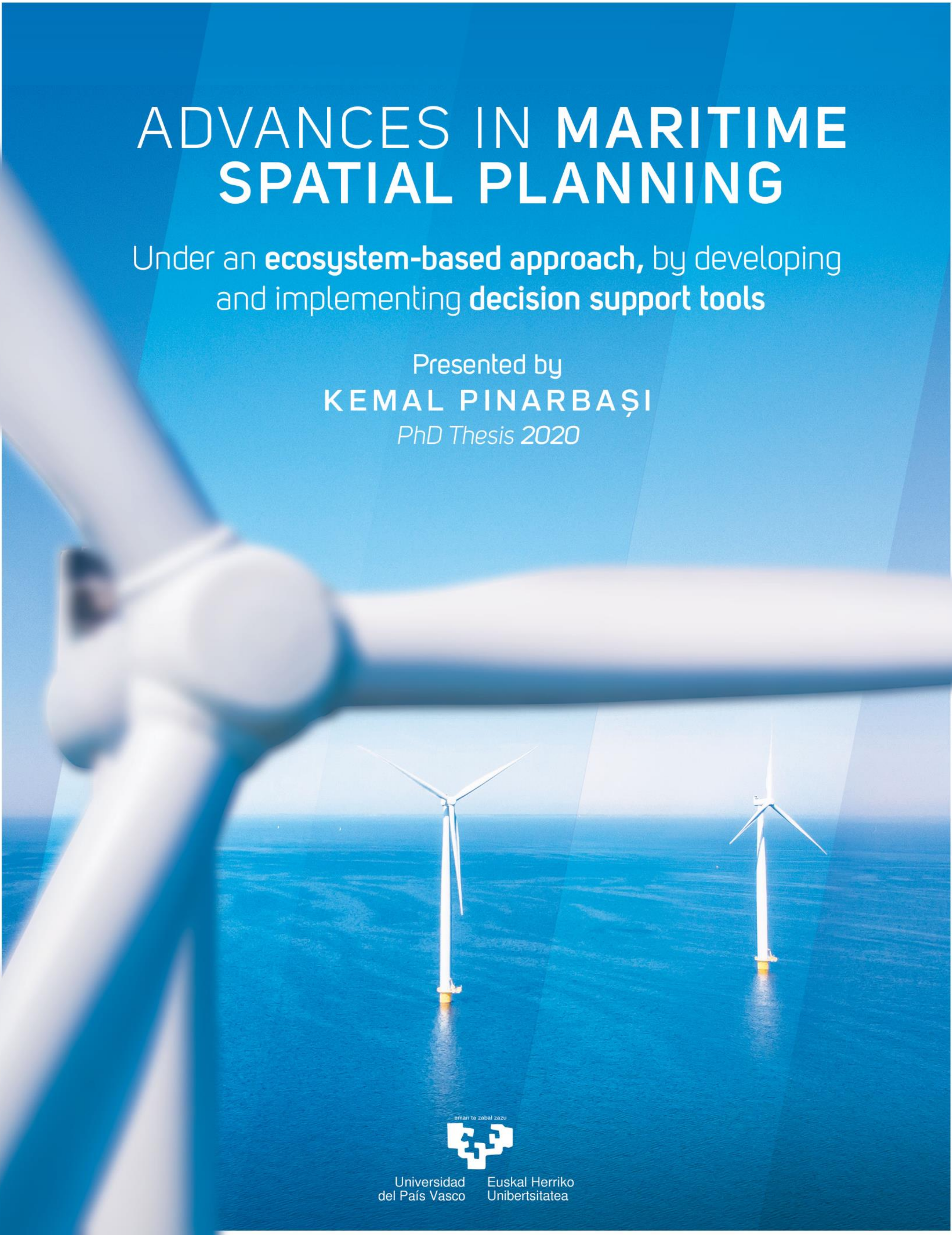
ADVANCES IN **MARITIME SPATIAL PLANNING**

Under an **ecosystem-based approach,** by developing and implementing **decision support tools**

Presented by

KEMAL PINARBAȘI

PhD Thesis ***2020***



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Universidad del País Vasco
Euskal Herriko Unibertsitatea

PhD Thesis

Advances in Maritime Spatial Planning, under an ecosystem-based approach, by developing and implementing decision support tools

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Content

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List of Acronyms

BBN	Bayesian Belief Network
CAGR	Compound Annual Growth Rate
CBD	Convention on Biological Diversity
CFP	Common Fishery Policy
CPT	Conditional Probability Tables
CVI	Cumulative Visibility Index
DST	Decision Support Tool
EBA	Ecosystem-based Approach
EBM	Ecosystem-based Management
EB-MSP	Ecosystem-based Maritime Spatial Planning
EEZ	Exclusive Economic Zone
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GES	Good Environmental Status
GIS	Geographic Information Systems
HBD	Habitat and Bird Directive
IHO	International Hydrographic Organization
IMO	International Maritime Organization
LCOE	Levelized cost of energy
MPA	Marine Protected Area
MSFD	Marine Strategy Framework Directive
MSP	Maritime Spatial Planning
MSPD	Maritime Spatial Planning Directive
NGO	Non-Governmental Organization
OSPAR Convention	Convention for the Protection of the Marine Environment of the North-East Atlantic
PoM	Program of Measures
UNCLOS	The United Nations Convention on the Law of the Sea
WFD	Water Framework Directive

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Resumen

Los humanos han utilizado el océano para la obtención de alimentos, el comercio, las aventuras y los descubrimientos desde el comienzo de la historia. Hoy en día, aproximadamente el 10% de la población mundial vive en áreas costeras que están a menos de 10 metros sobre el nivel del mar. Esto ha llevado a un incremento en las actividades marítimas como el transporte, la pesca, la producción de energía, el turismo, el dragado, la explotación de recursos naturales, las actividades militares o la investigación. En paralelo con el aumento continuo de la población humana y las necesidades derivadas de la creciente demanda de la humanidad, el espacio marítimo está más demandado que nunca. En consecuencia, la competencia por este espacio para todas las actividades y usos marítimos ha resaltado la importante necesidad de una gestión y planificación marítima coherente.

Debido a dicha competencia, al tiempo que se alcanzan objetivos sociales y económicos, los ecosistemas marinos deben protegerse equilibrando las actividades humanas y su distribución espacial. En este contexto, la directiva del Parlamento Europeo y del Consejo de planificación espacial marítima (MSP por sus siglas en inglés) tiene como objetivo apoyar el desarrollo sostenible y el crecimiento en los sectores marítimos, aplicando un enfoque basado en el ecosistema. Según esta directiva, cada estado miembro debe completar sus planes espaciales marítimos para 2021. Según la ultima revisión de MSP Platform (Mayo, 2019), hay siete planes nacionales y 11 subnacionales finalizados en países europeos. Además de estas iniciativas, los proyectos de investigación financiados por la Unión Europea también están contribuyendo significativamente a generar conocimiento y brindar apoyo a los estados miembros durante el desarrollo del plan.

De acuerdo con la definición de OSPAR; el enfoque de una gestión basada en el ecosistema (EBM por sus siglas en inglés) es "la gestión integrada de las actividades humanas basada en el mejor conocimiento científico disponible sobre el ecosistema y su dinámica, con el fin de identificar y tomar medidas sobre las influencias que son críticas para la salud de los ecosistemas marinos y, así, logrando el uso sostenible de los bienes y servicios del ecosistema y el mantenimiento de la integridad del ecosistema ”.

En los procesos de planificación, el desarrollo y la implementación de herramientas de apoyo a la toma de decisiones puede ayudar a los planificadores, tomadores de decisiones, la industria y los inversores, a la hora de implementar un MSP basado en el ecosistema. De acuerdo con este contexto, la hipótesis de esta tesis doctoral es que "las herramientas de apoyo a la decisión (DST por sus siglas en inglés) pueden ser aplicadas en función de los requisitos de los procesos de planificación y las opiniones de los usuarios finales para lograr planes de gestión basados en el ecosistema, teniendo en cuenta los aspectos económicos, ecológicos, de dinámica social y características transfronterizas del medio marino”. Para confirmar o refutar esta hipótesis, los objetivos han sido (i) caracterizar las DST existentes, registrar y analizar las percepciones de los usuarios finales de DSTs; (ii) desarrollar un ejemplo de la implementación de un DST, desarrollando un modelo que integre los componentes económicos, ambientales y sociales más relevantes para identificar áreas factibles y escenarios futuros para parques eólicos marinos; y finalmente (iii) identificar los problemas clave y desafíos para plantear recomendaciones para un Planificación del Espacio Marítimo Basado en el Ecosistema (EB-MSP por sus siglas en inglés) transfronterizo en el Golfo de Vizcaya. Para lograr estos objetivos, se realizó una investigación en cuatro fases que se corresponden con los capítulos de la presente tesis.

El **Capítulo 1** se centró en la caracterización y el análisis del uso actual de las herramientas en los procesos existentes de implementación de MSP en todo el mundo. Mientras tanto, se identificaron debilidades y lagunas de las herramientas existentes y se propusieron nuevas funcionalidades para mejorar su viabilidad y aplicabilidad. Los resultados mostraron que el 57% de las herramientas identificadas se utilizaron para recopilar datos, definir la situación actual e identificar problemas, limitaciones y condiciones futuras; por tanto, se aplican en las primeras fases de la implementación de MSP. Se observó que las principales brechas de las DSTs están vinculadas a su funcionalidad limitada, inestabilidad, altos costes y una menor consideración de los problemas de decisión económica y social. Además, las DSTs no siempre son fáciles de utilizar. Con una perspectiva de futuro, la investigación sugirió que las DSTs deberían considerar tanto la dinámica espacial como la temporal del ecosistema marino. También deberían ser fáciles de usar y de libre acceso.

Seguidamente en el **Capítulo 2**, para completar este esfuerzo inicial, se recopilaron las opiniones de los usuarios finales y se analizaron sus percepciones y experiencias sobre la aplicación de las DSTs. De acuerdo con estas percepciones y expectativas, se formularon recomendaciones para dar una idea de los futuros desarrollos y aplicaciones. En estos dos capítulos se identificaron tanto la imagen general como las perspectivas de los usuarios de las DSTs existentes. Se observó que las herramientas más necesarias en los procesos de MSP fueron las que consideraban la dimensión económica, ambiental y social del medio marino, las que identificaban los sitios para actividades emergentes y las que creaban escenarios futuros.

Los resultados de los capítulos 1 y 2 se utilizaron en el **Capítulo 3**, centrado en el desarrollo e implementación de un modelo de viabilidad para parques eólicos marinos. En este capítulo se presenta un enfoque novedoso en el que se aplicó y desarrollo un modelo basado en una Redes Bayesianas (BBN por sus siglas en inglés) para una identificación de zonas viables para el desarrollo de parques eólicos marinos, integrada y espacialmente explícita. El modelo desarrollado consideró parámetros técnicos como el coste de producción de energía; componentes ambientales tales como áreas importantes para mamíferos marinos, aves marinas y macrobentos; y componentes sociales, como la distribución espacial de las actividades existentes, la visibilidad y las preocupaciones estéticas. La aplicación de las BBNs para una tarea MSP integrada puede considerarse como la primera de su tipo.

Además, en el **Capítulo 4** de la presente tesis se dio un paso adelante y se analizaron temas clave, desafíos y el contexto de MSP en el Golfo de Vizcaya para formular recomendaciones basadas en una visión holística y las prácticas de gestión actuales. Este amplio trabajo puede considerarse como uno de los primeros intentos de establecer un EB-MSP transfronterizo en el Golfo de Vizcaya. Esta investigación mostró que la información existente producida por otras directivas de la UE, como la MSFD, puede constituir una contribución significativa en los procesos de MSP en términos de la consideración de la componente y los principales aspectos críticos. Se observó que Francia y España se centraron en cuestiones críticas similares, como la biodiversidad, la abundancia a largo plazo de las redes tróficas, la integridad del fondo marino y las basuras marina en el Golfo de Vizcaya. El conflicto espacial causado por la limitada superficie de la plataforma continental, las nuevas estructuras costeras planificadas, el riesgo conjunto y la evaluación ambiental, el aumento de la basura marina, las diferentes medidas de gestión y objetivos estratégicos, así como la limitada cooperación transfronteriza en términos de gobernanza se definieron como los principales problemas y se formularon varias recomendaciones para evitar presentes y futuros conflictos.

Los resultados de esta tesis pueden ayudar a los investigadores a comprender mejor los vínculos entre las DSTs y los procesos de MSP y a contribuir a los procesos de MSP con las herramientas necesarias. Además, los planificadores pueden usar los resultados de los dos capítulos iniciales de la tesis para decidir qué DST sería la más apropiada para las tareas y etapas específicas de la MSP. Asimismo, el modelo presentado en el Capítulo 3 se puede utilizar en los procesos de selección de sitios para cualquier actividad marítima, mediante el uso de datos técnicos, ambientales y sociales. Este enfoque novedoso puede ayudar a los gerentes a observar los posibles escenarios futuros y los impactos de las decisiones. Finalmente, los temas destacados y las recomendaciones dadas en el Capítulo 4 pueden informar a las autoridades competentes de Francia y España, ayudándoles a comprender el contexto socio-económico y ambiental, las similitudes y las diferencias entre ambos países en el Golfo de Vizcaya.

