and hypothesis testing with respect to the NPV of the project. This can be obtained by using Monte Carlo simulations.

**Monte Carlo Method** is a computational algorithm which is based on random sampling. To use the method specific subjective probability distributions (e.g. uniform, triangular, normal) to important cash flow variables should be assigned. The method proceeds in the following steps:

1. A value for a variable affecting the cash flow is selected from its predetermined distribution function using a random number generator.
2. A vector of specific values is defined (e.g. equipment, wind output, costs).
3. These values are used to calculate an NPV and an IRR which are stored for this replication.
4. After a large number of replications (1000 in our case) a frequency distribution is estimated for the NPV and/or the IRR.
5. Making the normality assumption the estimated distribution can be used to construct confidence intervals and perform hypothesis testing.

**Table 7.1** Variables examined in the sensitivity analysis

| | Min | Base* | Max |
|---|---|---|---|
| Equipment cost | 0,90 | 1,00 | 1,10 |
| Energy output (wind) | 0,80 | 1,00 | 1,20 |
| Energy output (wave) | 0,80 | 1,00 | 1,20 |

*Base refers to 100% of the central value for the corresponding variable. Min and max refer to the corresponding percentages of the base case.

## 7.2 Risk Analysis of the Atlantic Site

For the Atlantic site the financial costs and revenues, together with the benefits derived by the reduction of $CO_2$ emissions and research and education were included in the SCBA. For the case of $CO_2$ emissions both comparisons were used in the analysis (i.e. reduction of $CO_2$ emissions compared to coal energy production and ENTSO-E production). Since the baseline for the Atlantic site was considered to be "nothing", the presented results are concentrated on the Wind & Wave scenario of multi-use platform.

### *7.2.1 Sensitivity Analysis*

With regards to the sensitivity analysis, the scenarios refer to the wind & wave platform. We consider the variables presented in Table 7.1.

The results suggest that the critical variables are wind energy output and equipment cost. There is one switching value for wind output in the case where the discount rate is 4% and total cost reduction in terms of $CO_2$ refer to the ENTSO-E network which is around 17% below the base case (83% in the spider graph).

In the following we present spider graphs for the combined wind & wave platform for 3 and 4% discount rate (Figs. 7.1, 7.2, 7.3 and 7.4). Spider graphs for the single use scenarios, wind or wave project can be provided under request.

### *7.2.2 Monte Carlo Simulations*

#### 7.2.2.1 Wind & Wave, 3% Discount Rate, Compared to Coal Energy Production

Based on the results from the Monte Carlo Simulations for the Atlantic MUOP and considering discount rate to be 3%, the 95% confidence interval for the NPV is 442.3 ± 1.96*58.3. This confidence interval is strictly positive; therefore, we can conclude that at 95% confidence interval this project has a positive NPV. From the

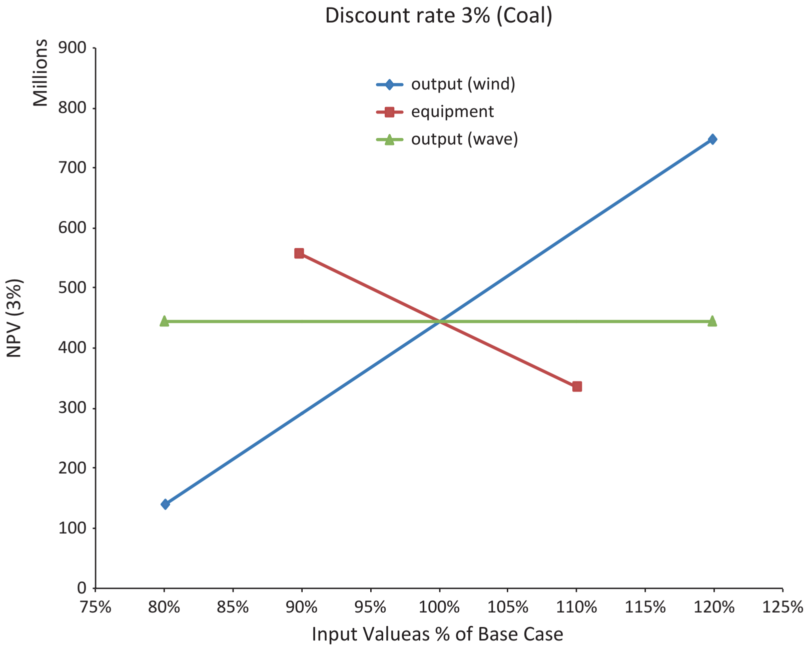


**Fig. 7.1** Sensitivity analysis on SCBA (3% discount rate, compared to coal energy production)

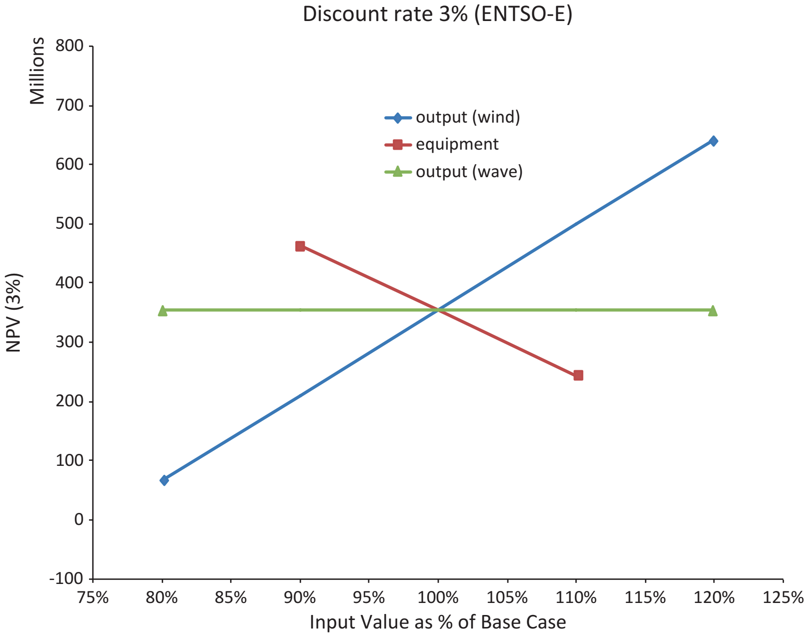


**Fig. 7.2** Sensitivity analysis on SCBA (3% discount rate, compared to ENTSO-E energy production)

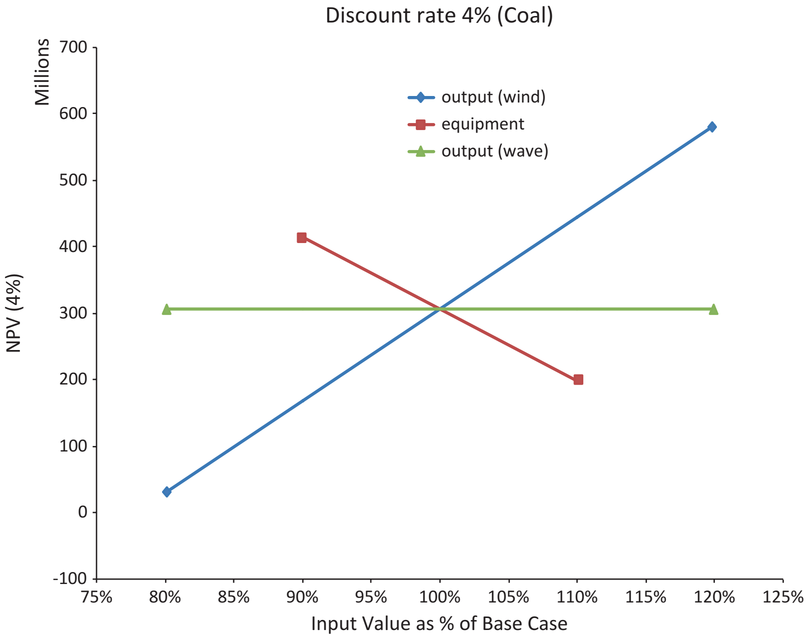


**Fig. 7.3** Sensitivity analysis on SCBA (4% discount rate, compared to coal energy production)

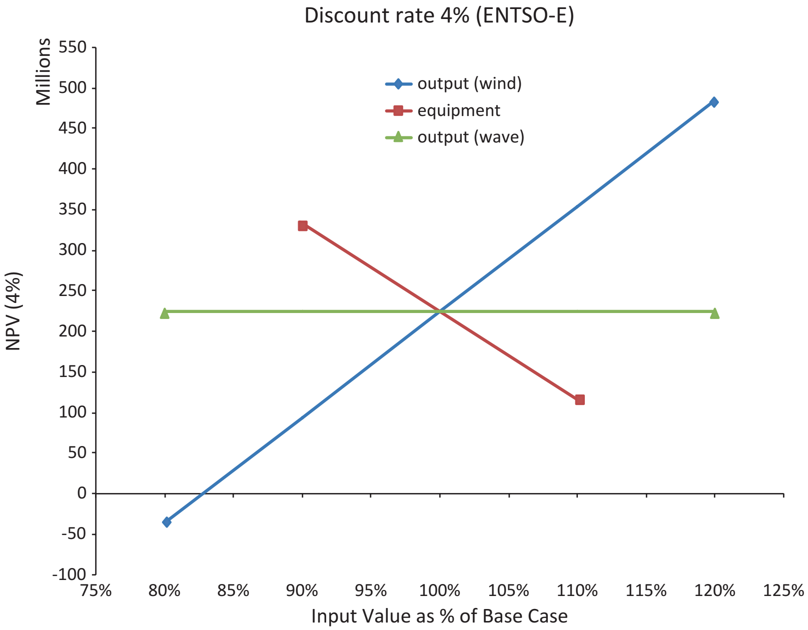


**Fig. 7.4** Sensitivity analysis on SCBA (4% discount rate, compared to ENSTSO-E energy production)

cumulative chart we can conclude that the probability of having an NPV less than 450 million is approximately 55% (Fig. 7.5 and Table 7.2).

#### 7.2.2.2 Wind & Wave, 3% Discount Rate, Compared to ENTSO-E Energy Production

Based on the results from the Monte Carlo Simulations for the Atlantic MUOP and considering discount rate to be 3%, the 95% confidence interval for the NPV is 355.4 ± 1.96*56. This confidence interval is strictly positive; therefore, we can conclude that at 95% confidence interval this project has a positive NPV. From the cumulative chart we can conclude that the probability of having an NPV less than 358 million is approximately 50% (Fig. 7.6 and Table 7.3).

#### 7.2.2.3 Wind & Wave, 4% Discount Rate, Compared to Coal Energy Production

Based on the results from the Monte Carlo Simulations for the Atlantic MUOP and considering discount rate to be 4%, the 95% confidence interval for the NPV is 305.7 ± 1.96*55.2. This confidence interval is strictly positive; therefore, we can conclude that at 95% confidence interval this project has a positive NPV. From the cumulative chart we can conclude that the probability of having an NPV less than 308 million is approximately 50% (Fig. 7.7 and Table 7.4).

#### 7.2.2.4 Wind & Wave, 4% Discount Rate, Compared to ENTSO-E Energy Production

Based on the results from the Monte Carlo Simulations for the Atlantic MUOP and considering discount rate to be 4%, the 95% confidence interval for the NPV is 225.9 ± 1.96*54.9. This confidence interval is strictly positive; therefore, we can conclude that at 95% confidence interval this project has a positive NPV. From the cumulative chart we can conclude that the probability of having an NPV less than 300 million is approximately 90% (Fig. 7.8 and Table 7.5).