Como resultado, **la Tesis es que:**

"La aplicabilidad de DST para lograr planes de gestión basados en el ecosistema que integren la dinámica económica, ecológica y social y las características transfronterizas del ecosistema marino ha sido comprobada. Su contribución a la MSP ha sido probada por: (i) identificación de los requisitos de DST en los procesos de planificación, (ii) consideración de las perspectivas de los usuarios finales, (iii) desarrollo y aplicación de una nueva DST, y (iv) una visión holística de un EB-MSP transfronterizo".

Summary

Ocean has been used by humanity for food provisioning, trade and commerce, adventure and discovery since the beginning of the history. Nowadays, approximately 10% of the world's population live in coastal areas that are less than 10 meters above sea level. This has led to increasing activities such as shipping, fishing, energy production, tourism, dredging, natural resources exploitation, military activities or research. In parallel with continuously increasing human population and needs with increasing demands of humanity, ocean space is busier than ever. Accordingly, competition for ocean space for all maritime activities and uses stressed the significant need for a coherent maritime management and planning.

Due to that increasing competition for ocean space, while achieving social and economic objectives, marine ecosystems should be protected by balancing human activities and their spatial distribution. In this context, European Parliament and the Council's directive of maritime spatial planning (MSP) aims to support sustainable development and growth in the maritime sectors, applying an ecosystem-based approach. According to this directive, each Member State needs to complete their maritime spatial plans by 2021. According to latest overview of MSP Platform (May, 2019), there are seven national and 11 sub-national plans finalized in European Countries. Besides these initiatives, European Union funded research projects are also contributing significantly to produce knowledge and give support to Member States during the plan development.

By definition of OSPAR; ecosystem-based management (EBM) approach is "the integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are

critical to the health of marine ecosystems, thus achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity”.

In planning processes, development and implementation of decision support tools can assist planners, decision makers, industry and investors in order to implement ecosystem-based MSP. According to this context, the **hypothesis** of this PhD thesis is that “the decision support tools (DSTs) can be applied based on requirements of planning processes, and end-users’ opinions to achieve ecosystem-based management plans considering economic, ecologic, and social dynamics and transboundary characteristics of marine environment”. In order to confirm or refute this hypothesis, it has been aimed (i) to characterise existing DSTs, capture and analyse DST end-user perceptions; (ii) to perform an example of the implementation of a DST by developing a model that integrates most relevant economic, environmental and social components to identify feasible areas and future scenarios for offshore wind farms; and finally (iii) to identify the key issues and challenges in order to raise recommendations for a transboundary EB-MSP in the Bay of Biscay. In order to achieve these objectives, following research was undertaken in four phases corresponding to the chapters of the present thesis.

Chapter 1 was focused on characterisation and analysis of the present use of the tools in existing MSP implementation processes around the world. Meanwhile, weaknesses and gaps of existing tools were identified, and new functionalities were proposed to improve their feasibility and applicability. The results showed that 57% of the tools identified were used for gathering data, defining the current situation and the identification of issues, constraints and future conditions. It was seen that the main gaps of DSTs are linked to their limited functionality, instability, high costs and a less than ideal consideration of economic and social decision problems. In addition, DSTs are not always easy to use. Looking towards the future, the research suggested that DSTs should consider both the spatial and temporal dynamics of the marine environment. They should also be made easy to use and freely available.

Further in **Chapter 2**, to complete this initial effort, end-user opinions were collected and their perceptions and experiences on DSTs application were analysed. According to these perceptions and expectations, recommendations were drawn to give insights for future developments and the applications. In these two chapters, the general picture and users' perspectives of the existing DSTs were identified. It was seen that tools considering both economic, environmental and social dimensions of marine environment, identifying sites for emerging activities and creating future scenarios were the ones required in MSP processes.

Outcomes of Chapter 1 and 2 were used in **Chapter 3** focusing on the development and implementation of a feasibility model for offshore wind farms. A novel approach using Bayesian Belief Networks (BBNs) for an integrated and spatially explicit site feasibility identification for offshore wind farms is presented in this chapter. The developed model considered technical parameters, such as levelized cost of energy; environmental components, such as important areas for marine mammals, sea birds and macrobenthos; and social components, such as spatial distribution of existing activities, visibility and aesthetic concerns. The application of a BBN for an integrated MSP task can be considered as the first of its kind.

Furthermore, in **Chapter 4**, this thesis took a step forward and analysed key issues, challenges and the MSP context in the Bay of Biscay to rise recommendations, based on a holistic vision and present management practices. This comprehensive work can be considered as one of the initial attempts to give insights for transboundary and EB-MSP in the area. This research showed that existing information produced by other EU directives such as MSFD can constitute significant input for MSP processes in terms of understanding of environmental perspective and main concerns. It was seen that France and Spain focused on the similar critical issues such as biodiversity, long-term abundance of food webs, sea floor integrity and marine litter in the Bay of Biscay. Space conflict caused by limited continental shelf, planned new coastal structures, joint risk and environmental assessment, increasing marine litter, different management measures and strategic objectives, and cross-border cooperation in governance were defined as the main issues and several recommendations were drawn in order to avoid future conflicts.

The findings of this thesis can help researchers to better understand the links between DSTs and MSP processes and to contribute to MSP processes with required tools. Besides, planners may use the outcomes of initial two chapters of the thesis in order to decide which DST would be the most appropriate one for the specific MSP tasks and stage. Furthermore, the model presented in Chapter 3 can be used in site selection processes for any maritime activity by using technical, environmental and social data. This novel approach can help decision makers to see the potential future scenarios and impacts of spatial decisions. Finally, highlighted issues and given recommendations in Chapter 4 can inform planning authorities of France and Spain and help them to understand the socio-economic and environmental context, similarities and differences in Bay of Biscay.

As a result, **the Thesis is that**:

"Application of DSTs to achieve ecosystem-based management plans considering economic, ecologic, and social dynamics and transboundary characteristics of marine environment has been tested and their contribution to MSP has been proved by: (i) identification of DSTs requirements based on planning processes, (ii) consideration of end-user opinions, (iii) design and application of a new DST, and (iv) a holistic visioning for a transboundary and EB-MSP."

List of Publications

During the thesis period, outcomes and research contributions have been published, accepted in or sent to international scientific journals with Science Citation Index. Some of these publications were used in the main body of the thesis, while others have supported the advances in MSP and DSTs applications.

Pınarbaşı, K., I. Galparsoro, Á. Borja, V. Stelzenmüller, C. N. Ehler, A. Gimpel, 2017. Decision support tools in marine spatial planning: Present applications, gaps and future perspectives. Marine Policy, 83: 83-91.

Gimpel, A., V. Stelzenmüller, S. Töpsch, I. Galparsoro, M. Gubbins, D. Miller, A. Murillas, A. G. Murray, **K. Pınarbaşı**, G. Roca, R. Watret, 2018. A GIS-based tool for an integrated assessment of spatial planning trade-offs with aquaculture. Science of The Total Environment, 627: 1644-1655.

Coccoli, C., I. Galparsoro, A. Murillas, **K. Pınarbaşı**, J. A. Fernandes, 2018. Conflict analysis and reallocation opportunities in the framework of marine spatial planning: A novel, spatially explicit Bayesian belief network approach for artisanal fishing and aquaculture. Marine Policy, 94: 119-131.

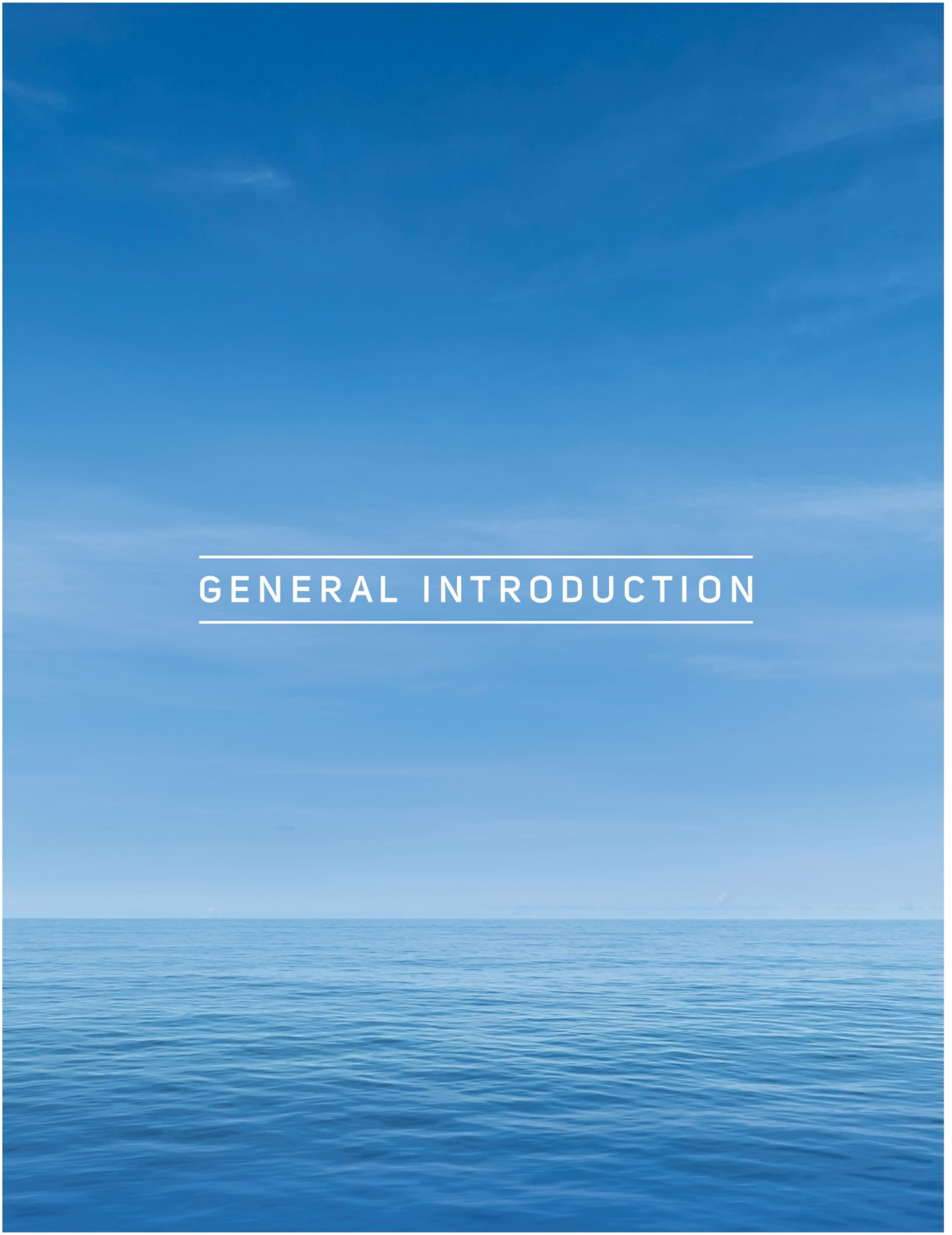
Pınarbaşı, K., I. Galparsoro, Á. Borja, 2019. End users' perspective on decision support tools in marine spatial planning. Marine Policy, 108: 103658.

Pınarbaşı, K., I. Galparsoro, D. Depellegrin, J. Bald, G. Pérez-Morán, Á. Borja, 2019. A modelling approach for offshore wind farm feasibility with respect to ecosystem-based marine spatial planning. Science of The Total Environment, 667: 306-317.

Galparsoro, I, A. Murillas, **K. Pınarbaşı**, A. Sequeira, V. Stelzenmueller, A. Borja,, A. O´Hagan, A. Boyd, S. Bricker, J.M. Garmendia,, A. Gimpel, A. Gangnery, S. Billing, Ø. Bergh, Ø. Strand, l. Hiu, B. Fragoso, J. Icely, J. Ren, N. Papageorgiou, J. Grant, D. Brigolin, R. Pastres, P. Tett. 2020, Global stakeholder vision for ecosystem-based marine aquaculture expansion from coastal to offshore areas, Reviews in Aquaculture. doi:10.1111/raq.12422,

Pınarbaşı, K., I. Galparsoro, N. Alloncle, F. Quemmerais-amice, Á. Borja, Visioning for a transboundary and ecosystem-based maritime spatial planning in the Bay of Biscay, Marine Policy (Submitted)

Galparsoro, I, **K. Pınarbaşı**, E. Gissi, F. Culhane, J. Gacutan, J. Kotta, D. Cabana, S. Wanke, R. Aps, D. Bazzucchi, G. Cozzolino, M. Custodio, M. Fetissov, M. Inácio, S. Jernberg, A. Piazzi, K. Prasad Paudel, A. Ziemba, D. Depellegrin, Operationalizing ecosystem services in support of ecosystem-based marine spatial planning (in prep.)



GENERAL INTRODUCTION

General Introduction

Ocean, by definition, is a body of water that composes most of the planet's hydrosphere, covering approximately 71% of Earth's surface and 90% of the Earth's biosphere (Lalli and Parsons, 1997). It is the largest ecosystem in the world; and climate, weather, even the quality of the air is dependent to oceans. In addition to be primary source of nourishment for the life, it has served for trade and commerce, adventure and discovery (Rozwadowski and Countryman, 2019). Like in the history, humanity still benefits goods and services provided by ocean (Costanza *et al.*, 1997). Approximately 600 million people (around 10 per cent of the world's population) live in coastal areas that are less than 10 meters above sea level, besides, nearly 2.4 billion people (about 40 per cent of the world's population) live within 100 km of the coast (United Nations, 2017). There are many human activities taking place in the sea such as shipping, fishing, energy production, tourism, dredging, natural resources exploitation, military activities or research. Ocean space is busier than ever in parallel with continuously increasing human population and needs (Hammar *et al.*, 2017). Besides, demand for provided goods and services usually exceeds the capacity of oceans to meet all the demands at once, and ocean boundaries can be overcome (Nash *et al.*, 2017). Common property resources lead to excessive use of marine resources by free access of each activity. Since there are also non-material benefits of ocean, it is hard to estimate values of marine ecosystem in order to allocate in the most appropriate way (Papathanasopoulou *et al.*, 2016). In addition to this valuation uncertainty, ocean space is limited, and it is not possible to satisfy space demand of each maritime activity. Competition for ocean space for all maritime activities and uses stressed the significant need for a coherent maritime management and planning (Noble *et al.*, 2019). A public process is needed to balance demands for human activities with the need to protect marine ecosystems, and to achieve social and economic objectives in a transparent way (Domínguez-Tejo *et al.*, 2016).

In 2014, European Parliament and the Council have adopted legislation to create a common framework for Maritime Spatial Planning Directive (MSPD) (European Union, 2014). According to this directive, each member state shall establish their maritime spatial plans at the latest by 31 March 2021 (Article 3). By definition, maritime spatial planning (MSP) was defined as a process by which the relevant Member State's authorities analyse and organise human activities in marine areas to achieve ecological, economic and social objectives (Article 3). This directive promotes an integrated planning and management approach for activities such as installations for the production of energy from renewable sources, oil and gas exploration and exploitation, maritime transport, fishing activities, ecosystem and biodiversity conservation, the extraction of raw materials, tourism, aquaculture and underwater cultural heritage, as well as the multiple pressures on coastal resources.

According to objectives of MSPD defined in Article 5, Member States shall consider economic, social and environmental aspects to support sustainable development and growth in the maritime sector, applying an ecosystem-based approach, and to promote the coexistence of relevant activities and uses when establishing and implementing maritime spatial planning (European Union, 2014). Besides, Member States shall aim to contribute to the sustainable development of human activities, and to the preservation, protection and improvement of the environment, including resilience to climate change impacts. In several locations, maritime spatial planning (MSP) was implemented as a public process of analysing and allocating the spatial and temporal distribution of human activities in maritime space to achieve ecological, economic, and social objectives that are usually specified through a political process. In order to achieve these objectives, MSPD provides minimum requirements for each plan (Article 6):

- Take into account land-sea interactions,
- Take into account environmental, economic and social aspects, as well as safety aspects,
- Aim to promote coherence between maritime spatial planning and the resulting plan or plans and other processes, such as integrated coastal management or equivalent formal or informal practices,
- Ensure the involvement of stakeholders,
- Organise the use of the best available data,
- Ensure trans-boundary cooperation between Member States,
- Promote cooperation with third countries.

At present, MSP is considered as a promising management approach to transform user to user and user to environment conflicts into solutions at sea (Gissi *et al.*, 2019). At European scale, the European Commission and Directorate General (DG) MARE uses the term "maritime spatial planning" to emphasise the holistic and cross-sectoral characteristics of MSP (European Commission, 2008). According to EU MSP Platform's overview (analysis performed in May 2019, www.msp-platform.eu), there are 7 national and 11 sub-national plans finalized in European Countries. These implementation examples can be found in several European countries, such as Lithuania, Malta, The Netherlands, Latvia, Germany, and Belgium (Olsen *et al.*, 2014a; Piet *et al.*, 2019). In addition to these, Poland has an advanced MSP process, and other European countries develop pilot plans and regional planning activities (Fernandes *et al.*, 2017; Rodríguez-Rodríguez *et al.*, 2016). As well as the political initiatives, European Union funded research projects are also contributing significantly to produce knowledge and give support to Member States during the plan development (Barale, 2018). These projects were used in several sea basins to analyse current conditions, requirements for different human activities and in general for governance practices. Among others, Baltic Sea countries have performed several projects aiming transboundary cooperation and coherent planning processes (Gee *et al.*, 2011; Schultz-Zehden and Gee, 2016).

Responding to increasing pressures on the marine environment, MSPD mentions another EU Directive, the Marine Strategy Framework Directive (MSFD) (European Union, 2008) to be taken as the base for environmental status assessment and to take measures in order to balance pressures created by maritime activities. MSFD aims to achieve good environmental status (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend (Borja *et al.*, 2010). In order to achieve the GES objective, the directive sets out 11 qualitative descriptors:

- Descriptor 1. Biodiversity is maintained.
- Descriptor 2. Non-indigenous species do not adversely alter the ecosystem.
- Descriptor 3. The population of commercial fish species is healthy.
- Descriptor 4. Elements of food webs ensure long-term abundance and reproduction.
- Descriptor 5. Eutrophication is minimised.
- Descriptor 6. The sea floor integrity ensures functioning of the ecosystem.

- Descriptor 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem.
- Descriptor 8. Concentrations of contaminants give no effects.
- Descriptor 9. Contaminants in seafood are below safe levels.
- Descriptor 10. Marine litter does not cause harm.
- Descriptor 11. Introduction of energy (including underwater noise) does not adversely affect the ecosystem.

These descriptors help Member States to interpret what GES means, and to describe what the environment will look like when GES has been achieved (Borja *et al.*, 2013; European Union, 2008), providing a guidance on how to implement this (European Commision, 2017b). MSPD mentions MSFD and GES in parallel with requirement of sustainable growth of maritime economies, the sustainable development of marine areas and the sustainable use of marine resources (Frazão Santos *et al.*, 2014; Gilbert *et al.*, 2015). According to MSPD (Recital 14) (European Union, 2014), *"maritime spatial planning should apply an ecosystem-based approach as referred to in Article 1(3) MSFD with the aim of ensuring that the collective pressure of all activities is kept within levels compatible with the achievement of good environmental status and that the capacity of marine ecosystems to respond to human-induced changes is not compromised, while contributing to the sustainable use of marine goods and services by present and future generations".*

By definition, ecosystem-based management (EBM) approach is *"the integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thus achieving sustainable use of ecosystem goods* *and services and maintenance of ecosystem integrity"* (OSPAR Commision, 2003). Ecosystem-based approach promotes to balance the human activities according to ocean's capacity to provide ecosystem services, while integrating ecological, economic and social perspectives into planning process (Katsanevakis *et al.*, 2011). In the context of marine management, EBM aims to maintain marine ecosystem in a healthy and productive condition that they can sustain human activities in the ocean while they provide goods and services (Ansong *et al.*, 2017; Borja *et al.*, 2010).

- **Decision Support Tools**

In this context, the development and implementation of decision support tools (DSTs) can assist planners, decision makers, industry and investors in order to implement ecosystem-based maritime spatial planning (EB-MSP) (Ansong *et al.*, 2017). Among the various definitions of DSTs, the following was agreed upon for the purposes of this thesis: DSTs are software-based intermediaries that provide support in an evidence-based, decision making process (Rose *et al.*, 2016). These tools and approaches were used in several cases to integrate economic, environmental and social dimensions of ocean, as required in EB-MSP processes (Stelzenmüller *et al.*, 2013b). They can be used for several purposes in MSP processes such as site identification, environmental assessment, communication, databases or stakeholder engagement platforms. These fully computerized or human-powered tools were recently used by managers/authorities, decision makers, NGOs, scientists and academy (Janßen *et al.*, 2019). Based on its vital characteristics and functionalities, it is necessary to investigate how DSTs were applied to support planners in the plan development, in an objective, efficient, and fast manner.

According to existing review studies, decision makers benefit these mechanisms to assist the planning processes (Janßen *et al.*, 2019). However, their application processes and detailed benefit of tool outcomes not explicitly described in available MSP reports. There are many tools and approaches explained in scientific literature and databases, in contrast it is hard to find direct evidences of their application by authorities or planners. This uncertainty on application and outcomes of the tools, make it essential to study the demand side of the equation, integrate end user opinions to existing review efforts and clarify requirements of DSTs from primary sources. It is significant to analyse the variety of end user profiles engaged in the different MSP processes and collect their opinions in terms of satisfaction, required tool capabilities and future expectations.

- **Blue Growth and Offshore Wind Farms**

Besides directives, European Union supports sustainable growth of maritime sectors by Blue Growth strategy (European Union, 2012). The Blue Growth strategy/initiative aims to achieve smart, sustainable and inclusive growth of activities with complete contribution of ocean-based economies (FAO, 2013; Rodríguez-Rodríguez *et al.*, 2016). According to FAO's definition, Blue Growth should focus on maximizing profit and production, maximizing environmental sustainability and benefits and livelihoods has traditionally not been prioritized. In Europe, Blue Growth has taken as a maritime strategy by EU Maritime Affairs as a part of Europe 2020 goals (European Commision, 2017a). This strategy has three components:

1) Develop sectors that have a high potential for sustainable jobs and growth, such as: aquaculture, coastal tourism, marine biotechnology, ocean energy and seabed mining.

2) Essential components to provide knowledge, legal certainty and security in the blue economy:
    - Marine knowledge to improve access to information about the sea,
    - Maritime spatial planning to ensure an efficient and sustainable management of activities at sea,
    - Integrated maritime surveillance to give authorities a better picture of what is happening at sea.
3) Sea basin strategies to ensure tailor-made measures and to foster cooperation between countries.

Concepts of blue economy and corresponding Blue Growth caused several debates in terms of the possibility of economic growth and maintenance of the natural assets at the same time (Frazão Santos *et al.*, 2014). Recent studies have addressed this issue and analysed weak and strong sustainability under the concept of Blue Growth (Eikeset *et al.*, 2018; Rickels *et al.*, 2019).

Among other Blue Growth activities, offshore renewable energy is the fastest growing activity in the blue economy. As it was mentioned in MSPD, plans should be coherent with the timetables set out in other relevant legislation such as Directive 2009/28/EC on the promotion of the use of energy from renewable sources (European Union, 2009), and Decision No 884/2004/EC, which requires that the trans-European transport network be established by 2020. Renewable energy sector was considered as an environmentally friendly solution to increasing energy demand of societies. International and national energy policies and agreements are promoting these new devices in order to reduce the negative environmental impacts from traditional energy production methods (Michaelides, 2012). Critically, offshore wind energy production has experienced an annual growth of 101% in 2017 in Europe, further, it is expected to see an increasing production trend with the promotion of Blue Growth (FAO, 2013), and provide up to 560,000 jobs in 2030 (WindEurope, 2017). In contrast to this growth expectations in the sector, the installation of wind farms is constrained to a set of factors that limits their technical and economic viability (Weiss *et al.*, 2018). Conditions of bathymetry and feasibility of wind platforms in deep sea areas, aesthetic problems with coastal societies, suitable seafloor habitats, uncertain environmental pressures and conflicts with existing human activities make it essential to perform an efficient and integrated planning process of wind energy platforms to consider complex conditions (Göke and Lamp, 2012). Similar to offshore wind platforms, other maritime activities such as fishing, shipping or marine protected areas (MPA) requires continuous, iterative, and adaptive participatory spatial planning processes to achieve sustainable growth. These processes frequently require planners to specify spatial and temporal boundaries, map important areas, identify spatial conflicts of use, define scenarios, and design management actions at different stages of the MSP implementation process.

- **Transboundary characteristics of MSP**

MSPD and MSFD require Member States to take into account enhanced cross-border cooperation in order to consult and coordinate plans with related Member States in the marine region. Although MSPD requires a national transposition, transnational coordination is required to ensure national plans, within a regional sea, are coherent and do not contradict each other (Article 11). This cooperation can be pursued by (i) existing regional institutional cooperation structures such as Regional Sea Conventions; and/or (ii) networks or structures of Member States' competent authorities; and/or (iii) any other method such as in the context of sea-basin strategies. In this context, Member States should consult and coordinate their plans with the relevant Member States and should cooperate with third-country authorities in the marine region concerned in conformity with the rights and obligations of those Member States and of the third countries concerned under Union and international law (Recital 20). In the environmental context, MSFD also requires the cooperation of Member States to ensure the coordinated development of marine strategies for each marine region or subregion (Article 6). For the purpose of establishing and implementing these marine strategies, Member States shall, within each marine region or subregion, make every effort, using relevant international forums, including mechanisms and structures of Regional Sea Conventions (Article 6).