## 7.3 Risk Analysis of the Baltic Site

For the Atlantic site the financial costs and revenues, together with the benefits derived by the $CO_2$ emissions reduction and artificial reefs effect due to wind energy production were included in the SCBA. Costs derived from the production of $CO_2$ emissions due to salmon harvesting were not included in the SCBA, since due to lack of information only the single-use scenario of energy production was

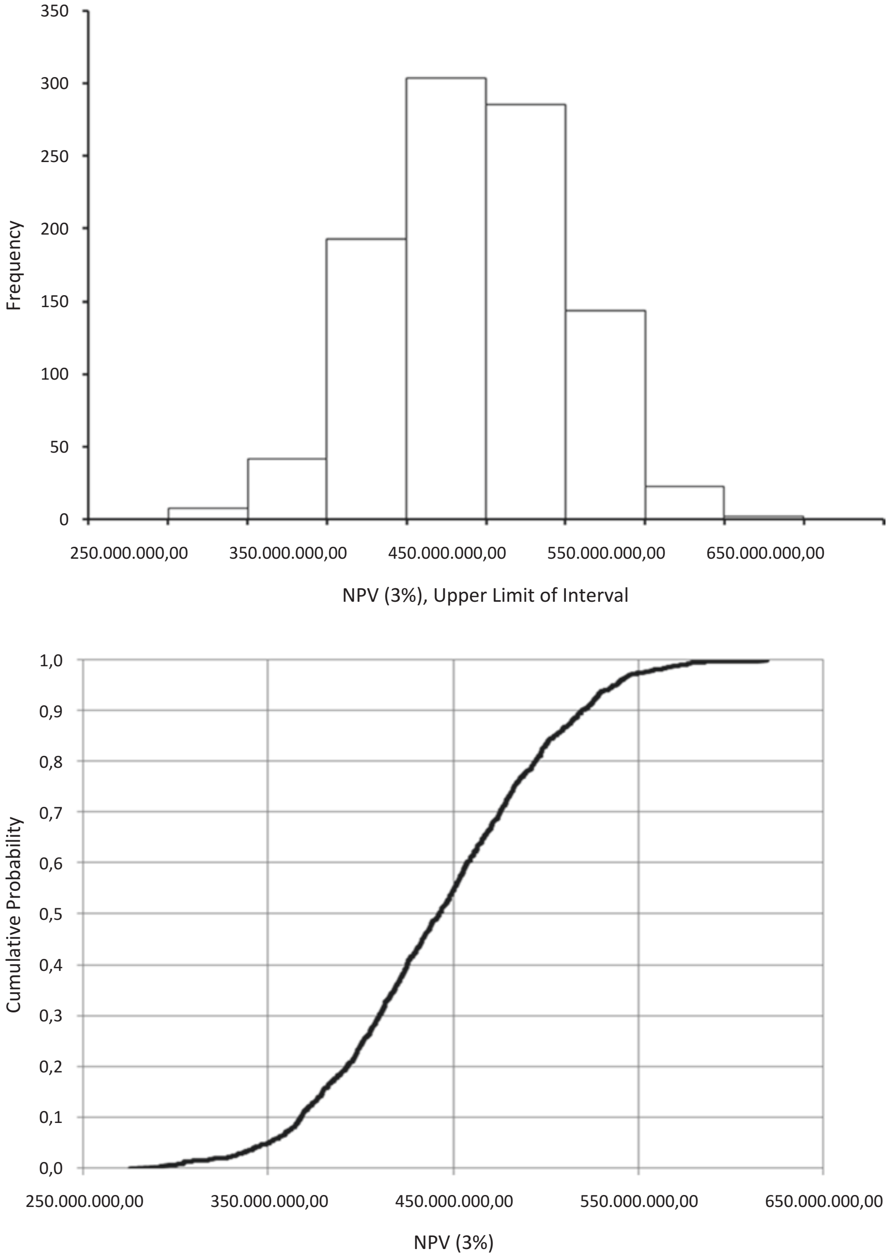


**Fig. 7.5** Monte Carlo simulation for "Wind & Wave" compared to coal energy production (NPV, 3% discount rate)

**Table 7.2** "Wind & Wave" compared to coal energy production (NPV, 3% discount rate)

| | |
|---|---|
| Mean | 442,343,771.94 |
| St. dev. | 58,288,143.94 |
| Mean St. error | 1,843,232.95 |
| Minimum | 275,148,899.85 |
| First quartile | 401,167,456.76 |
| Median | 442,375,607.15 |
| Third quartile | 482,805,388.36 |
| Maximum | 619,791,081.58 |
| Skewness | −0.0057 |

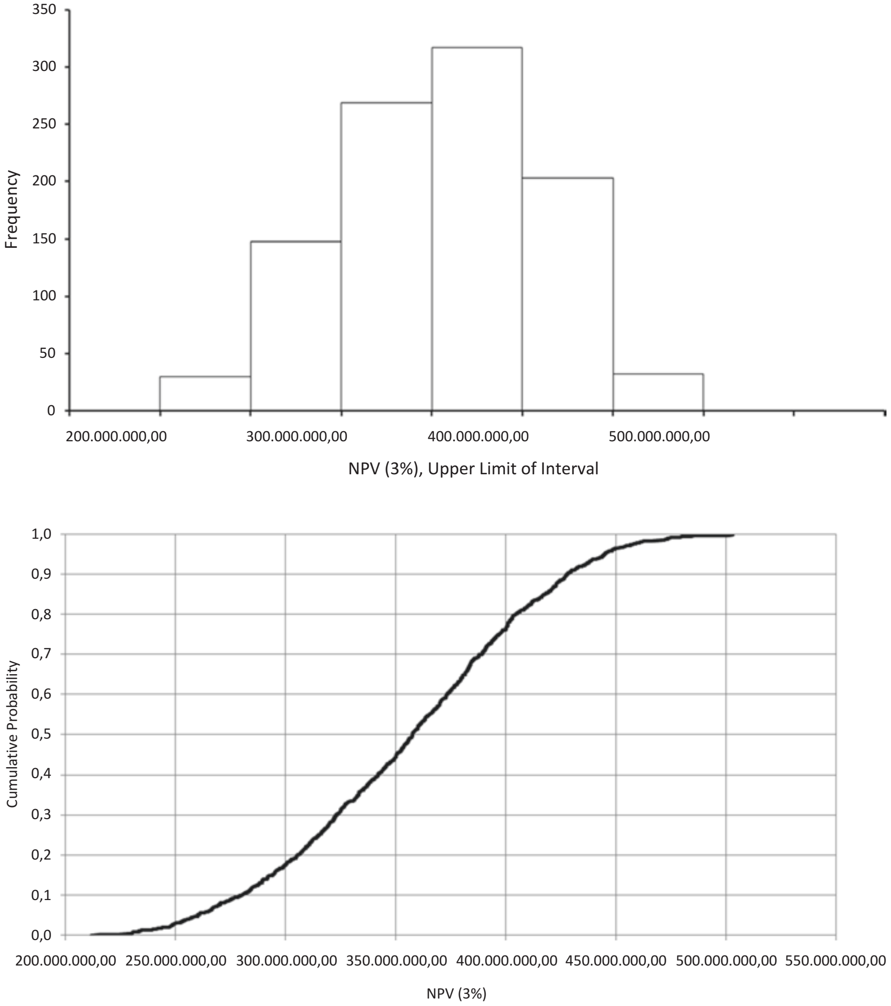


**Fig. 7.6** Monte Carlo simulation for "Wind & Wave" compared to ENTSO-E energy production (NPV, 3% discount rate)

**Table 7.3** "Wind & Wave" compared to ENTSO-E energy production (NPV, 3% discount rate)

| | |
|---|---|
| Mean | 355,399,160.92 |
| St. dev. | 56,008,811.17 |
| Mean St. Error | 1,771,154.12 |
| Minimum | 211,566,642.09 |
| First Quartile | 314,870,681.01 |
| Median | 357,464,014.39 |
| Third Quartile | 396,439,358.27 |
| Maximum | 503,039,011.29 |
| Skewness | −0.0836 |

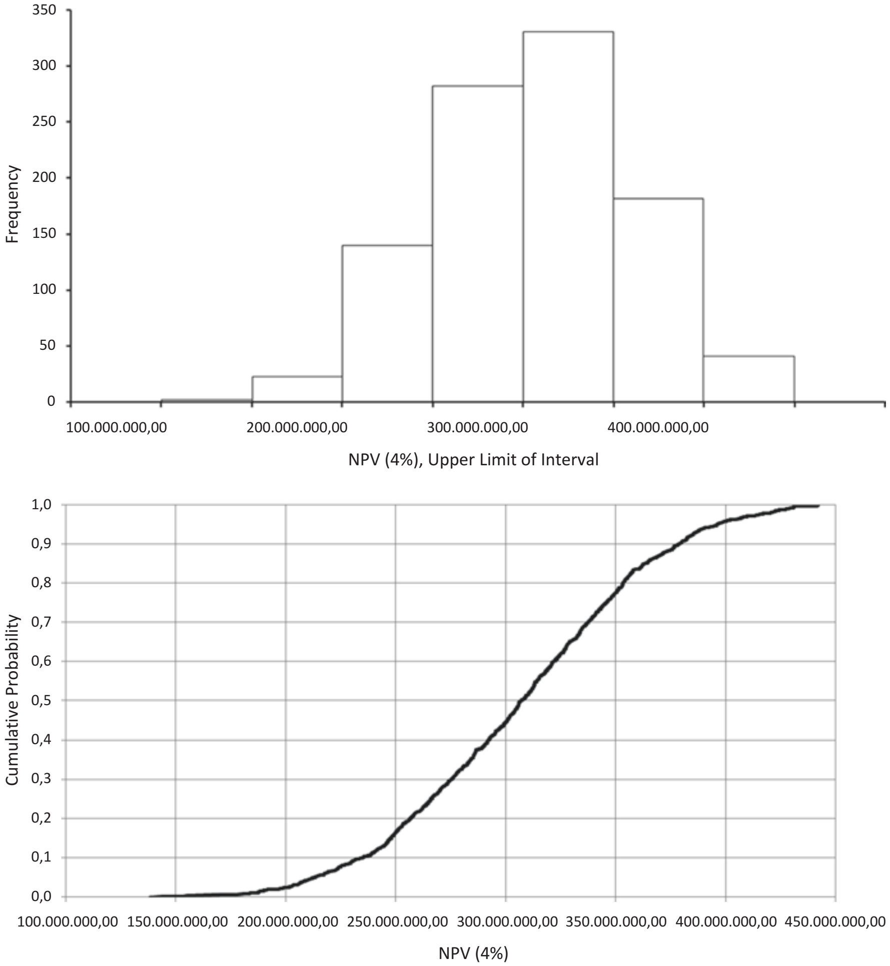


**Fig. 7.7** Monte Carlo simulation for "Wind & Wave" compared to coal energy production (NPV, 4% discount rate)

**Table 7.4** "Wind & Wave" compared to coal energy production (NPV, 4% discount rate)

| | |
|---|---|
| Mean | 305,730,883.29 |
| St. dev. | 55,184,066.20 |
| Mean St. error | 1,745,073.40 |
| Minimum | 138,090,091.64 |
| First quartile | 265,816,667.65 |
| Median | 306,618,557.11 |
| Third quartile | 345,318,445.43 |
| Maximum | 442,005,485.77 |
| Skewness | −0.0763 |