As an important regional unit, the Bay of Biscay represents an interesting area for such cooperation. The Bay is bordered by two EU Member States, Spain and France. The region was named as Bay of Biscay and Iberian coasts in MSFD ecoregion list (Borja *et al.*, 2019a). It hosts important ecosystem components to life such as plankton, vital seafloor habitats as spawning and feeding grounds for several fish species, as well as mammals and sea birds (Pascual *et al.*, 2011). Several maritime activities take place in the bay including shipping (with important commercial harbours, e.g. Bordeaux, Bilbao, Gijón, Brest), fishing (both pelagic and demersal, including recreational, traditional and industrial fishing), tourism, coastal discharges and dredged sediment disposal. Both Spain and France took important actions in marine governance with regards to their national marine policies, EU policies and regional bodies such as Atlantic Commission and OSPAR Convention. At the moment, Maritime Spatial Plans are not in place, however, both countries have adapted MSPD to their national legislation, defined responsible authorities for MSPD and started planning processes taking MSFD as a base directive. “Royal Decree 363/2017 of 8 April, establishing a framework for the management of maritime space” in Spain, and article 123 of law n° 2016-1087 for the 2^{nd} “reconquest of biodiversity, nature and landscapes” in France represent the legal foundation of MSPD. Since MSPD asks Member States to take into account enhanced cross-border cooperation and coordinate plans with related Member States in the marine region, it is significant to realize cooperation of Spain and France in the region to reach sustainable and efficient plans in both countries (European Union, 2014).

Hypothesis and objectives

Hypothesis

According to the context and information previously presented, the hypothesis is that "the decision support tools can be applied based on requirements of planning processes, and end-users' opinions to achieve ecosystem-based management plans considering economic, ecologic, and social dynamics and transboundary characteristics of marine environment".

Objectives

To confirm or refute the above-mentioned hypothesis four objectives have been defined:

1. To characterize and analyse the present use of the DSTs in existing MSP implementation processes, to identify weaknesses and gaps of existing tools, and to propose new functionalities both to improve their applicability and to promote their application.
2. To capture and analyse DST end-user perceptions on their applications in MSP processes to draw recommendations and to give insights for future developments.
3. To develop a model that integrates most relevant economic, environmental and social components to identify feasible areas and future scenarios for offshore wind farms and to apply it in different case study areas.
4. To identify the key issues and challenges in order to raise recommendations for a transboundary EB-MSP in the Bay of Biscay based on a holistic vision of economic, environmental and social settings, and present management practices.

The results responding to each specific objective were presented in four chapters (Figure 1). In the general discussion, the results of the partial analyses have been combined in order to perform an integrated understanding of tendencies in DSTs, end-users' opinions, tool application processes and MSP requirements, to refute or confirm the hypothesis.

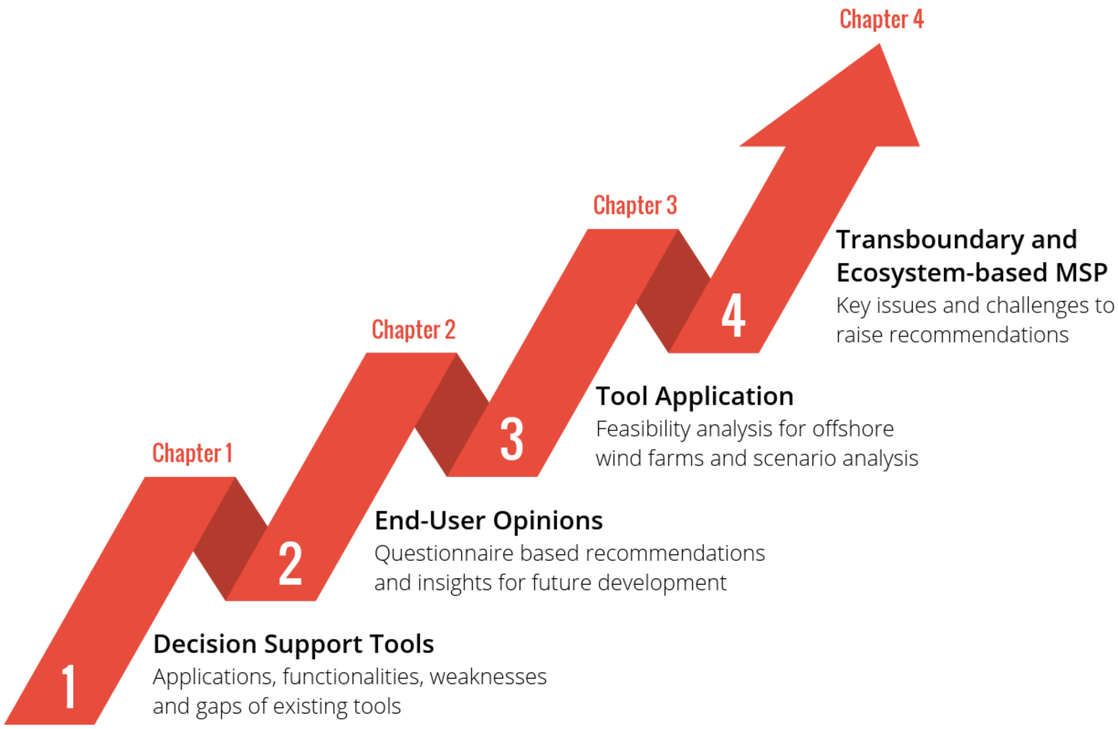


Figure 1: Thesis structure and the main topics tackled in each chapter. MSP: Maritime Spatial Planning.

CHAPTER 1

Decision support tools in marine spatial planning: present applications, gaps and future perspectives

PUBLISHED AS

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1. Introduction

Due to the present and future demand for marine resources, human activities in the marine environment are expected to increase, which will produce higher pressures on marine ecosystems, as well as competition and conflicts among marine users (Burgess *et al.*, 2018; Gee *et al.*, 2011; Halpern *et al.*, 2008; Uusitalo *et al.*, 2016). This fact highlights the need for new management approaches, synergies, transnational coordination, visions, and actions (Gee *et al.*, 2011). At present, MSP is considered as a promising management approach to transform conflicts into solutions, when managing multiple activities and users at sea (Domínguez-Tejo *et al.*, 2016). MSP aims to balance the development of maritime activities and increase cross-border cooperation through transparency, clearer legislation, better coordination between administrations, and the early identification of impacts that can arise from the multiple uses of marine space (European Union, 2014). Thus, MSP is a public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process (Ehler and Douvere, 2007; Foley *et al.*, 2010; Rodríguez-Rodríguez *et al.*, 2016). In addition, the widely accepted management philosophy of MSP is ecosystem-based management, which strives to support healthy and productive marine ecosystems (Borja *et al.*, 2016; Borja *et al.*, 2010; Katsanevakis *et al.*, 2011; Stelzenmüller *et al.*, 2013a). Ecosystem-based MSP covers effective implementation of ecosystem management frameworks in planning processes and focuses on achieving sustainable management of marine resources (Domínguez-Tejo *et al.*, 2016). This approach enhances other responsibilities and activities to reach sustainable development. Despite the limitations and questionable aspects, MSP has been already implemented in many countries around the world (Collie *et al.*, 2013).

One of the earliest examples of MSP was the plan developed for the Great Barrier Reef Marine Park in Australia (Kemp, 2003). Since 1975, initial zoning plans have been produced for concerns about oil and gas exploration, limestone mining, overfishing and environmental protection. The United States is another pioneer country in MSP. In 2013, the federal government provided a policy guidance framework: National Policy for the Stewardship of the Ocean, Coasts, and Great Lakes (National Ocean Council, 2013). Additionally, responsible authorities of several states (Oregon, Massachusetts and Rhode Island) have planned the human use of their marine space within their marine waters (three nautical miles of the coast). One of the most well-known MSP cases in United States is the state of Rhode Island, which used a previously-existing federal law as a legal framework for policy guidance: the Coastal Zone Management Act of 1972 (Olsen *et al.*, 2014b). The Massachusetts Ocean Management Plan has been revised and re-published recently (Executive Office of Energy and Environmental Affairs, 2015). In Asia, China has implemented the National Marine Functional Zoning Scheme for the period from 2001 to 2020 (Feng *et al.*, 2016). A pilot project, the Israel Marine Plan, was completed in November, 2015 (Israel Institute of Technology, 2015). At the European scale, the Maritime Spatial Planning directive (European Union, 2014) is legally binding for Member States to complete their maritime spatial plans by 2021. In this legislation, the European Commission and DG MARE use the term "maritime spatial planning" to underline the holistic and cross-sectorial nature of MSP and to differentiate their work from that of the environmentally-oriented authority, DG Environment (*in this paper we use both terms with the acronym of MSP).

Several countries in Northern Europe, such as Germany, Norway, Belgium, and the Netherlands have already implemented their plans (Belgian Royal Decree, 2014; Bundesamt für Seeschifffahrt und Hydrographie, 2009a,b; Ministry of Infrastructure and the Environment, 2015; Olsen *et al.*, 2007). Furthermore, some eastern European countries such as Lithuania, Poland and Latvia have quite advanced MSP achievements (Zaucha *et al.*, 2014). Apart from the political initiatives, research projects are also contributing significantly to different aspects of the MSP development and implementation. The main objectives of such projects have been to provide knowledge, science-based approaches and tools to improve the capacity of countries and to support the implementation of MSP. Many projects have developed analytical frameworks, guidelines, and recommendations for countries that are initiating MSP (Buhl-Mortensen *et al.*, 2016; Schultz-Zehden and Gee, 2016; Schultz-Zehden and Kira, 2015; Schultz-Zehdenn and Kira, 2013; Stelzenmüller *et al.*, 2013a; Zaucha *et al.*, 2014).

During these MSP processes, experiences have demonstrated that marine spatial planning should be a continuous, iterative, and adaptive participatory process, comprising a set of actions including research, analysis and planning, financing, implementation, monitoring, and evaluation of the plan. It has been stated that all of these individual functions must be carried out for successful management (Buhl-Mortensen *et al.*, 2016; Ehler, 2008; Stelzenmüller *et al.*, 2013a). This process frequently requires planners to undertake essential tasks, such as specifying spatial and temporal boundaries, mapping important areas, identifying spatial conflicts of use, defining scenarios, and designing management actions at different stages of the MSP implementation process (Ehler and Douvere, 2009). Moreover, it has been observed that DSTs can be used to simplify these tasks (Curtice *et al.*, 2012). The aforementioned characteristics of an MSP implementation process require decision making to achieve efficient and sustainable plans. In that sense, decision support tools (DSTs) are considered to be an important assistant in this process (Stelzenmüller *et al.*, 2013b). Considering the various definitions of DSTs, the following was agreed upon for the purposes of this paper. DSTs are software-based intermediaries that provide support in an evidence-based, decision making process (Rose *et al.*, 2016). Tools may help users, including managers (but also scientists, industry, or NGOs, among others), and support decision making. These tools can also be used for data and information transfer, analysis or storage (Rose *et al.*, 2016). They can be either fully computerised, human-powered or a combination of both (Curtice *et al.*, 2012; Rose *et al.*, 2016). Based on these characteristics and functionalities, DSTs can be considered as important intermediaries to help planners in the management plan development, in an objective, efficient, and fast manner (Rose *et al.*, 2016). With the help of these tools, support for decision making could be undertaken in a more systematic and objective manner. Hence, DSTs can be used to support decision making processes and alternative management plan development, including ecosystem-based MSP.

Previous studies have focused on DSTs and their role in MSP. These studies described a selected number of tools in specific case studies by using workshops as a bottom-up source for tool functionality requirements (Coleman *et al.*, 2011; Kannen *et al.*, 2016; Stelzenmüller *et al.*, 2013b). There are also web databases on DSTs that can be used at different stages of the MSP implementation process steps (e.g. MESMA: http://mesmacentralexchange.eu/tools.html and EBM Research Network: https://ebmtoolsdatabase.org). Despite the wide range of DSTs for different purposes, reported uses in MSP process are limited. Tool databases list approaches that could be classified as DSTs according to their nature, but many of them are conceptual and not used in real MSP implementation (Collie *et al.*, 2013). Hence, this indicates that there is a significant need for DST development and improvement to fulfil the expectations and functionality requirements of planners in the planning process. As a result, existing research needs to be updated and a broader review is required. Thus, this research aims to: (i) characterize and analyse the present use of the DSTs in existing MSP implementation processes, (ii) identify weaknesses and gaps of existing tools, and (iii) propose new functionalities both to improve their applicability and to promote their application.

2. Methods

A comprehensive review of the use of DSTs in international, national and local MSP implementation experiences around the world was performed (Table 1). Main characteristics of the tools were transferred into a comprehensive DST matrix.

The UNESCO MSP reference list (http://msp.ioc-unesco.org) was used to select MSP examples. At the European scale, the European MSP Platform (http://www.msp-platform.eu/) was used to understand the current status of EU Member States. While multiple websites of planning authorities were consulted to characterise management plans, technical reports were used to understand the general role of DSTs in the planning processes along with the aim of use and technical characteristics. As not all management and technical reports mentioned DSTs, related websites and scientific articles were systematically screened. In addition, EU projects related to MSP were considered to track the tool production and their use in the planning process. This research was conducted between April 2016 and February 2017.