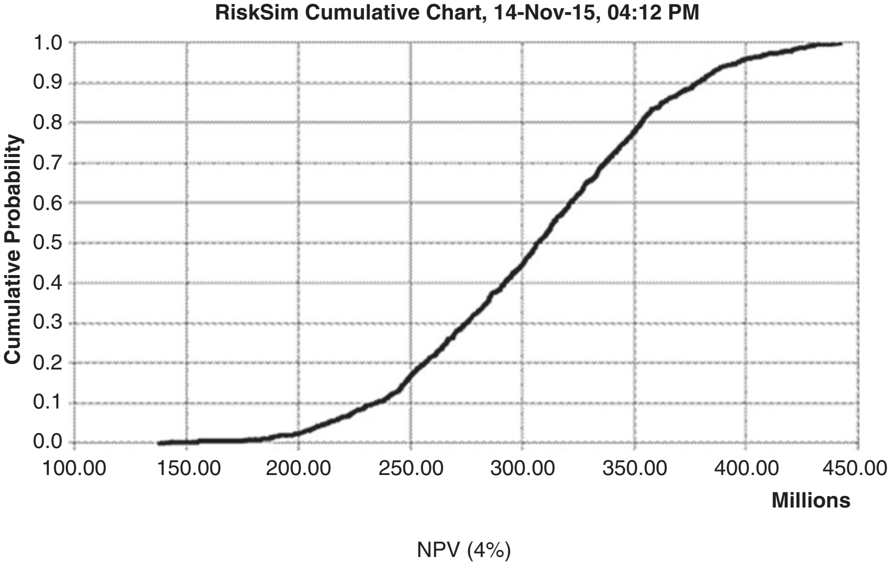


**Fig. 7.8** Monte Carlo simulation for "Wind & Wave" (NPV, 4% discount rate)

**Table 7.5** "Wind & Wave" compared to ENTSO-E (NPV, 4% discount rate)

| | |
|---|---|
| Mean NPV | 225.915.262,55 |
| St. dev. | 54.937.265,13 |
| Mean St. Error | 1.737.268,86 |
| Minimum | 43.041.973,37 |
| First Quartile | 187.856.542,51 |
| Median | 226.909.141,10 |
| Third Quartile | 263.717.964,18 |
| Maximum | 371.746.326,63 |
| Skewness | −0,0418 |

**Table 7.6** Variables examined in the sensitivity analysis

| | Min | Base* | Max |
|---|---|---|---|
| Construction cost | 0,8 | 1 | 1,2 |
| Energy output | 0,8 | 1 | 1,2 |
| Maintenance cost | 0,85 | 1 | 1,15 |
| Artificial Reefs effect | 0,75 | 1 | 1,25 |

*Base refers to 100% of the central value for the corresponding variable. Min and max refer to the corresponding percentages of the base case.

examined. Although the baseline for the Baltic site was considered to be "nothing", the results present the risk analysis undertaken for the wind energy function.

## *7.3.1 Sensitivity Analysis*

With regards to the sensitivity analysis, the scenarios refer only to the energy project. Note that due to lack of data the NPV calculations do not include operating costs, thus the sensitivity analysis refers to the NPV defined in terms of construction cost, maintenance cost and revenues due to energy output and artificial reefs effect. In the Monte Carlo analysis, we have calculated the maximum annual equivalent operating cost which would result in a positive NPV (Table 7.6).

The results suggest that the critical variables are the energy output and construction cost. There are no switching values. The spider graphs for the 3% and 4% discount rate are shown below (Figs. 7.9, 7.10, 7.11 and 7.12).

## *7.3.2 Monte Carlo Simulations*

### 7.3.2.1 Wind, 3% Discount Rate, Compared to Coal Energy Production

Based on the results from the Monte Carlo Simulation for the Baltic offshore platform and considering discount rate to be 3%, the 95% confidence interval for the NPV is 1283.97 ± 1.96*115.22. This confidence interval is strictly positive; therefore, we can conclude that at 95% confidence interval this project has a positive NPV. From the cumulative chart we can conclude that the probability of having an NPV less than 1300 million is approximately 57% (Fig. 7.13 and Table 7.7).

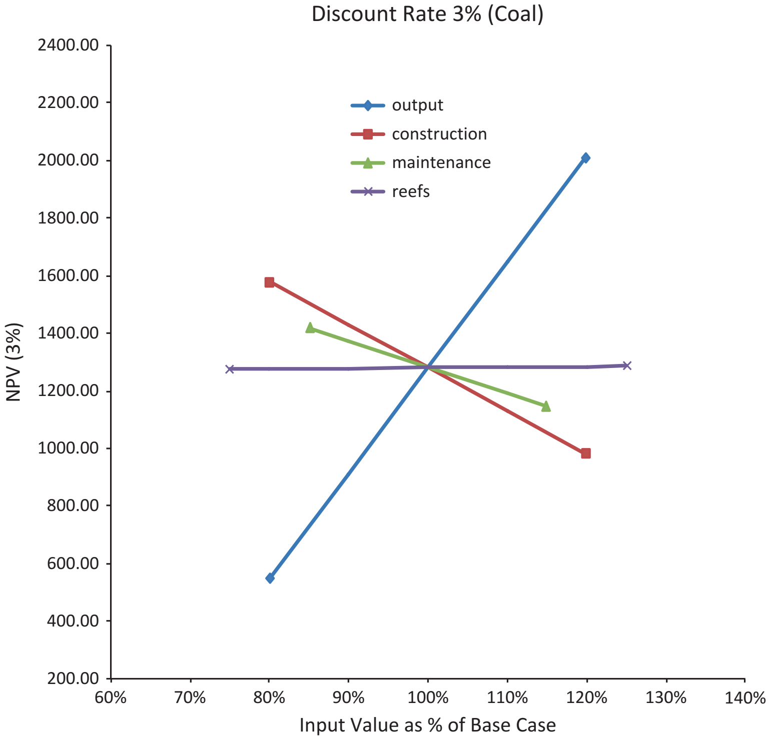


**Fig. 7.9** Sensitivity analysis on SCBA (3% discount rate, compared to coal energy production)

#### 7.3.2.2 Wind, 3% Discount Rate, Compared to ENTSO-E Energy Production

Based on the results from the Monte Carlo Simulation for the Baltic offshore platform and considering discount rate to be 3%, the 95% confidence interval for the NPV is 1062.2 ± 1.96*112.29. This confidence interval is strictly positive; therefore, we can conclude that at 95% confidence interval this project has a positive NPV. From the cumulative chart we can conclude that the probability of having an NPV less than 1068 million is approximately 40% (Fig. 7.14 and Table 7.8).

#### 7.3.2.3 Wind, 4% Discount Rate, Compared to Coal Energy Production

Based on the results from the Monte Carlo Simulation for the Baltic offshore platform and considering discount rate to be 4%, the 95% confidence interval for the NPV is 1018.85 ± 1.96*110.61. This confidence interval is strictly positive; therefore, we can conclude that at 95% confidence interval this project has a positive

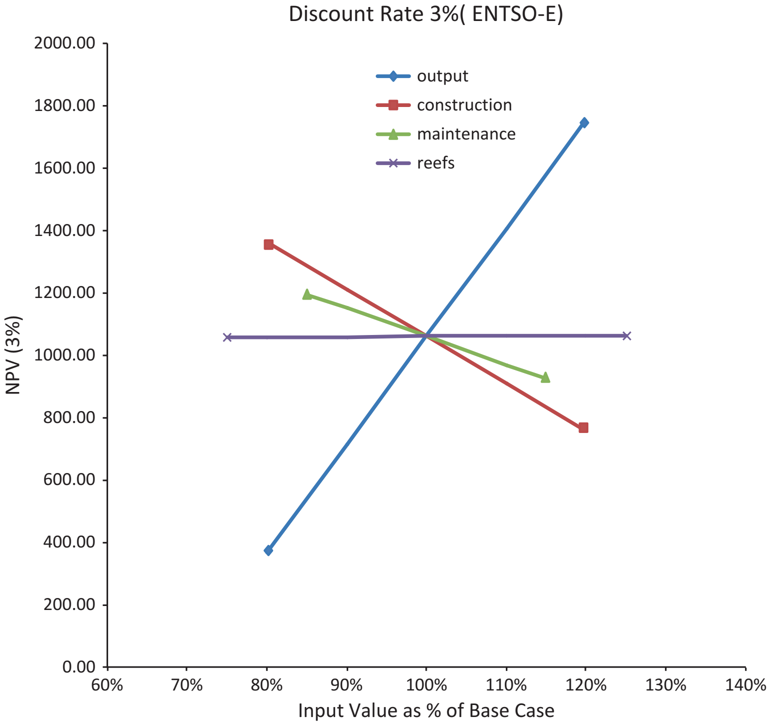


**Fig. 7.10** Sensitivity analysis on SCBA (3% discount rate, compared to ENTSO-E energy production)

NPV. From the cumulative chart we can conclude that the probability of having an NPV less than 1026 million is approximately 50% (Fig. 7.15 and Table 7.9).

### 7.3.2.4 Wind, 4% Discount Rate, Compared to ENTSO-E Energy Production

Based on the results from the Monte Carlo Simulation for the Baltic offshore platform and considering discount rate to be 4%, the 95% confidence interval for the NPV is 823.60 ± 1.96*107.31. This confidence interval is strictly positive; therefore, we can conclude that at 95% confidence interval this project has a positive NPV. From the cumulative chart we can conclude that the probability of having an NPV less than 830 million is approximately 50% (Fig. 7.16 and Table 7.10).

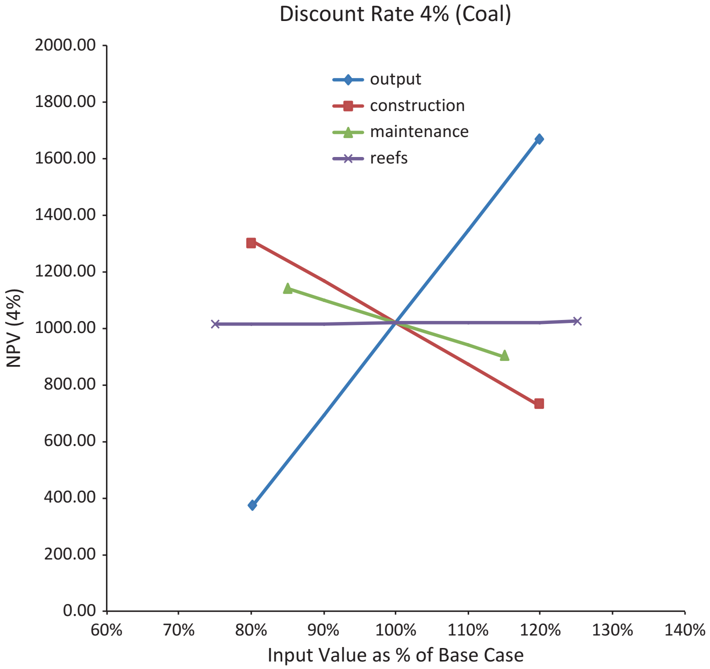


**Fig. 7.11** Sensitivity analysis on SCBA (4% discount rate, compared to coal energy production)

## 7.4 Risk Analysis of the Mediterranean Site

For the Mediterranean site the financial costs and revenues, together with the costs derived by the $CO_2$ emissions produced due to fishing operation were included in the SCBA. Benefits derived from the reduction of $CO_2$ emissions were not included in the SCBA, since due to lack of information only the single-use “Aquaculture” scenario was examined. Although the baseline for the Mediterranean site was considered to be “nothing”, the results present the risk analysis undertaken for the aquaculture function due to lack of information.

### *7.4.1 Sensitivity Analysis*

For the purposes of sensitivity analysis the scenarios refer only to the single-use of fish production (Table 7.11).