Table 1. Reviewed Marine Spatial Planning experiences for Decision Support Tools identification and application analysis; MPA: Marine Protected Area.

Scale	Plan/Initiative name	Reference
International	BaltSeaPlan	Fetissov *et al.* (2011), Göke and Lamp (2012), A. Schultz-Zehdenn Jörg and Lamp (2012); (Schultz-Zehdenn and Kira, 2013)
International	Trilateral Wadden Sea Plan	Common Wadden Sea Secretariat (2010)
National	China Territorial Sea zoning	Feng *et al.* (2016)
National	Barbuda Blue Halo	SeaSketch: http://www.seasketch.org/projects
National	New Belgium Marine Spatial Plan (2014)	Belgian Royal Decree (2014)
National	Germany Spatial Plan for North Sea and Baltic Sea	BFN (2006), (Bundesamt für Seeschifffahrt und Hydrographie, 2009a,b)
National	Israel Marine Spatial Plan Pilot	Israel Institute of Technology (2015)
National	The Netherlands National Water Plan	Ministry of Infrastructure and the Environment (2015)
Local	Rezoning of the Great Barrier Reef Marine Park	Kemp (2003)
Local	Habitat Risk Assessment Module: Belize Case	Rosenthal *et al.* (2012)
Local	Eastern Scotian Shelf Integrated Ocean Management Plan (ESSIM)	ESSIM Planning Office (2007) SeaSketch: http://www.seasketch.org/projects/
Local	Galapagos Marine Reserve Zoning, Ecuador	Direction of the Galapagos National Park (1998)
Local	Sea Change, Hauraki Gulf New Zealand	SeaSketch: http://www.seasketch.org/projects
Local	Integrated Management of the Marine Environment of the Barents Sea and the Sea Areas off the Lofoten Islands	Norwegian Ministry of the Environment (2012)
Local	Irish Sea Pilot Project	Kidd (2013), Kidd and McGowan (2013), Vincent (2004)
Local	MPAs in the Channel Islands National Marine Sanctuary	Airamé *et al.* (2003)
Local	Gulf of Mexico	Beck and Odaya (2001)
Local	Massachusetts Ocean Plan	MassGIS (http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/) MORIS (http://www.mass.gov/eea/agencies/czm/program-areas/mapping-and-data-management/moris) North East Ocean Data (http://www.northeastoceandata.org/) Altman *et al.* (2012)
Local	Channel Islands National Marine Sanctuary Education and Outreach Platform	SeaSketch: http://www.seasketch.org/projects
Local	Washington Marine Spatial Plan	SeaSketch: http://www.seasketch.org/projects
EU Project	BONUS BALTSPACE Project	(Kannen *et al.*, 2016), SeaSketch: http://www.seasketch.org/projects
EU Project	PartiSEApate Project	http://www.partiseapate.eu/

Scale	Plan/Initiative name	Reference
EU Project	Vectors Project: Ecosystem Model	http://www.marine-vectors.eu/
EU Project	Coexist Project	Coexist: http://www.coexistproject.eu/coexist-results/tool
EU Project	MASPNOSE Project - Maritime Spatial Planning (MSP) in the North Sea	https://www.wur.nl/en/show/maspnose-maritime-spatial-planning-in-the-North-Sea.htm
EU Project	AquaCross Project: Trade Off´s in Ecosystem Based Fisheries in the North Sea	AquaCross Website: http://aquacross.eu
EU Project	BALANCE – Baltic Sea Management – Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning	Andersson *et al.* (2008)
EU Project	ADRIPLAN: Adriatic Ionian Maritime Spatial Planning	Barbanti (2015), Menegon *et al.* (2016) ADRIPLAN Website: http://adriplan.eu/
EU Project	MESMA: Monitoring and evaluation of spatially managed marine areas	Buhl-Mortensen *et al.* (2016)

2.1. MSP stages

Seven different stages of the MSP process were defined after reviewing the ones proposed by Coleman *et al.* (2011), Ehler and Douvere (2009), and Stelzenmüller *et al.* (2013b):

i. Define goals and objectives
ii. Gather data and define current conditions
iii. Identify issues, constraints, and future conditions
iv. Develop alternative management actions
v. Evaluate alternative management actions
vi. Monitor and evaluate management actions
vii. Refine goals, objectives and management actions

Each of the analysed DSTs was assigned to one of those stages according to its functionality. The application of the tool in more than one of the aforementioned MSP stages was also taken into account.

2.2. General characteristics

These fields refer to general information related to the specific MSP initiatives, including country, aim of use, spatial scale, year, and references. The aim of use field listed the main uses that were reported in the case studies. Since there were multi-functional DSTs, this field contained one or more aims for each tool. The following application categories were defined: (1) environmental impact assessment, (2) communication, (3) data gathering, (4) economic analysis, (5) evaluation, (6) governance assistance, (7) management plan proposal, (8) scenario creation and analysis, (9) site identification, (10) socio-economic analysis, and (11) uses conflict analysis. Besides this general categorization, the field "specific aim" defined more detailed tool functions and capabilities. If an existing tool was used in a MSP initiative or a new tool was produced specifically for the plan, this information was listed in the "Existing/Produced" field.

2.3. Technical characteristics

DSTs were categorized according to their technical characteristics. The type of information used as input for the DST was identified for each. These inputs were broadly grouped into three categories, represented in MSP frameworks (Ehler and Douvere, 2009; Zaucha *et al.*, 2014): environmental, economic, or social data. Tools were listed according to their technical classification as qualitative, quantitative, spatially explicit and temporally explicit. The prerequisites to run specific software were defined for each tool (i.e., geographic information system (GIS) software, LAN or server connection, Microsoft Excel, etc.). Further, the output data of each tool were identified. In addition, types of the tools were recorded in different categories (toolbox, website, web-based application, add-in, etc.).

2.4. User fields

The user field includes user skills (skills needed to operate tools such as GIS or modelling), user groups (i.e., authorities, general public, marine users, NGO's, planners, and scientists) and cost of DSTs.

3. Results

The results given were extracted from the DST matrix as a result of the review that is publicly available in http://dst.azti.es. A review of 34 DSTs from 29 MSP experiences can be found in the matrix.

3.1 Present application of DST in MSP

Classification of DSTs according to MSP stages showed that 5% of tools are dedicated to defining goals and objectives (Stage i of the MSP process) (Figure 2). The majority (57%) of the identified DSTs were used for gathering data, defining current situation and identification of issues, constraints, and future conditions (Stages ii and iii). Moreover, 16% of the tools were used for the development of alternative management actions (Stage iv). Among first four stages, 7% of DSTs were dedicated to evaluate alternative management actions (Stage v), 10% of DSTs were used in monitoring and evaluation of management action (Stage vi) and just 5% of DSTs were applied to refine goals and objectives (Stage vii).

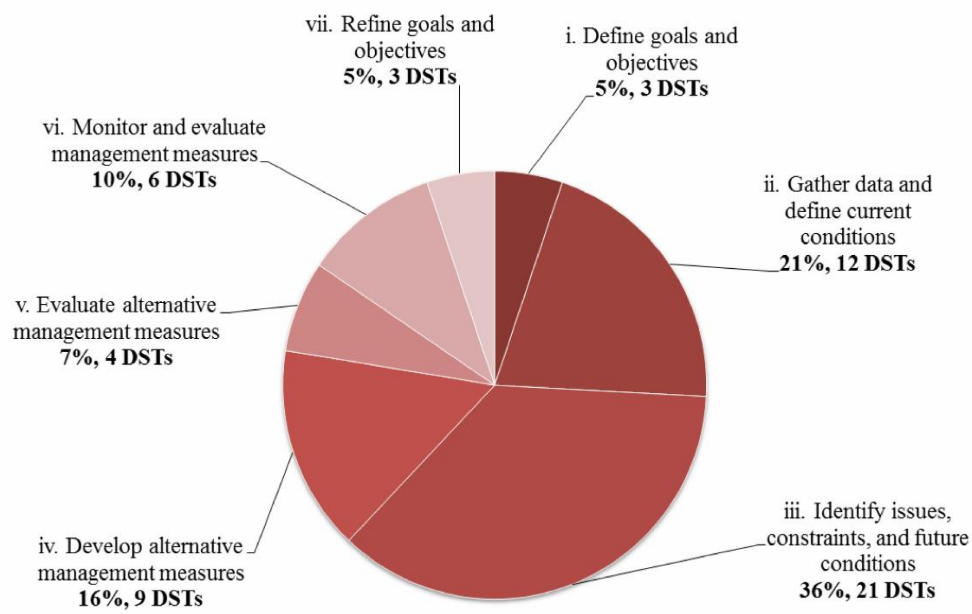

Figure 2: Percentage and number of the total of Decision Support Tools (DST) used at different stages of Marine Spatial Planning process (see Section 2.1 for the definition of MSP stages).

3.2 Purpose of use

The principal purpose of use of DSTs was site identification (21% of DSTs). In eight different experiences (i.e., 16% of the total), DSTs were used to assess environmental impact of marine activities (e.g. InVEST, Marxan). Communication was the third most common purpose of the DST use (14% of the total). Interactive platforms, web-based maps, communication lists, databases and other practical tools were used for interaction between planners and stakeholders (e.g., SeaSketch, etc.). In each of the seven cases, a new DST was created to communicate with stakeholders, and most of them were web-based. The next most frequent purpose of use (12% of cases) was scenario creation and analysis (Figure 3).

The reviewed DSTs were also used in MSP for data gathering, economic analysis, management plan proposal, socio-economic analysis, and governance assistance purposes (see DST matrix online (http://dst.azti.es) for the specific tools cited here).

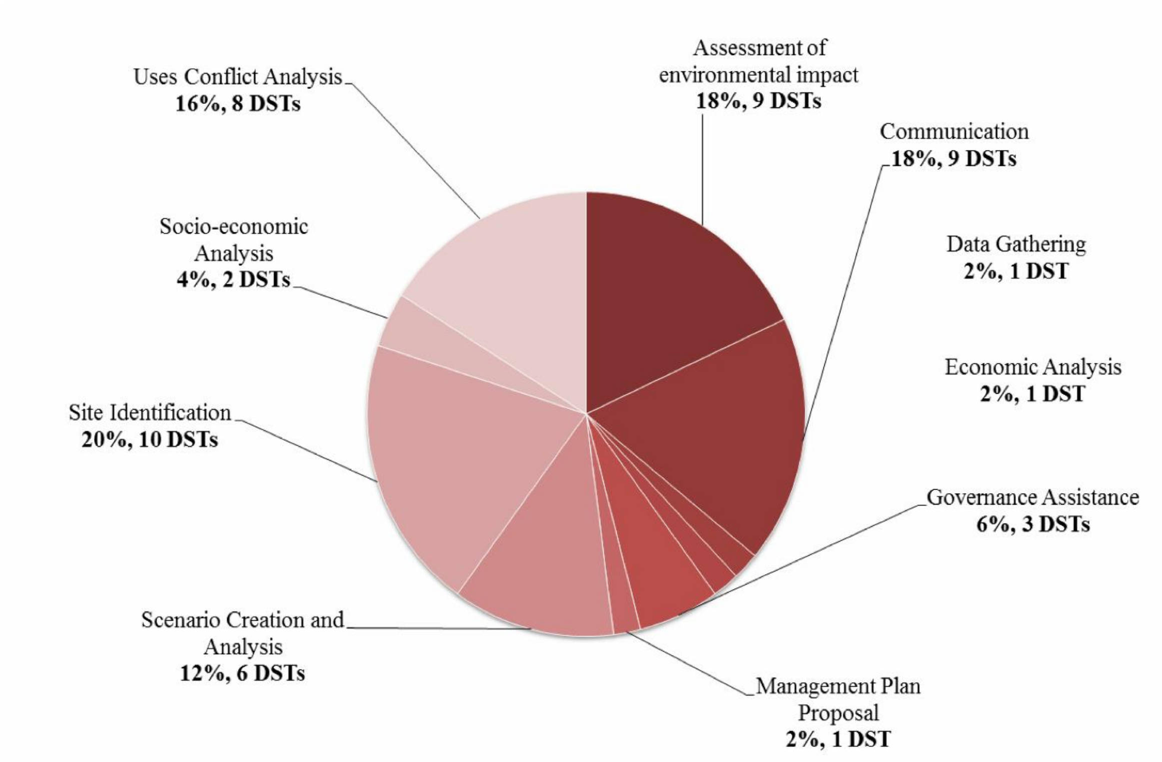

Figure 3: Purpose of use for Decision Support Tools (DST) (percentage and number of the total number of cases) within Marine Spatial Planning process.