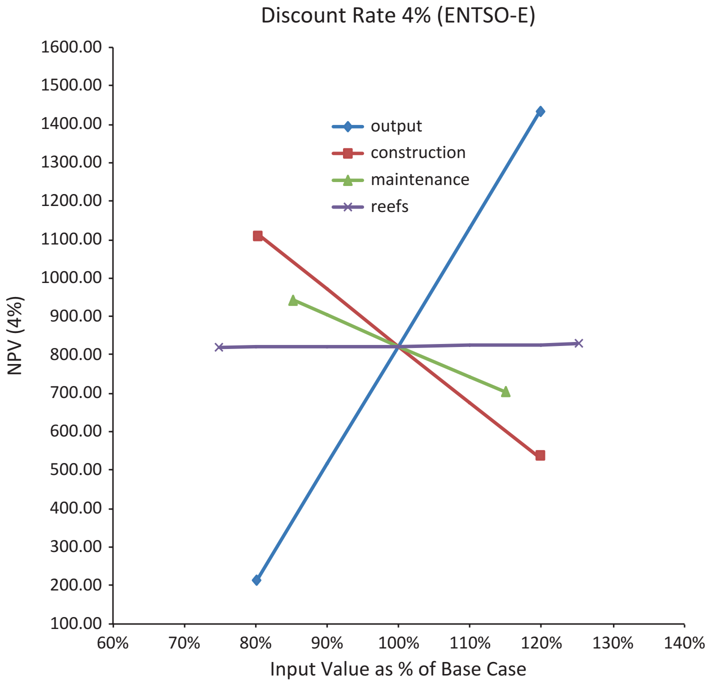


**Fig. 7.12** Sensitivity analysis on SCBA (4% discount rate, compared to ENTSO-E energy production)

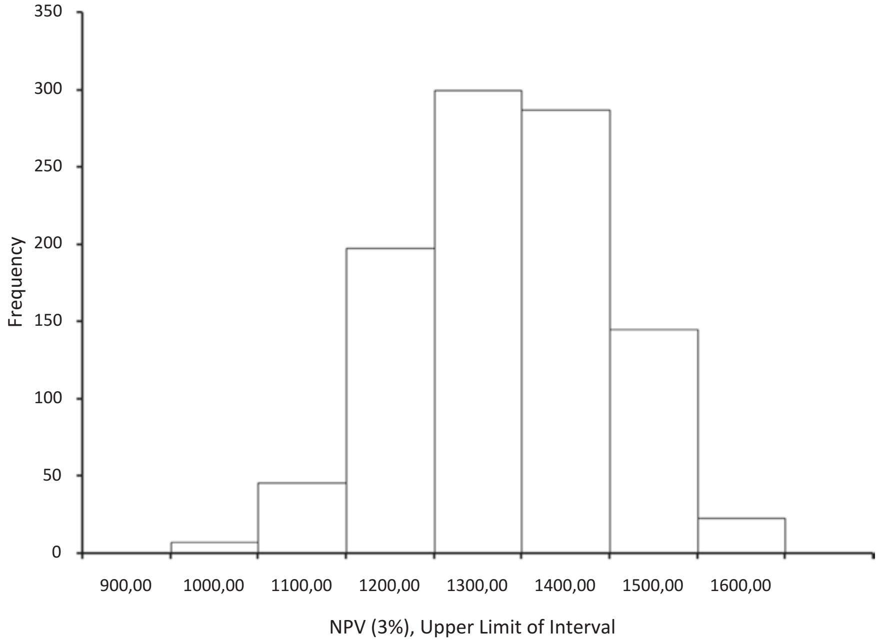
The results suggest that the critical variables are raw materials and fish revenue. There is a switching value for raw materials which is around 10–11% above the base case (110–111% in the spider graph), and a switching value for fish revenue which is around 6–7% below the base case (93–94% in the spider graph).

The spider graphs for the 3% and 4% discount rate are shown below (Figs. 7.17 and 7.18).

## *7.4.2 Monte Carlo Simulations*

### 7.4.2.1 Aquaculture, 3% Discount Rate

Based on the results from the Monte Carlo Simulation for the Mediterranean offshore platform and considering discount rate to be 3%, the 95% confidence interval for the NPV is 16.05 ± 1.96*6.18. This confidence interval is not strictly positive; therefore, we cannot conclude that at 95% confidence interval this project has a positive NPV. From the cumulative chart we can conclude that the probability of having an NPV less than 16.1 million is approximately 50%. However, the probability of having a negative NPV is less than 1% (Fig. 7.19 and Table 7.12).



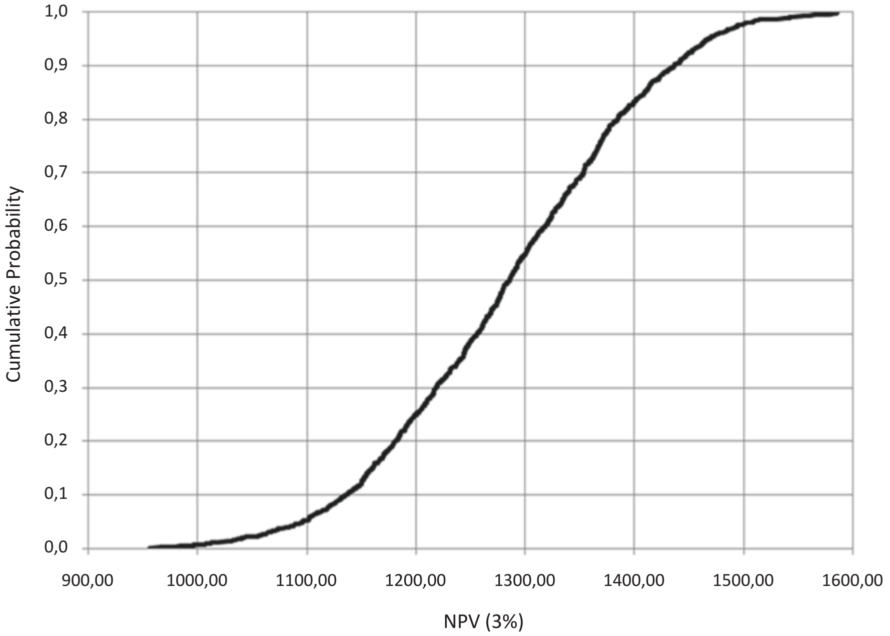


**Fig. 7.13** Monte Carlo simulation for “Wind” compared to coal energy production (NPV, 3%)

**Table 7.7** "Wind" compared to coal energy production (NPV, 3%)

| | |
|---|---|
| Mean | 1283,97 |
| St. dev. | 115,22 |
| Mean St. Error | 3,64 |
| Minimum | 955,45 |
| First Quartile | 1200,18 |
| Median | 1285,15 |
| Third Quartile | 1366,96 |
| Maximum | 1585,49 |
| Skewness | −0,0684 |

#### 7.4.2.2 Aquaculture, 4% Discount Rate

Based on the results from the Monte Carlo Simulation for the Mediterranean offshore platform and considering discount rate to be 4%, the 95% confidence interval for the NPV is 12.14 ± 1.96*5.59. This confidence interval is not strictly positive; therefore, we cannot conclude that at 95% confidence interval this project has a positive NPV. From the cumulative chart we can conclude that the probability of having a NPV less than 16.1 million is approximately 50%. However, the probability of having a negative NPV is less than 2% (Fig. 7.20 and Table 7.13).

## 7.5 Risk Analysis of the North Sea Site

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). Since the baseline for the North Sea site was considered to be the wind energy function, the presented results are concentrated on the Seaweed & Mussels functions of the multi-use platform.

### *7.5.1 Sensitivity Analysis*

For the sensitivity analysis we consider seaweed, mussels and wind MUOP scenario (Table 7.14).

The results suggest that the critical variables are energy operating cost and energy output. There are no switching values.

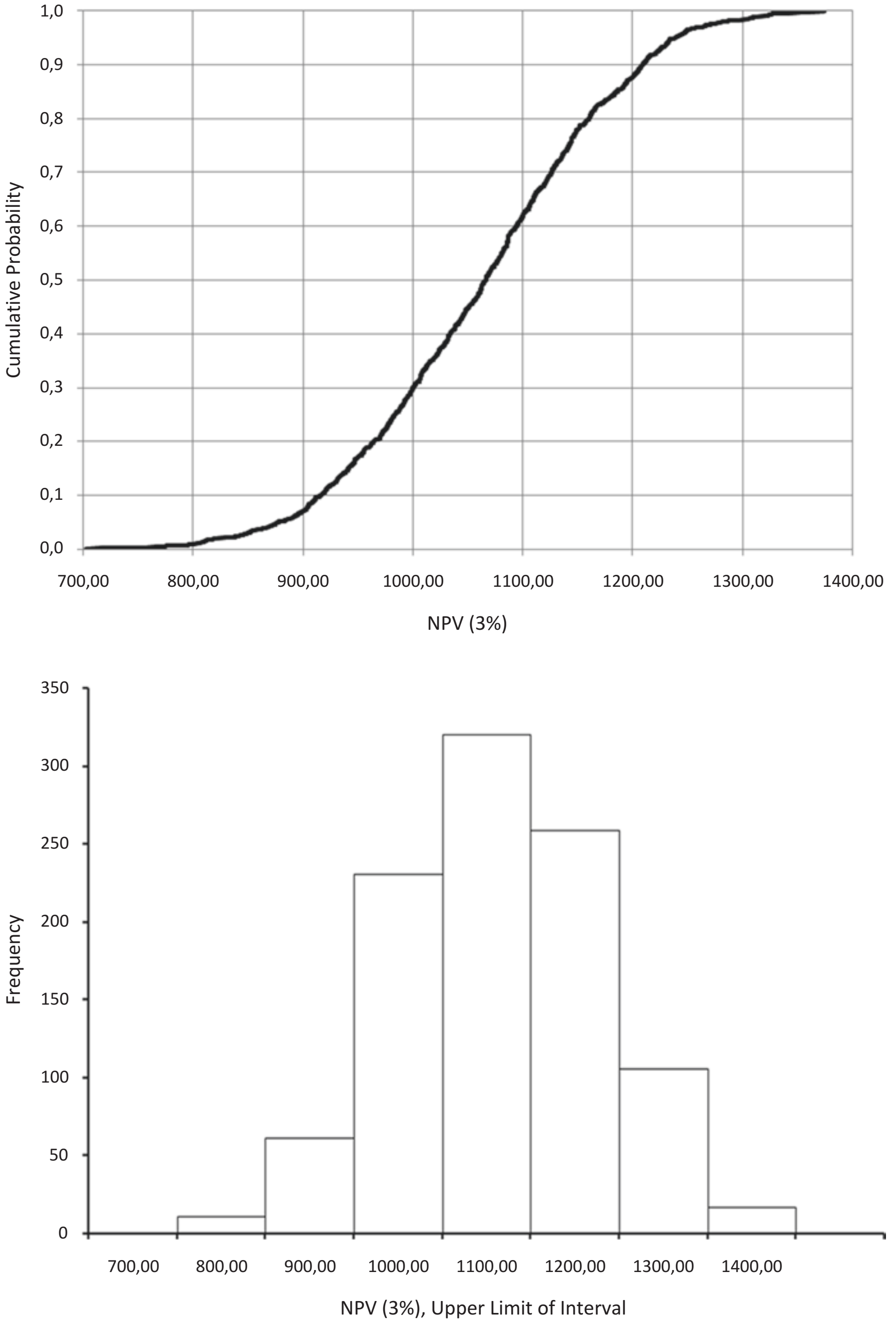


**Fig. 7.14** Monte Carlo simulation for “Wind” compared to ENTSO-E energy production (NPV, 3%)

**Table 7.8** "Wind" compared to ENTSO-E energy production (NPV, 3%)

| | |
|---|---|
| Mean | 1062.20 |
| St. dev. | 112.29 |
| Mean St. Error | 3.55 |
| Minimum | 702.77 |
| First Quartile | 983.51 |
| Median | 1065.93 |
| Third Quartile | 1142.12 |
| Maximum | 1373.72 |
| Skewness | −0.0964 |

In the following we present spider graphs for the combined energy, seaweed and mussels project for 3% and 4% discount rate (Figs. 7.21, 7.22, 7.23 and 7.24). Spider graphs for the stand-alone energy, seaweed, mussels and the rest of possible pairs can be provided under request.