3.3 Type of users

DSTs were used by six different types of users in MSP processes. Most of the users were planners (47% of all tool users) followed by marine users (24% of the total users) (Figure 4). Approximately a third of the tools required the user to employ GIS skills. On the other hand, some ecosystem-related tools (i.e. Artificial Intelligence for Ecosystem Services and Atlantis), require additional modelling skills. In 14 cases (48%), planners used tools that could have been applied with basic computer skills.

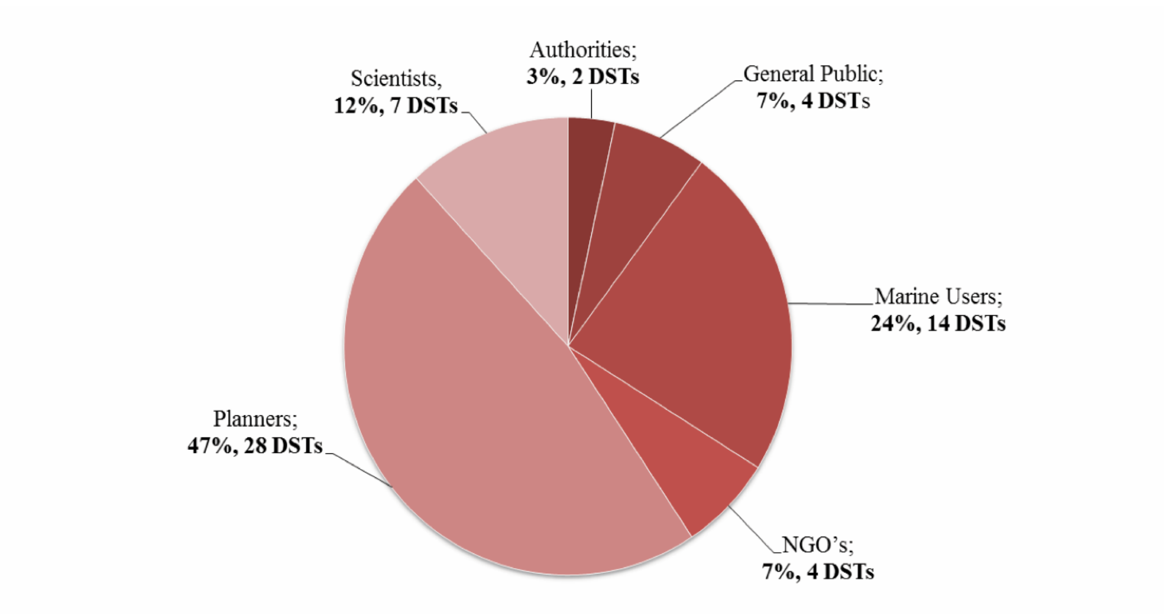

Figure 4: Percentages number and of different type of Decision Support Tools (DST) users.

3.4 Technical characteristics

Most of the DSTs were spatially explicit (68%) including mapping and visualisation tools. Mapping tools and visualisation options can. In contrast, just 16% of tools were temporally explicit. This result was in parallel with a low number of scenario creations and analysis tools (12%). In total, 56% of tools were dedicated to environmental data processing, with a smaller number of tools dedicated to process economic and social data (22% and 22%; respectively). Although economic data were taken into account in ten different cases, there was just one tool that was used for economic analysis purposes (Dorset Coastal Explorer Planning).

A total of 84% of tools used quantitative input data in decision support process and only 16% of tools used qualitative data as input. In terms of type of tool, 46% of all tools were stand-alone tools and 29% of tools were websites. GIS-based tools, add-ins, toolboxes and web-based applications were representing just 14% of all tools that were found in research.

3.5 Cross-cutting characteristics of DSTs

Diversification of aims of use according to MSP stages was identified (Figure 5). These results showed that MSP initiatives used DSTs in the same stage and for the same purposes. This analysis demonstrated the lack of DSTs used for data gathering, economic analysis, governance assistant and scenario creation and analysis. DSTs were not used for data gathering, socio-economic analysis, and governance assistance in many MSP stages. In contrast, DSTs used for communication and site identification were distributed throughout all MSP stages.

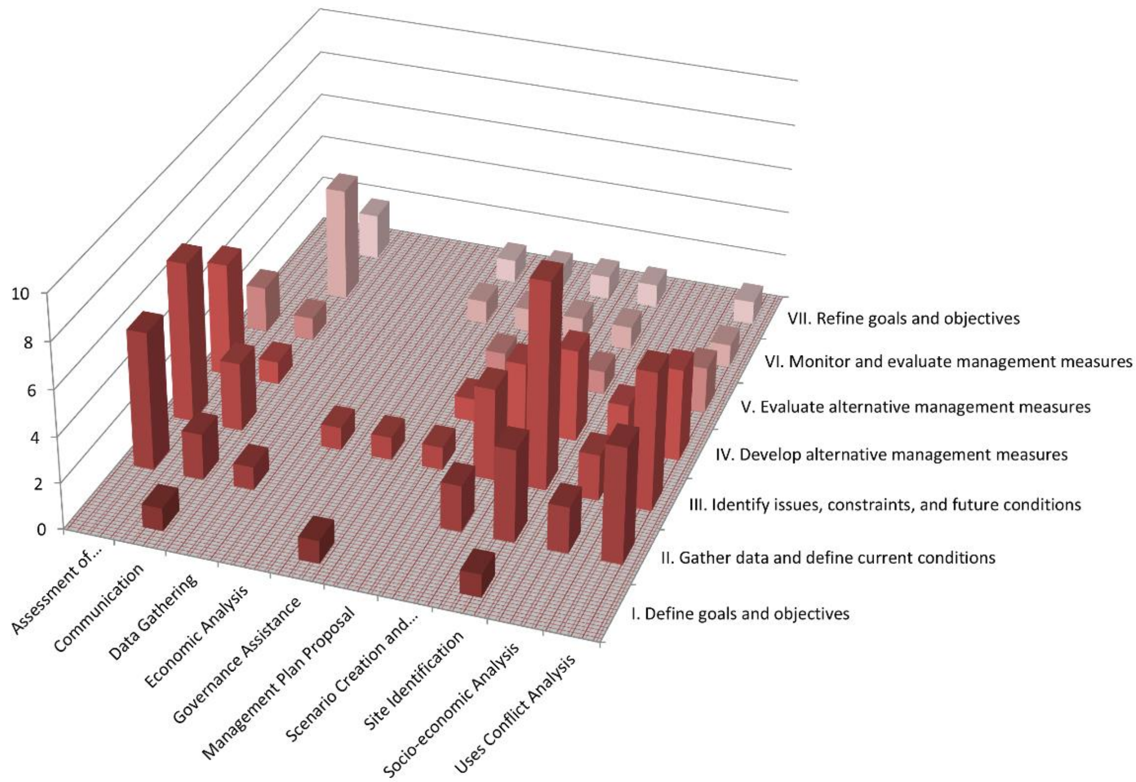

Figure 5: Aim of use of Decision Support Tools at each Marine Spatial Planning stage (see Section 2.1 for the definition of MSP stages).

According to an analysis of user groups in different MSP stages, planners were actively involved in most of the MSP stages (Figure 6). Planners were able to apply 14 DSTs in stage iii and nine DSTs in stage ii. On the other hand, scientists were observed as the user group in stage iv ‘‘development of alternative management actions’’ and in stage v ‘‘evaluation of alternative management actions’’. DSTs for marine users were mostly employed in stage vi ‘‘monitoring and evaluating management actions’’. These results revealed a scarcity of DSTs used by authorities and the general public.

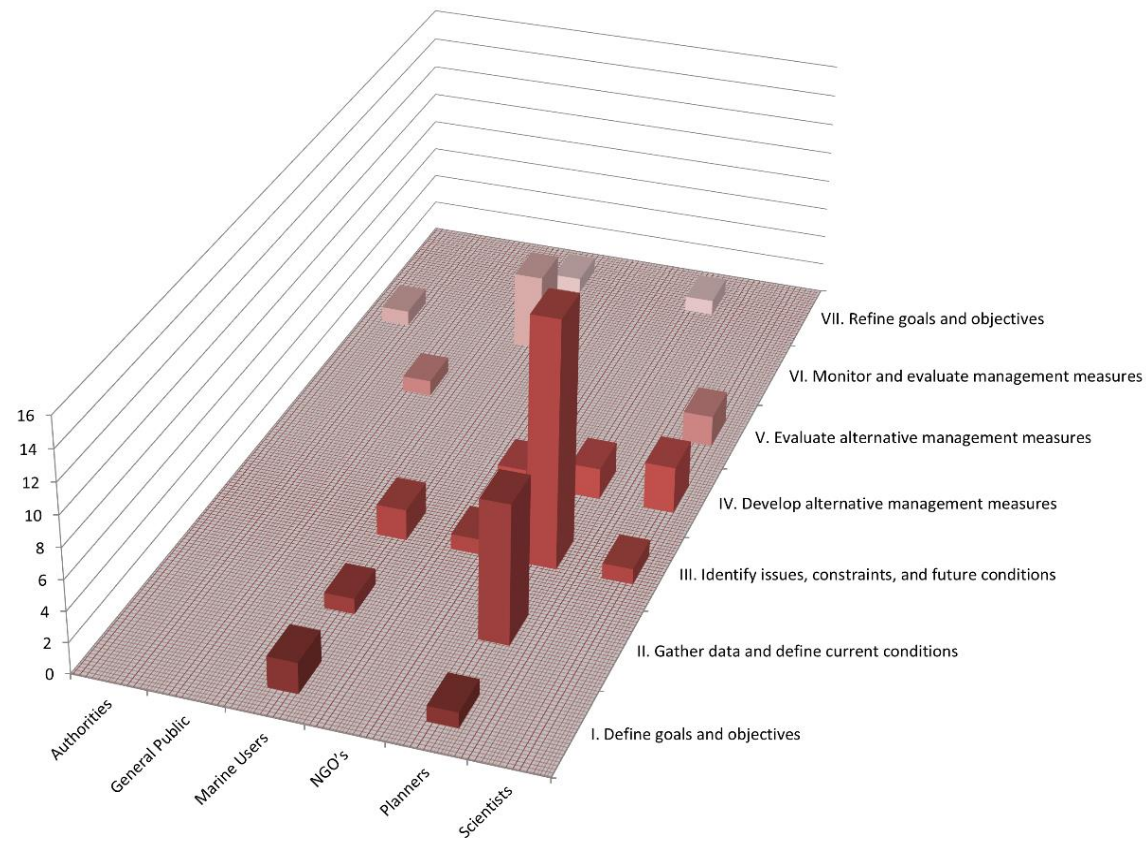

Figure 6: Diversity of user types at different Marine Spatial Planning stages (see Section 2.1 for the definition of MSP stages).

4. Discussion

This study reviewed DSTs that were used in MSP processes, and analysed their characteristics that vary according to MSP stages in which they have been used, the specific purpose of their use, their technical characteristics and user profiles. Experiences from existing MSP initiatives showed the necessary development for DSTs to satisfy the needs of the MSP process. The considerations in this section refer to the outcomes abovementioned and open source initiatives; therefore, they may have another interpretation or valuation in the real planning process.

4.1 Experiences in the applications of DSTs in the MSP process

Even if there is general agreement on the usefulness of DSTs in plan development, there are many plans that did not use DSTs. Since marine spatial plans are created to help society adapt to change, DSTs can be considered as a part of the plan or aid to planners. As a result of this, their real application is not evident. It was observed that usage of DSTs is not explicitly cited in MSP reports (Belgian Royal Decree, 2014; Bundesamt für Seeschifffahrt und Hydrographie, 2009a,b; Kidd, 2013; Kidd and McGowan, 2013), whereas pilot projects are more DST-friendly due to less time pressure and financial resources from external institutions. Pilot projects allow testing many different approaches. On the contrary, real MSP processes are rapid, output-oriented, in many times authority-driven with limited financial resources (Zaucha *et al.*, 2014). On the other hand, one must also take into account that management plans will not rely solely on outputs of DSTs, and that these plans will be developed by different approaches and expert knowledge (Stelzenmüller *et al.*, 2015). Thus, it could be expected that the use of DSTs could be undertaken at different stages and on a very informative level.

Results revealed that the majority of DSTs were used in the first stages of the MSP process. These stages include the tasks of gathering data, defining the current situation and the identification of issues, constraints, and future conditions. Ehler and Douvere (2009) defined collecting and collating spatially-explicit databases as the most time consuming aspect of planning activities. The current situation analysis of a planning area highlights the direction of next planning stages. The outputs of tasks undertaken in the initial stages of the MSP process feed the development and evaluation stages of management plans. The use of DSTs in the first stages of the MSP process reflects the current level of the MSP process around the world. Even though MSP is not a new concept, its real implementation is in progress and at an early stage in many countries. It could be expected that the development of new tools will be needed for future stages (i.e., evaluation, monitoring and refining goals and objectives).