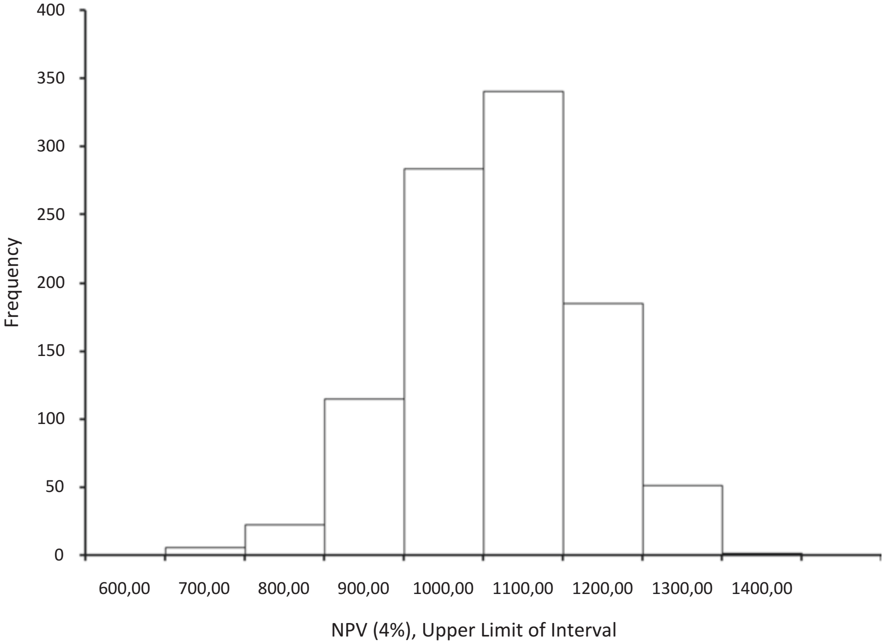
## 7.5.2 *Monte Carlo Simulations*

### 7.5.2.1 Wind & Seaweed & Mussels, 3% Discount Rate, Compared to Coal Energy Production

Based on the results from the Monte Carlo Simulation for the North Sea site MUOP and considering discount rate to be 3%, the 95% confidence interval for the NPV is 755.90 ± 1.96*153.43. This confidence interval is strictly positive; therefore, we can conclude that at 95% confidence interval this project has a positive NPV. From the cumulative chart we can conclude that the probability of having an NPV less than 750 million is approximately 50% (Fig. 7.25 and Table 7.15).

### 7.5.2.2 Wind & Seaweed & Mussels, 4% Discount Rate, Compared to ENTSO-E Energy Production

Based on the results from the Monte Carlo Simulation for the North Sea site MUOP and considering discount rate to be 4%, the 95% confidence interval for the NPV is 328.12 ± 1.96*147. This confidence interval is not strictly positive; therefore, we cannot conclude that at 95% confidence interval this project has a positive NPV. From the cumulative chart we can conclude that the probability of having an NPV less than 330 million is approximately 50%. However, the probability of having a negative NPV is less than 1% (Fig. 7.26 and Table 7.16).



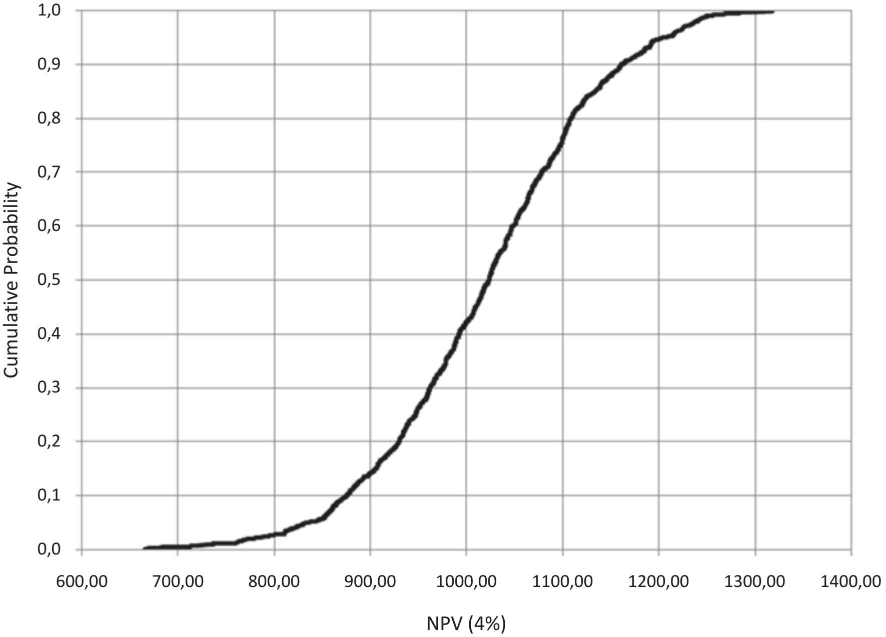


**Fig. 7.15** Monte Carlo simulation for "Wind" compared to coal energy production (NPV, 4%)

**Table 7.9** "Wind" compared to coal energy production (NPV, 4%)

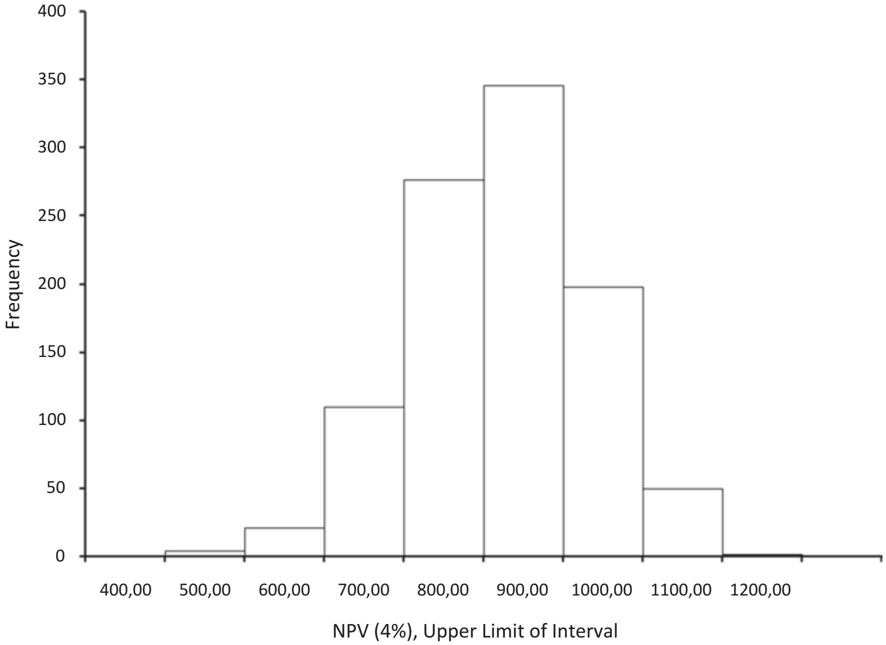
| | |
|---|---|
| Mean | 1018.85 |
| St. dev. | 110.61 |
| Mean St. Error | 3.50 |
| Minimum | 664.59 |
| First Quartile | 946.38 |
| Median | 1023.05 |
| Third Quartile | 1097.00 |
| Maximum | 1316.98 |
| Skewness | −0.1685 |

## 7.6 Comparing Sensitivity Analysis and Monte Carlo Simulations

Comparing the sensitivity analysis and the Monte Carlo analysis we see that the results are consistent by looking at the base-case NPV for the sensitivity analysis and the expected NPV from the Monte Carlo simulations. Observing the risk analysis results for the Atlantic case study, the base-case NPV for the sensitivity analysis is around 225 million while the expected NPV resulting from Monte Carlo analysis is 225.9 million. We can thus conclude with a high degree of confidence that the project passes the CBA test at a 4% discount rate (comparing with ENTSO-E energy production). Similar conclusions we have when comparing with coal energy production. For the CBA test at a 3% discount rate and compared to coal energy production, the results of the two methods are also consistent (i.e. NPV equal to 442 million estimated using Monte Carlo and around 440 million derived from the sensitivity analysis). Similar conclusions we have when comparing with ENTSO-E energy production.

Moving on to the Baltic case study, the base-case NPV for the sensitivity analysis is around 823 million while the expected NPV resulting from Monte Carlo analysis is 823.60 million. We can thus conclude with a high degree of confidence that the project passes the CBA test at a 4% discount rate comparing with ENTSO-E energy production. Hence, both methods are indeed consistent. Similar conclusions we have when comparing with coal energy production. For the CBA test at a 3% discount rate, the results of the two methods are still consistent (i.e. NPV equal to 1283.97 million estimated using Monte Carlo and around 1280 million derived from the sensitivity analysis). Similar conclusions we have when comparing with ENTSO-E energy production.

Same conclusions are derived with regards to consistency of the methods, when observing the results from the other two case studies, ie. Mediterranean case study and North Sea case study.



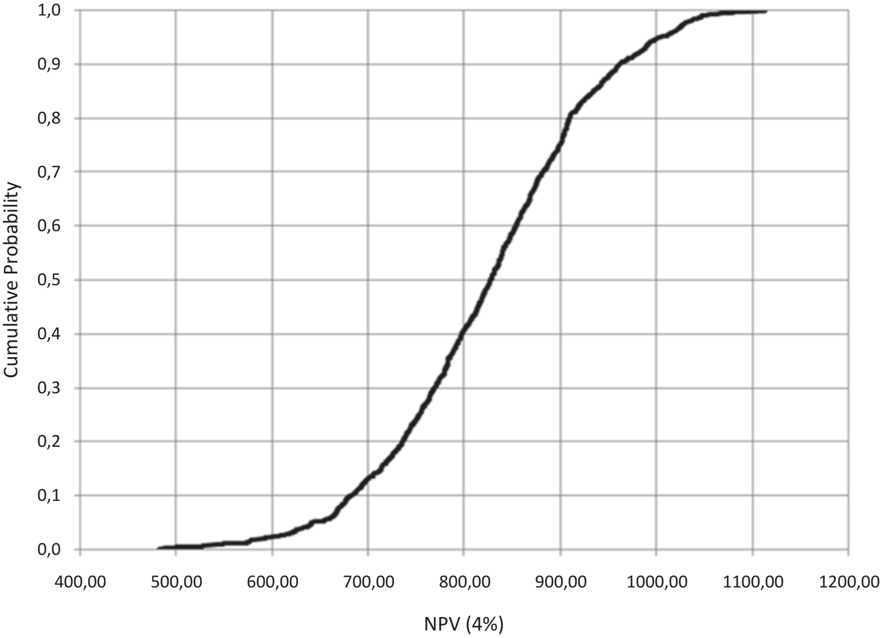


**Fig. 7.16** Monte Carlo simulation for "Wind" compared to ENTSO-E energy production (NPV, 4%)

**Table 7.10** "Wind" compared to coal energy production (NPV, 4%)

| | |
|---|---|
| Mean | 823,60 |
| St. dev. | 107,31 |
| Mean St. Error | 3,39 |
| Minimum | 481,26 |
| First Quartile | 752,65 |
| Median | 826,59 |
| Third Quartile | 898,33 |
| Maximum | 1113,31 |
| Skewness | −0,1675 |

**Table 7.11** Variables examined in the sensitivity analysis

| | Min | Base* | Max |
|---|---|---|---|
| Equipment cost (fish) | 0,85 | 1,00 | 1,15 |
| Revenue (fish) | 0,75 | 1,00 | 1,25 |
| Labor (fish) | 0,75 | 1,00 | 1,25 |
| Raw material cost (fish) | 0,75 | 1,00 | 1,25 |
| Other costs (fish) | 0,75 | 1,00 | 1,25 |
| Maintenance cost(fish) | 0,75 | 1,00 | 1,25 |
| Operating costs (fish) | 0,75 | 1,00 | 1,25 |

*Base refers to 100% of the central value for the corresponding variable. Min and max refer to the corresponding percentages of the base case.

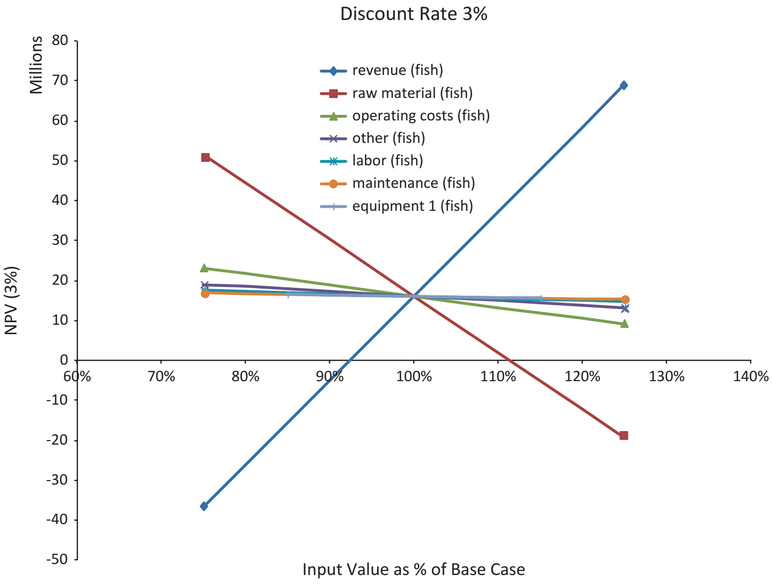


**Fig. 7.17** Sensitivity analysis on SCBA (3% discount rate)

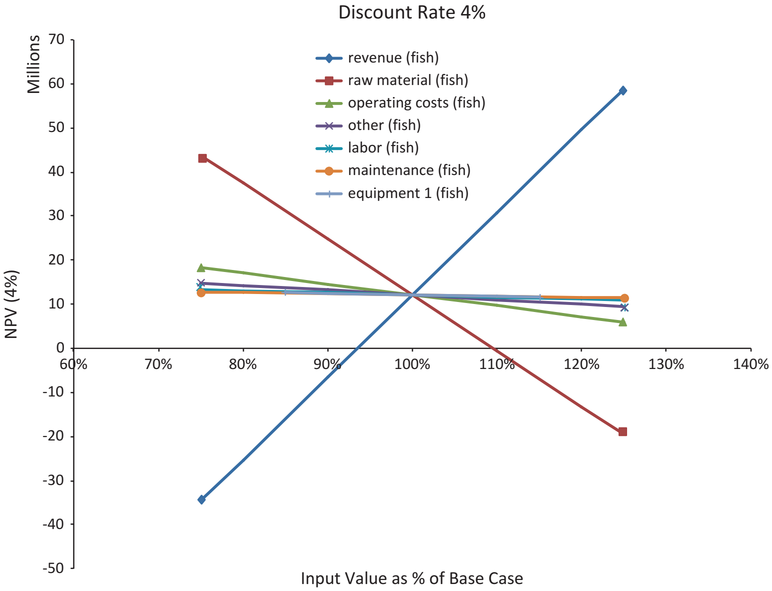
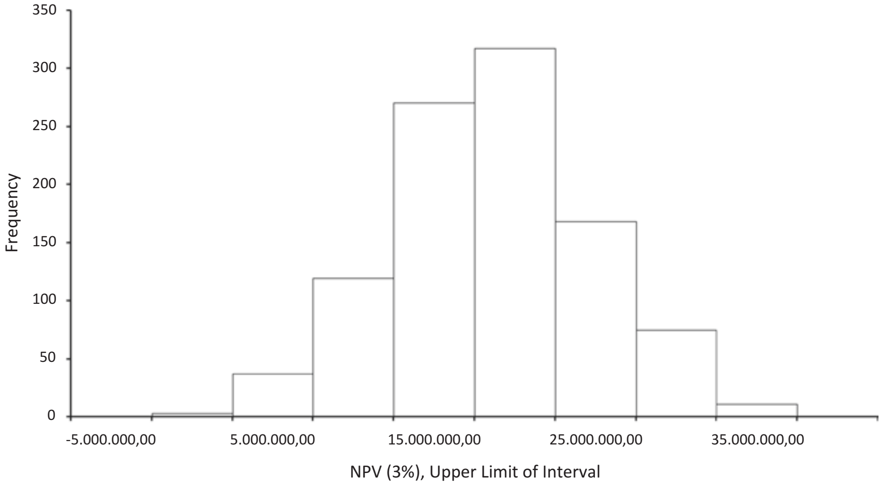


**Fig. 7.18** Sensitivity analysis on SCBA (4% discount rate)



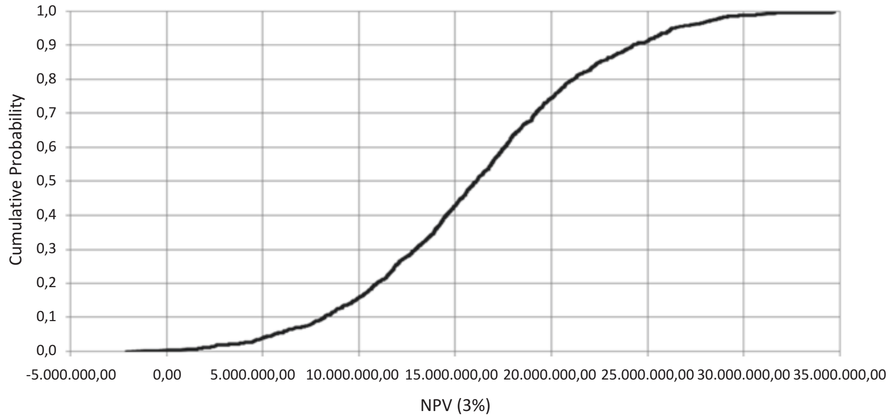


**Fig. 7.19** Monte Carlo simulation for "Aquaculture" (NPV, 3%)

**Table 7.12** "Aquaculture" (NPV, 3%)

| | |
|---|---|
| Mean | 16.052.583,76 |
| St. dev. | 6.179.906,34 |
| Mean St. Error | 195.425,80 |
| Minimum | −2.108.360,84 |
| First Quartile | 11.860.864,75 |
| Median | 16.051.626,22 |
| Third Quartile | 20.095.165,88 |
| Maximum | 34.711.943,79 |
| Skewness | 0,0088 |

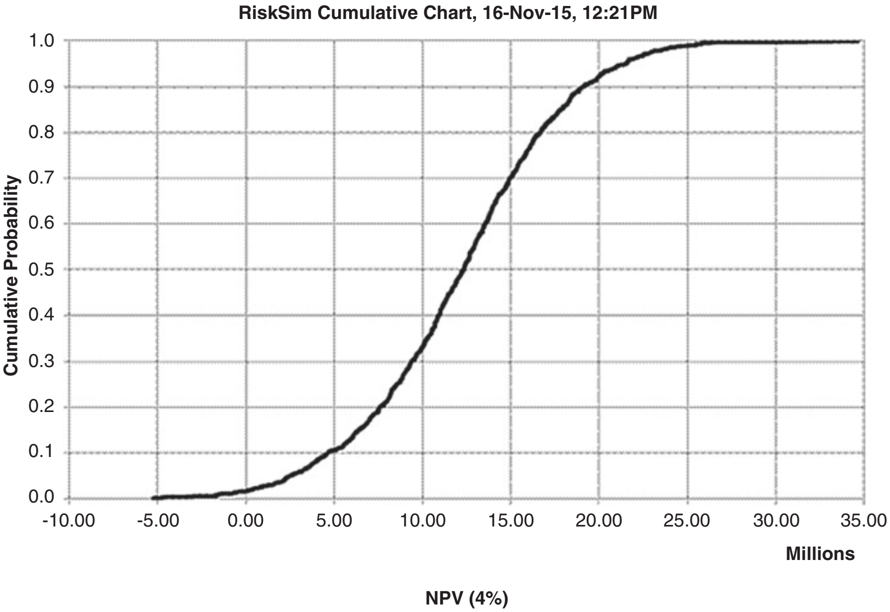


**Fig. 7.20** Monte Carlo simulation for “Aquaculture” (NPV, 4%)

**Table 7.13** “Aquaculture” (NPV, 4%)

| | |
|---|---|
| Mean | 12.140.351,31 |
| St. dev. | 5.589.853,89 |
| Mean St. Error | 176.766,70 |
| Minimum | −5.234.981,20 |
| First Quartile | 8.546.981,10 |
| Median | 12.307.186,42 |
| Third Quartile | 15.797.696,43 |
| Maximum | 34.681.235,59 |
| Skewness | −0,0497 |

**Table 7.14** Variables examined in the sensitivity analysis

| | Min | Base* | Max |
|---|---|---|---|
| Seaweed investment cost | 0,525 | 1,00 | 1475 |
| Seaweed output | 0,9625 | 1,00 | 1,0375 |
| Seaweed price | 0.5185 | 1.00 | 1.4815 |
| Seaweed operation costs | 0.812 | 1.00 | 1.188 |
| Mussels investment cost | 0.7805 | 1.00 | 1.2195 |
| Mussels output | 0.9375 | 1.00 | 1.0625 |
| Mussels price | 0.9787 | 1.00 | 1.0213 |
| Mussels operation costs | 0.261 | 1.00 | 1.739 |
| Energy output | 0.885 | 1.00 | 1.115 |
| Energy operation costs | 0.5919 | 1.00 | 1.4081 |

*Base refers to 100% of the central value for the corresponding variable. Min and max refer to the corresponding percentages of the base case.