Furthermore, it can be observed that planners drew on assistance of DSTs for site identification in the initial stages of MSP implementation process. In this sense, DSTs were used by planners to analyse large amounts of data, to visualise current spatial allocation of marine activities, and to perform integrated suitability analysis. As a part of integrated suitability analysis, DSTs were also used in the initial stages of MSP to identify existing human activities that could create conflicts (ESSIM Planning Office, 2007; Menegon *et al.*, 2016). Sustainable and precise spatial allocation is an important task that can help balance high competition for limited marine space between sectorial interests (Galparsoro *et al.*, 2012). In addition to using DSTs for site identification of a certain human activity, planners also used DSTs to assess the environmental impact generated by the uses on the environmental components in current and future scenarios (Barbanti, 2015; ESSIM Planning Office, 2007; Glaas *et al.*, 2017; Rosenthal *et al.*, 2012). DSTs were used to see actual or potential effects of planned activities on adjacent and other ecosystems (Menegon *et al.*, 2016).

Among others, one extended use of these tools was to identify suitable areas for declaring MPA, as well as for the establishment of renewable energy production platforms (Göke and Lamp, 2012; Jörg and Lamp, 2012; Watts *et al.*, 2009). In this context, DSTs were used to achieve conservation targets for MPA identification, and to seek energy production targets for renewable energy platforms. In terms of particular species, ecosystems, or processes and hence, for humans (i.e. delivering ecosystem services), some parts of the sea have much greater importance than others (Costanza *et al.*, 2014). As in land planning, the 'real estate value' varies greatly in the sea space (Ehler and Douvere, 2009). Experiences showed that DSTs were helpful to fulfil predefined environmental targets and to see which locations were compatible with development of new human activities, which is central to the art of MSP.

Tools dedicated to communication were used mostly in the last stages of MSP (i.e., monitor and evaluate management measures) (Fetissov *et al.*, 2011; Vincent, 2004). Unfortunately, there are few DSTs dedicated to eliciting the opinion of stakeholders in the beginning stages of the MSP process. In contrast, identified tools were able to provide advanced collaboration and engagement options, as well as analytical feedback about planned areas. Online communication tools can increase transparency and collaboration in the MSP process through the involvement of stakeholders' opinions (i.e., Belgium North Sea Atlas: www.noordzeeatlas.nl). Using communication-focused DSTs in the beginning stages of the MSP process could allow stakeholders to share their opinions of potential outcomes early on. Stakeholder participation is a requirement for community-based and adaptive management from the early planning stages. Stakeholders may give a better understanding of issues and conflicts through participation in the co-design and co-development of management plans (Newton and Elliott, 2016).

4.2 Current gaps of Decision Support Tools

Functionality gaps of existing tools and the requirements within the MSP process can highlight the future development of DSTs. Fulfilment of these gaps related to tool functionality, MSP stages, maintenance, and complexity of use would help tool developers satisfy the requirements of MSP process.

As compared to other reasons, limited functionality could be considered as the main reason for the infrequent usage of DSTs. Planners may need to use more than one tool for the tasks in a single stage as a result of limited functionality. This observation highlights the need for integrated and multi-functional tools. Furthermore, recognised tool functions are mostly focused on specific purposes, such as site identification and environmental assessment. Only a few tools offer future projection, socio-economic analysis, and stakeholder engagement. These are the functions expected to be needed in future stages like plan monitoring, evaluation and adaptation. In addition to deficiencies of the tools, the limited use of DSTs can also be caused by a lack of demand from the MSP side or a lack of awareness of the available tools that could support the planning tasks. We recognize that this assumption requires screening of the demand side and opinions of marine spatial planners and stakeholders.

As mentioned earlier, tool functions are mainly used for the early stages of MSP. Besides, the use of tools for the evaluation of management actions, monitoring, and refinement of goals / objectives is limited today. Assistance of DSTs is weak in these later stages. The provision of tools that help monitor implemented plans and collect opinions from stakeholders is essential. Fulfilment of these gaps may increase the usage frequency of DSTs in further stages of the MSP process. These future expectations should be considered by planners because the life-cycles of DSTs are directly dependent on their demand and usage. As a result of low-frequency tool usage, many developed DSTs are not available anymore or given sources are not active. These tools have mostly remained as scientific experiences and disappeared. Maintenance and stability of DSTs is one of the primary challenges of tool developers (Curtice *et al.*, 2012).

Although the MSP process should be focused on the balance of environmental, social and economic interests, DSTs were mostly used to assist in environmental issues. There are few DSTs that can support planners to solve economic and social issues in the MSP process. In Europe, diversity of socio-economic activities in marine areas is expected to increase (Ehler and Douvere, 2009). Thus, tool functions that can analyse economic and social data, in a balanced and integrative way, could have high relevance. For instance, stakeholder-focused DSTs can provide an opportunity for conflict identification and resolution, and also for the proposal of jointly designed solutions. Development of participatory DSTs may increase the ownership and ease of acceptance of management plans.

As these tools reach a wide range of user groups, one of the critical issues in their application is the technical skills needed for tool operation. GIS and modelling knowledge are often needed to apply DSTs. These skills bring the necessity of expert team members to use tools in MSP processes. The use of tools would become more popular if they are easy to use or user-friendly with simple interfaces/apps. Additionally, education and training should be a prerequisite to introducing a DST into the MSP process. The importance of educating and training non-technical users, including marine planners and stakeholders may be underestimated by DST developers and advocates.

Furthermore, cost is another important parameter that affects the degree of DST usage. Some of the tools require commercial licenses to execute. Accessibility of such tools should be free to achieve broader range of users. Especially for developing countries, the licence cost, data collection and labour costs for DST usage can limit MSP developments. In most cases, DSTs require a large amount of information, and the effort of collecting/organizing the data is often time-consuming. This activity can draw resources away from equally important tasks such as specifying clear and measurable objectives and management actions. One can observe examples where data portal developments became the principal output of MSP rather than a plan. Such time consuming and costly tasks have caused MSP initiatives to be finalized as data portals that put real planning actions off until the next round. (e.g. Mid-Atlantic Ocean Data Portal: http://portal.midatlanticocean.org/, Northeast Ocean Data: http://www.northeastoceandata.org/).

4.3 Future DST developments for MSP

Developments for DSTs should be parallel to the future needs of the MSP process. Since there are many countries in the initial stages of MSP, demand for DSTs for review and monitoring tasks may increase in the near future. Successful implementation requires a wide range of tasks and complex decisions. In this regard, it is necessary to aim for more attractive innovations and new strategies for the market. Development trends can be analysed from this perspective in parallel with the MSP process.

Firstly, DSTs should be more functional and integrative in order to assist present and future needs of MSP. Future projection, scenario analysis, plan review, monitoring, cost-benefit analysis and online participation functions can be foreseen as the future functionality needs of MSP. On the other hand, DSTs that can perform more than one function may have higher demand for complicated and multi-phased decision problems such as the spatial allocation of human activities affecting the marine environment. DSTs should address needs of decision makers for different kind of tasks that may be continuous given the dynamic nature of the sea.

In this sense, DSTs may be an important contribution for temporally explicit analysis. By considering the time dimension, potential future conflicts may be highlighted prior to their development. Historical data can highlight future patterns, and tools may use flexible input to change conditions for different objectives. For instance, DSTs should be able to run scenarios in which climate change, as well as human activities on the sea, will influence marine ecosystems (Glaas *et al.*, 2017). Since changes in sea level, air pressure and wind conditions are expected due to climate change, DSTs can help planners to foresee possible impacts. As a result of impacts on fisheries, marine traffic, aquaculture and other human activities, society will also be affected directly (Meiner and Reker, 2013). Therefore, DSTs can be useful to help society adapt to these changes in the geographical distribution of the marine ecosystem with a more sustainable MSP.

In contrast, tool innovations should focus social and economic concerns (Rice *et al.*, 2010). As an alternative to different techniques, computer-based tools can support planners to project economic effects of spatial decisions (European Union, 2014). In that sense, cost-benefit analysis may help planners to compare expected utility and possible impacts for economy and society. Planners can have a broader perspective if they can evaluate the opportunity cost of a spatial decision. In that sense, tools supporting bio-economic and socio-economic assessment in an integrative way may have great potential in the future.

Besides advanced functionality, financial and technical stability should be also maintained and DSTs should be sustainable. Tool developers should seek multiple revenue streams and ensure financial support (Curtice *et al.*, 2012). Although academia develops many tools, financial sources are not enough to maintain and host all of the DSTs that are created. It is recommended that responsible authorities establish a public funding system for maintenance of DSTs and project outputs. MSP tools developed by an academic project shouldn't have the same lifetime with a project website. For instance, the European Commission can act as a key institution in collecting project results and providing maintenance as well as technical support for upcoming tools. Although there were platforms that keep records of tool examples, a clear and constantly funded database that hosts existing and future DSTs may help to achieve sustainability. Future developments should be in this direction to satisfy the need of planners that seek for stable tools.

Moreover, the development of communication tools can increase stakeholder involvement. Online tools that ask for the feedback of marine users in real time can have a significant effect on participation. DSTs can be used in stakeholder meetings and workshops to increase the participatory process. Furthermore, the development of user-friendly tools that require fewer technical skills can help to reach different user profiles and increase application frequency. The involvement of stakeholders in DST development should be improved to decrease reluctance of users. Essential needs and rules for decision making proposed by stakeholders should be considered in the first phase of tool development. In that sense, there is still the need for DST developments that could fulfil the needs of planners and stakeholders to support MSP.

Although the characteristics given here may describe an ideal tool for MSP, it is hard to include all desired features in a single DST. Given the specificities and individual planning processes, it seems rather impossible to develop a tool, which considers both spatial and temporal dynamics of the ocean, provides multi-functionality and integrity, meanwhile being easy to use and available for free. But these concepts should not be forgotten. On the contrary, this analysis summarizes the expected development trends and innovations for DSTs and new DSTs can be positioned according to the current level of MSP around the world.

5. Conclusions

In this work, a detailed review of scientific papers and MSP implementation work was completed to analyse and assess the use of DSTs, allowing the identification of existing functionality gaps and future requirements. Most of the MSP reports examined did not explicitly state the application of DSTs. Thus, it is possible that this lack of specificity could lead to uncertainty regarding the DST outcomes in the management plans. It was identified that most of the tools were applied in the first stages of the MSP process, which reflects the fact that most countries have only just started to apply MSP. Based on these results, it is likely that as more countries implement MSP measures, this might trigger the demand of additional functions of DSTs. Thus, new tools and functionalities should be available to fulfil this demand. Based on expected needs, new DSTs should have the capacity to address future scenarios, socio-economic aspects, and improve communication and participation of stakeholders. Moreover, it can be expected that the availability of user-friendly tools with advanced functions and stable financial and technical support will facilitate further tool development and encourage decision makers to use them in the MSP process.

In conclusion, this review contributes to the present status and the future development of DSTs by highlighting current gaps and future needs in the MSP implementation process. In addition, it is likely that additional information derived from inputs and perceptions of end-users and planners will provide a broader perspective on further research.

CHAPTER 2

End users' perspective on decision support tools in marine spatial planning

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1. Introduction

Human activities produce pressures on marine environment and their increase can derive conflicts among users in the limited ocean space (Fernandes *et al.*, 2017). Marine Spatial Planning (MSP; also referred to as Coastal and Marine Spatial Planning, Ocean Planning, Maritime Spatial Planning and Marine Planning) is an adaptive process of analysing and guiding the spatial and temporal distribution of human activities at sea (Gissi *et al.*, 2019). Effective marine spatial plans require evidence-based decision-making processes in order to achieve sustainable use of marine resources and ecosystem services (Janßen *et al.*, 2019; Katona, 2017). In accordance with this purpose, Decision Support Tools (DSTs) could be considered to be the primary assistant of planners and managers (Stelzenmüller *et al.*, 2013b). By definition, DSTs are software-based intermediaries that provide support in decision-making processes (Rose *et al.*, 2016). Outcomes of tool applications for marine planning tasks lead users (including planners but also, policy-makers, scientists, industry, or NGOs) through clear steps and support decisions (Bolman *et al.*, 2018). In addition to software-based tools, a broader application of simulative and analytical approaches such as board games or mind maps are also seen in various planning activities.

Decision makers frequently benefit these practical mechanisms to have a more systematic and objective determination. However, tool application processes are not explicitly described in available MSP reports (see Chapter 1). New tools and case study applications are being published continuously (Gimpel *et al.*, 2018b; Menegon *et al.*, 2018b) , and there is a high number of tools for MSP in scientific literature and tool databases (Ball and Possingham, 2000; Coleman *et al.*, 2011; Nath *et al.*, 2000; Watts *et al.*, 2009). In contrast, direct evidences of DSTs application by authorities and planners are not evident (Belgian Royal Decree, 2014). Lack of information on the application of DSTs in management plans made it significant to study the demand side of the equation, integrate end user opinions to existing review efforts and clarify requirements of DSTs from primary sources. Since it is essential to reach adaptive and participatory MSP processes (Flannery *et al.*, 2018; Newton and Elliott, 2016), tool users' opinions should also be considered, as they have become essential in the MSP implementation processes. For this purpose, it is required to highlight the variety of end user profiles engaged in the different MSP processes (e.g. governance authorities, research institutions, academics, NGOs, etc.) and analyse their opinions in terms of satisfaction, required tool capabilities and future expectations.