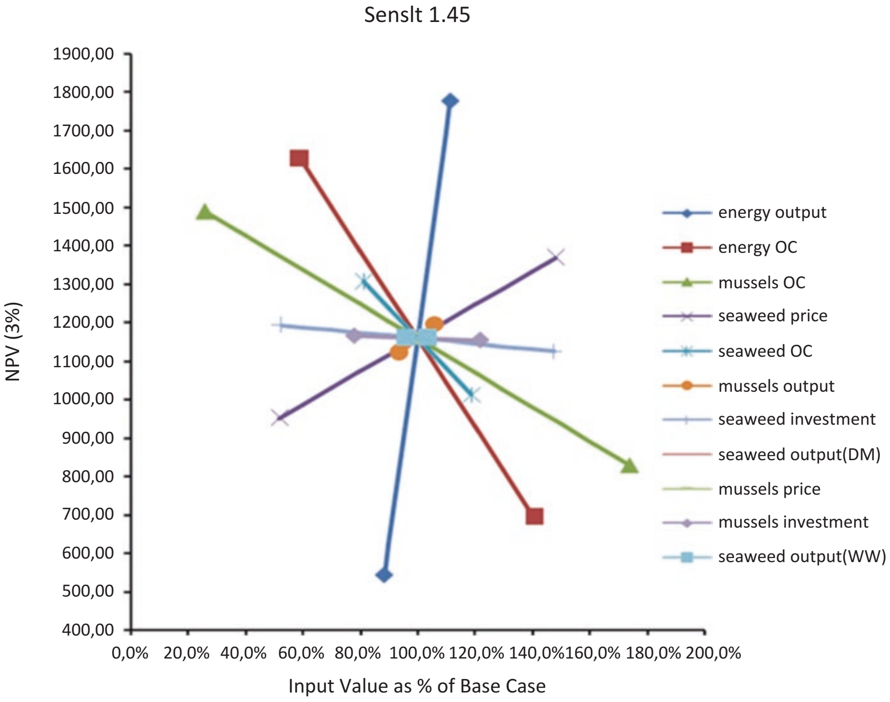


**Fig. 7.21** Sensitivity analysis on SCBA (3% discount rate, compared to coal energy production)

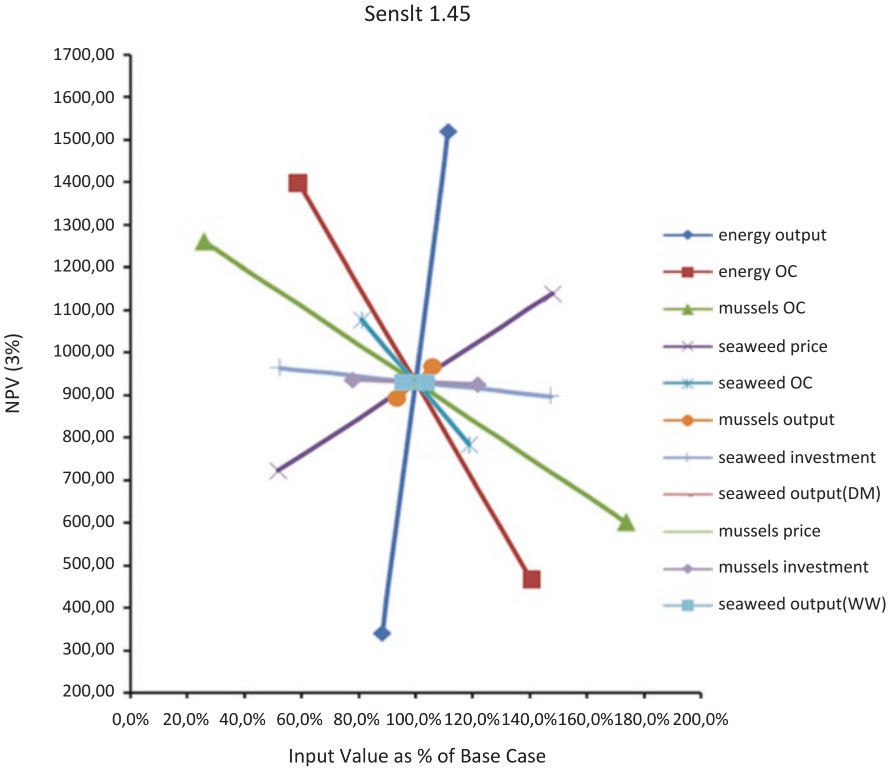


**Fig. 7.22** Sensitivity analysis on SCBA (3% discount rate, compared to ENTSO-E energy production)

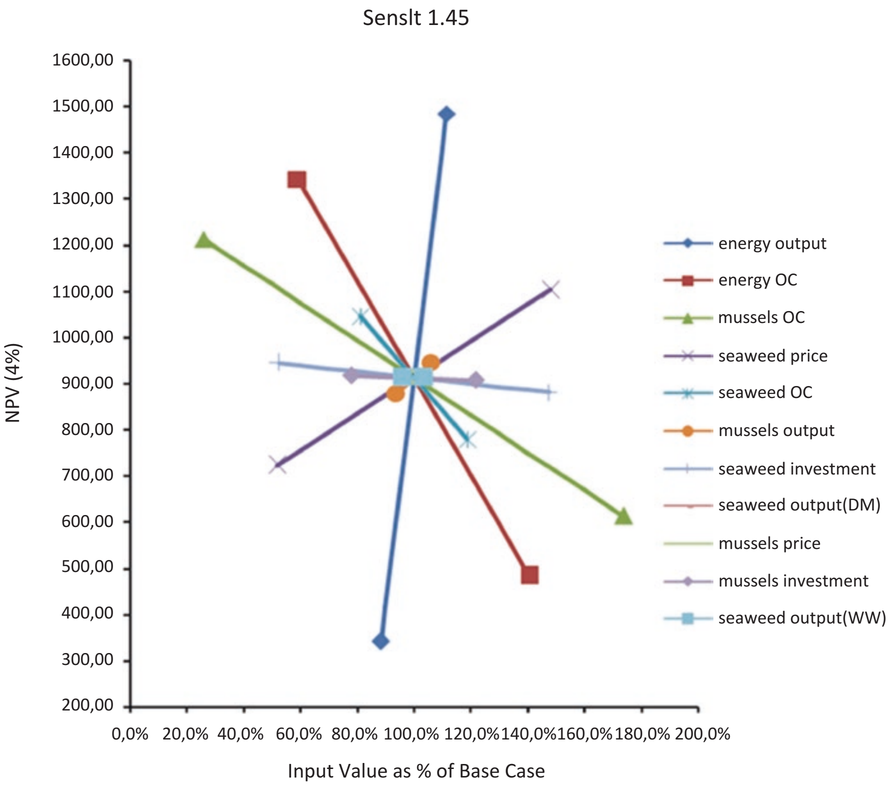


**Fig. 7.23** Sensitivity analysis on SCBA (4% discount rate, compared to coal energy production)

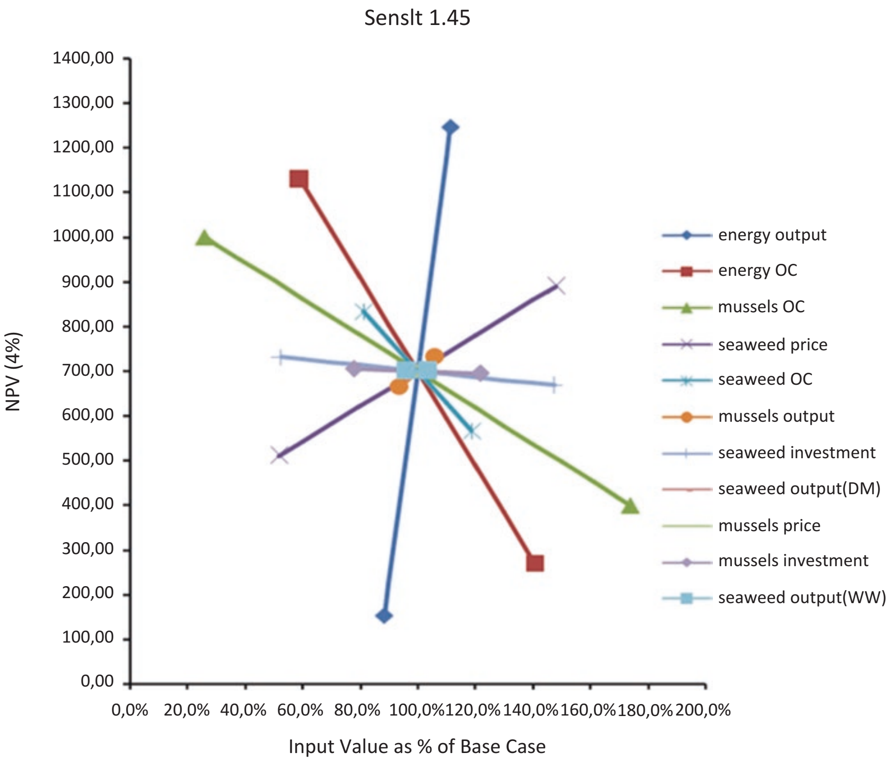


**Fig. 7.24** Sensitivity analysis on SCBA (4% discount rate, compared to ENTSO-E energy production)

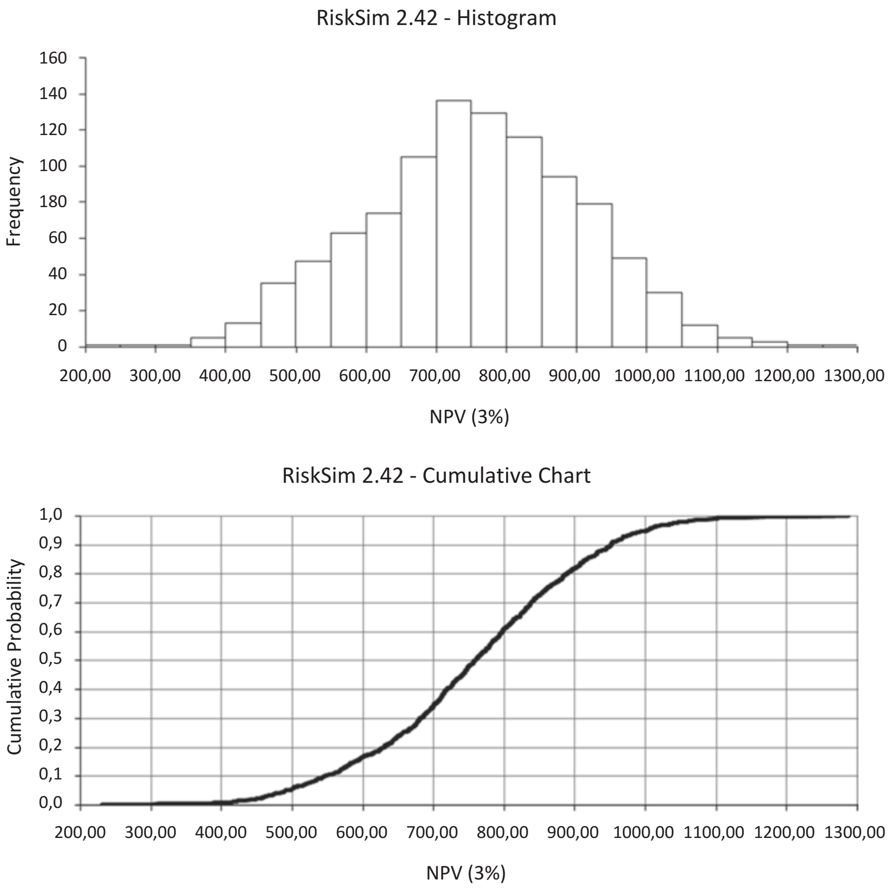


**Fig. 7.25** Monte Carlo simulation for "Mussels & Seaweed & Wind" compared to coal energy production (NPV, 3%)

**Table 7.15** "Mussels & Seaweed & Wind" compared to coal energy production (NPV, 3%)

| | |
|---|---|
| Mean | 755.90 |
| St. dev. | 153.43 |
| Mean St. Error | 4.85 |
| Minimum | 229.21 |
| First Quartile | 656.18 |
| Median | 758.34 |
| Third Quartile | 860.58 |
| Maximum | 1286.91 |
| Skewness | –0.0763 |

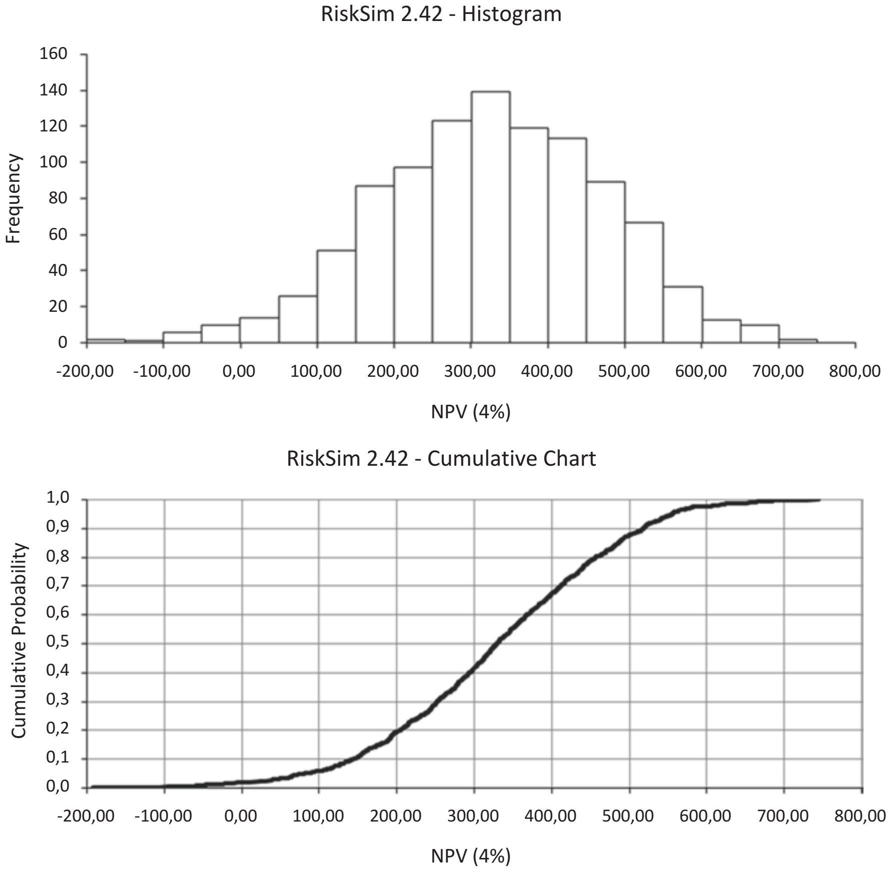


**Fig. 7.26** Monte Carlo simulation for "Mussels & Seaweed & Wind" compared to ENTSO-E energy production (NPV, 4%)

**Table 7.16** "Mussels & Seaweed & Wind" compared to ENTSO-E energy production (NPV, 4%)

| | |
|---|---|
| Mean | 328.12 |
| St. dev. | 147.00 |
| Mean St. Error | 4.65 |
| Minimum | −193.24 |
| First Quartile | 230.31 |
| Median | 328.33 |
| Third Quartile | 434.11 |
| Maximum | 743.65 |
| Skewness | −0.1878 |

# Chapter 8
# Conclusions and Recommendations

**Phoebe Koundouri, Amerissa Giannouli, Elias Giannakis, Eleftherios Levantis, Aris Moussoulides, and Stella Tsani**

**Abstract** This chapter summarizes the concluding remarks and recommendations based on the analysis presented in the previous chapters. The socio-economic assessment of the investment in multi-use off-shore platforms (MUOPs) in different EU sites indicates that the obstacles that impede their development are associated to policy, institutional and social considerations. Geopolitical features of the sites also play part in determining acceptability and feasibility of the projects. Financial considerations are also important to their acceptance and development. MUOPs may need financial support that can create incentives for developers to explore possibilities of these type of investment and make them more attractive. For the initial state of MUOPs development, subsidies and other economic instruments could be used to create investment incentives. At the same time MUOPs should be able to compete with conventional producers. Research outcomes on the feasibility of the MUOPs have to be made available and communicated to relevant stakeholders and policy makers. Given the data limitations and the significant research potential in this area pilot MUOPs projects can be proposed that could close the knowledge gaps and be used as examples to explore the possible benefits and challenges.

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A rapid development of marine infrastructure is expected to take place in the European oceans the next few decades. Massive offshore wind farms have already been constructed and new prototypes for marine renewable energy extraction from tides and waves have been tested to meet the objectives of renewable energy set by the EU Energy Strategy. However, the increasing development of marine infrastructure unavoidably exerts significant pressures on the marine ecosystems. Off-shore platforms that combine multiple functions within the same infrastructure offer significant economic and environmental benefits and could contribute to the optimization of the marine spatial planning.

Investing in offshore platforms implies that the economic costs of marine space use and the environmental impacts of the human activities should remain within acceptable limits. Providing there is little information on the economic viability of these platforms, this book examined the economic and environmental feasibility of such multi-use off-shore platforms (MUOPs). Inevitably, forecasts based on current knowledge and future expectations created uncertainty related to future cash flows of such projects. The uncertainty of the offshore wind/wave energy and aquaculture values (eg. output, costs, prices) is further increased due to the spatial differentiation of the economic, environmental and technological aspects among the different MUOP projects (North Sea, Atlantic, Mediterranean, Baltic). Based on the risk analysis results, the output and operation costs represent the most vulnerable to changes parameters for the projects. However, we should note that the results are based on limited information and time horizon (20–25 years) that do not allow for the inclusion of long-run effects (e.g., environmental effects that take place after more than 40 years of platform operation). Hence the results of the undertaken analysis could be uncertain. Nevertheless, that was a first step to identify challenges and opportunities with regards to offshore marine infrastructures, as well as to consider important knowledge gaps for the future design development and research.

The most important obstacles that impede the development of the MUOPs can be grouped in three categories:

(a) policy obstacles related to international agreements, regional or local constraints on the coordination of the actions
(b) institutional obstacles related to legal barriers and bureaucracy
(c) social constraints related to lack of social consensus of the groups affected by the projects, public unfamiliarity and distrust towards MUOPs

Policy and governance frameworks for the implementation of MUOPs need to be adjusted to reduce uncertainties with regards to licensing and operation that usually contribute to complexity of decision making and implementation process. Clear and agile licensing procedures that are open to accept innovative solutions and co-existence of uses in offshore environment are advisable. The licensing procedure should be based on site-specific environmental studies that guarantee the implementation of an environmental monitoring system in the designated marine areas for multi-use platforms development. For example, an environmental monitoring program that considers environmental issues such as the spreading of invasive species, biodiversity, underwater noise and electromagnetic radiation and water pollution. Minimizing the environmental impact and the continued monitoring should not be seen as burdens, instead, they contribute to the social license to operate for MUOPs.

Apart from these common obstacles applied to all case studies, the geopolitical features of each site further affect the nature of the site-specific perceived obstacles. For example, it is worth mentioning that off-shore wind development has been excluded from the recent renewable energy subsidy program launched in the North Sea areas contrary to what is applicable in the Mediterranean case study. In addition, in the Atlantic Sea and Baltic Sea, several licenses are required to start off-shore aquaculture or wind energy projects. These examples portray the importance of the location factor on the final design of the MUOPs.

In addition, the engagement of different case specific actors and stakeholders is essential for the maritime spatial planning and the design of efficient policy instruments. Within the MERMAID project, a wide range of stakeholders, including, policy makers, business partners and future end-users, local and regional authorities, local NGOs, relevant professional associations etc., was engaged to identify different views on economic, social and environmental objectives of MUOPs, as well as challenges and constraints faced (Rasenberg et al. 2013). The participatory process of the project revealed the importance of having a representative sample of stakeholders, since participants may have different perceptions of risks, costs and benefits involved, while a balance should be kept between the economic benefits and ecological impacts. Diverse knowledge and competences, as well as different responsibilities are spread out by several stakeholders capable of affecting the policy making process that is required for planning and developing future MUOPs.

With respect to socio-economics, MUOPs provide significant future opportunities for efficient marine space, which can generate new jobs, both direct and indirect, strengthen the cooperation between the different countries involved in the implementation of the MUOP and contribute to the overall regional and local development. In particular, MUOPs can promote R&D, which will create new jobs for high skilled workers. In addition technological synergies could correspond to energy efficiency and less environmental effects i.e., less $CO_2$ emissions that could be expressed in monetary values and included in the socio-economic assessment of MUOPs.

The assessment and implementation of the MUOPs is constrained by the lack of data (financial, socio-economic environmental, and technological) that make the monetization of externalities difficult. Based on the current results, the final designs for the Atlantic and North Sea site seem to be economically sustainable. However, stand alone functions of wave energy production for the Atlantic site and seaweed production for the North Sea site seem not economically sustainable. We have to note here that a considerable uncertainty relates to the existence of potential synergies when combining different functions due to economies of scale and efficiency gains. For example, in the Atlantic Sea site, synergies between wind and wave energy could lead to technical progress that may produce further economic benefits apart from the reduction of $CO_2$ emissions. For the Mediterranean and the Baltic site, since financial data with regards to the multi-use scenario were not available, experts' opinions and initial financial analysis have been used in the assessment. The results showed that the Baltic site can be economically sustainable. The Mediterranean MUOP scenario could be economically sustainable in the long run when the ocean space will get limited.

The assessment results presented here are associated to the adoption of specific assumptions and scenarios as discussed in the previous chapters. Thus the outcomes could potentially differ in magnitude and significance if additional information could become available and incorporated in the analysis (regarding for instance monetization of externalities). In addition the analysis would potentially differ if we would allow for a longer time horizon in the SCBA, or if a more precise investigation of synergy opportunities would be adopted, or if the comparison of implementing MUOPs has been conducted between off-shore and on-shore or near-shore activities.

Subsidies included in the SCBA can alleviate for negative profitability with respect to stand alone functions. One way to motivate subsidies for the MUOPs development is to point out that these subsidies are used to cover the installation cost of the MUOPs' different functions with the purpose of capturing the positive externalities not only in terms of environmental benefits such as $CO_2$ reductions, but also in terms of more general positive network externalities that promote technical change, support the transition to low carbon, support an energy independent economy, and improve food security due to more controlled aquaculture. 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. This is the opposite of imposing taxes to restrict activities that generate negative externalities. In the absence of subsidies market economy might not install MUOPs and the wider social and economic benefits would be lost. In this sense subsidies should not be regarded as a form of supporting the income of a pressure group but as means to secure the benefits accruing from positive externalities (although it is advised to be avoided in the long-run).

MUOPs should be able to compete with "conventional" producers if site conditions are good enough. Other mechanisms for financial support that create incentives for developers to explore possibilities of these type of investment and make them more attractive need to be further examined. Apart from subsidies, taxes to conventional energy production uses could be applied or make sure that insurance to reduce risks is effectively addressed. Furthermore, the advantage of first mover and the benefit of pioneer with regards to investors should not be disregarded.

Given the knowledge gaps, future decision making needs to take advantage of research undertaken for other related projects. In formal procedures such as impact assessment of plans, programs (Strategic Environmental Assessment) and projects (Environmental Impact Assessment), consultation is already a given. This helps taking into account a variety of institutional, technical, environmental, financial and socio-economic aspects in maritime spatial planning and for developing policy instruments that can support the development, implementation and running of MUOPs. Research outcomes on the feasibility of the MUOPs have to diffuse and be visible to all relevant stakeholders and policy makers. It is clear that private funding is required in order MUOPs to be able to generate public benefits. For the initial state of MUOPs development, subsidies and other possible economic instruments are advised to be used to create incentives of investment. Awareness campaigns on the multiple functions of these platforms will improve the understanding of the multi-disciplinary benefits and may improve their acceptability from the local societies. Given the lack of data and the high research potential in this area, it is suggested to have pilot MUOPs projects that could close the knowledge gaps and be used as examples to exhibit the possible benefits to policy makers and potential investors.

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