Recent studies have investigated the DST applications in MSP processes by providing assessment framework for their usefulness and effectiveness (Bolman *et al.*, 2018) or with special focus on bunch of specific tools (Janßen *et al.*, 2019). Regarding to a more general scope, a systematic review was undertaken to assess existing DSTs and to understand how these are being used in on-going MSP implementation processes (see Chapter 1). Current tool applications, their main gaps and the future trends were discussed in Chapter 1 – (http://dst.azti.es) according to MSP stages, tool characteristics and application purposes. Results of this study acknowledged ease of use, advanced functionality, financial stability and constant technical support as significant tool requirements to improve their applicability in MSP processes.

As a further step of this comprehensive review, this research aimed to add value to current knowledge by capturing DST user perceptions on their applications in MSP processes. For this purpose, MSP experts were reached to collect information on: (i) DST users' profile; (ii) the contribution of tools in MSP implementation processes, (iii) user opinions and experiences; and (iv) their expectations to draw recommendations and to give insights for future developments. This research contributes to identify requirements in DST developments for their further and successful application in MSP processes.

2. Methodology

- Questionnaire

Perceptions and experiences on tools were acquired using an inclusive questionnaire. In total, 24 questions were asked to end users (Table 2). Respondents answered to multiple choice (64%), scoring (14%) and open answer type of questions (22%). These questions were structured to identify and analyse user perceptions in five basic stages:

(i) general characteristics of respondents, enquiring personal information, country information, fields of work and user background. This information later supported the user type based categorical analysis;

(ii) planning profiles, requesting information related with tool users' MSP experiences. This section included questions asking the name of MSP initiatives, plan scales and planning steps (Coleman *et al.*, 2011; Ehler and Douvere, 2009; Stelzenmüller *et al.*, 2013b);

(iii) tool user profile, analysing tool application processes and purposes by user groups. Besides applied DSTs were listed in this section;

(iv) users were asked to score their satisfaction levels and desired future tool characteristics by closed list questions. Users also scored the main reasons for not using tools based on their experiences; and

(v) in the final stage, end users defined their opinions for failure topics, functionality gaps, and desired developments through open answers. These answers shaped general opinions, tool application challenges and future recommendations.

- **Data analysis**

The results of the questionnaire were analysed in three different steps:

(i) The general distribution of response quantities and percentage responses were assessed.

(ii) Mean values and standard deviation were calculated for the scoring-based questions. For these questions three possible responses were (1) low; (2) moderate; and (3) high. Average scores for each user group and plan types were identified to be used in comparison analysis. Besides, Chi-square and Kruskal Wallis statistical tests were performed for these numerical answers. Due to low number of responses (4 to 6 responses) in this section from three out of the seven user groups (NGOs, private consultancy firms, marine industry), these responses were merged to an “others” group to perform meaningful statistical analysis.

(iii) User groups, tool application purposes and plan types were compared in cross-comparison tables. The aforementioned analyses resulted in the users’ characteristics and their tool preferences in planning process.

Table 2: List of research questions in four stages: (i) general characteristics of respondents, (ii) plan profiles, (iii) tool user profile, and (iv) user opinions.

Questions:
General characteristics of respondents
1) What is your age?
2) In what country do you work?
3) What is the highest level of school you have completed or the highest degree you have received?
4) In which field do you work?
5) Your background is:
• Environmental
• Economic
• Social
• Other (please specify)
Plan profiles
6) Have you participated in any Marine Spatial Planning (MSP) process?
7) In which MSP initiative(s) did you participate? (You can write more than one answer)
8) What was the scope of the MSP processes you participated in? (You can choose more than one answer)
• Legally Binding Plan
• Pilot Project
• Plan Proposal
• Research Project
• Others
9) What was the scale of the MSP processes you participated in? (You can choose more than one answer)
• Local Plan
• National Plan
• Regional Plan
• International Plan
• Others
10) In which dimensions of MSP did you participate?
• Environmental issues
• Economic issues
• Social issues
Tool User Profile
11) Have you ever used a Decision Support Tool (DST) in a MSP process? If yes, which ones?
12) In which MSP step have you used a DST?
• 1. Define goals and objectives
• 2. Gather data and define current conditions
• 3. Identify issues, constraints, and future conditions
• 4. Develop alternative management actions
• 5. Evaluate alternative management actions
• 6. Monitor and evaluate management actions
• 7. Refine goals, objectives and management actions
13) What were the main purposes to use a DST?
14) Can you score your satisfaction level according to technical parameters? (1-3)
• Ease of Use
• Input Preparation

	• Outcomes
	• Functions
	• Technical Support
	• Cost of the tool
15)	How much of the DST outcomes have been used in real MSP implementation?
User Opinions	
16)	In general terms, where do you think that the DSTs have failed or could not reach total satisfaction?
17)	What are the tool related gaps you observed while using DSTs? (Please define the weaknesses of tools)
18)	What are the external gaps you observed while using DST? (In this section, we ask you external factors that impacted the DST usage: e.g. lack of data)
19)	In general terms, do you rely on the outcomes from DSTs to advise MSP implementation?
20)	Which reason would restrain you to use a DST? You can choose more than one answer.
21)	What are your recommendations for DST developments?
22)	Can you score the importance of characteristics for future DSTs?
	• Integrity
	• Multi-functionality
	• Easy to use
	• Less costly
	• Temporally explicit
	• Other (explain)
23)	Do you think that DSTs are useful enough to continue investing time for its use?
24)	According to your experiences, do you have any specific tool(s) that you would prefer to use in the future?

- **Survey distribution**

An online survey tool (http://www.surveymonkey.com) was used to launch this questionnaire. To reach the target group who was actively involved in MSP processes, the questionnaire was distributed by several well-known communication channels such as the MSP Platform (www.msp-platform.eu), EBM Network, MEAM (Marine Ecosystems and Management newsletter) and Open Channels (www.openchannels.org). Besides, survey was sent to an inclusive contact list of 2000 people from marine field and it was announced in social media (Twitter and LinkedIn). These communication channels were selected to influence DST users from broader geographic areas and MSP initiatives. The questionnaire was open to public for eight months between July 2017 and February 2018.

3. Results

3.1 Profile of the Respondents

In total, 92 individuals responded to the questionnaire, from 28 countries distributed in Europe (18), North America (3), South America (3), Asia (2), Africa (1) and Oceania (1). Among all, Spain (14), United States (12), United Kingdom (7), Belgium (6), Greece (6), Portugal (6), and Italy (5) were the countries with higher contribution (Figure 7).

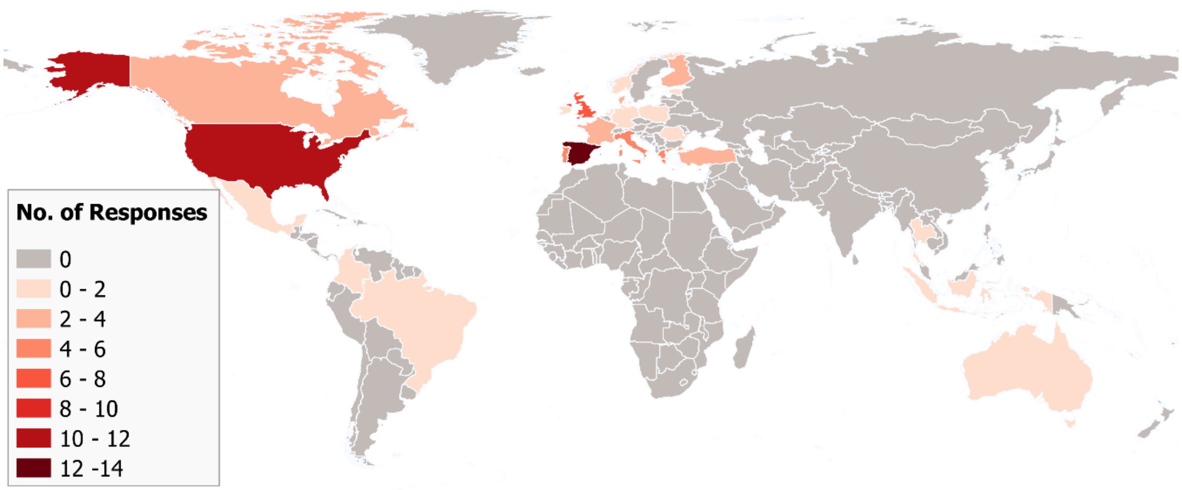

Figure 7: Number of responses from Marine Spatial Planning and Decision Support Tool users per country.

In total, 75% of the respondents declared having participated in MSP processes (Table 3). The profile of the respondents was mainly mid-age individuals (30-39 years old, 36%), highly educated (master's degree 46%, doctorate 43%), working in research institutions (38%) or governance authorities (22%), with a variety of backgrounds (dominated by biology (24%), and environmental sciences (18%)).

Table 3: Survey respondents' profile in terms of (i) age, (ii) education, (iii) background, (iv) working field and (v) participation in Marine Spatial Planning (MSP). NGO: Non-governmental organisation.

Age	**Responses**	**%**
21 - 29	13	13.7
30 - 39	34	35.8
40 - 49	23	24.2
50 - 59	16	16.8
60 or older	5	5.3
Total	91	95.8
Education	**Responses**	**%**
Bachelor's degree	6	6.3
Master's degree	44	46.3
Doctorate degree	41	43.2
Total	91	95.8
Background	**Responses**	**%**
Biology	23	24.2
Environmental Sciences	17	17.9
Others	12	12.6
Planning	9	9.5
Oceanography	9	9.5
Fishery	7	7.4
Geography	5	5.3
Economics	3	3.2
Engineering	2	2.1
Aquaculture	2	2.1
Computer Science	1	1.1
Information Technologies	1	1.1
Sociology	1	1.1
Total	92	96.8
Field	**Responses**	**%**
Research Institution	36	37.9
Governance Authority	21	22.1
Academics	15	15.8
Private Consultancy Firm	9	9.5
NGO	4	4.2
Others	4	4.2
Marine Industry	2	2.1
Total	91	95.8
MSP Participation	**Responses**	**%**
Yes	71	74.7
No	20	21.1
Total	91	95.8

3.2 DST application in MSP processes

Respondents have participated in 62 different MSP initiatives (list of these initiatives can be found in Appendix, Table A1). The highest number of respondents have participated in research projects (30%) (Table 4). On the other hand, in total 58% of the respondents have participated in legal planning initiatives (legally binding plans, plan proposals and pilot projects). Regarding to the plan scales, respondents have been involved in regional (33%), local (25%) and national scale (25%) planning processes. Respondents stated that they used the tools mostly in the beginning stages of MSP: to gather data and define current conditions (2^{nd} step, 26%), and to identify issues, constraints and future conditions (3^{rd} step, 24%).

Table 4: General characteristics of planning processes defined by respondents showing (i) planning steps, (ii) plan types and (iii) plan scales.

Marine Spatial Planning Steps	**Responses**	
	N	**Percent**
1. Define goals and objectives	10	10.8%
2. Gather data and define current conditions	24	25.8%
3. Identify issues, constraints, and future conditions	22	23.7%
4. Develop alternative management actions	14	15.1%
5. Evaluate alternative management actions	13	14%
6. Monitor and evaluate management actions	3	3.2%
7. Refine goals, objectives and management actions	7	7.5%
Total (multiple answers)	**93**	**100%**

Plan Type	**Responses**	
	N	**Percent**
Research Project	40	30.5%
Legally Binding Plan	32	24.4%
Plan Proposal	25	19.1%
Pilot Project	19	14.5%
Others	15	11.5%
Total (multiple answers)	**131**	**100%**

Plan Scale	Responses	
	N	**Percent**
Regional Plan	40	34.5%
Local Plan	29	25.0%
National Plan	28	24.1%
International Plan	10	8.6%
Others	9	7.8%
Total (multiple answers)	**116**	**100%**

3.3 Application Purposes

Respondents from academy reported the highest participation rate (87%) in MSP processes, followed by governance authorities (81%) and research institutions (74%). Among all, 36% of respondents applied DSTs in an MSP process. These respondents stated 20 different tools (list of these tools can be found in Appendix, Table A2). Unlikely to the high number of Marxan applications (13, including Marxan with zones), the other reported tools showed high diversity, from 1 to 9 applications. The highest number of tool uses was reported by research institutions (12 responses, 33%). However, governance authorities (10 responses, 48%) showed higher tool application rate in group-based analysis. No significant difference was found between the four user groups (Pearson Chi-square test, $p = 0.729$). In terms of MSP steps, each user group reported tool application in initial steps (2^{nd} and 3^{rd} steps). In addition to these, tool application in development (4^{th} step) and evaluation (5^{th} step) of alternative management actions were reported by research institutions and governance authorities.

In terms of application purposes, these tools were mostly implemented for uses conflict analysis (14%), scenario creation and analysis (13%), environmental impact assessment (11%), data gathering (10%) and governance assistance (10%) (Table 5). Purposes of economic analysis (3%) and social analysis (2%) were reported with smaller number of responses. From the point of view of user groups, highest number of responses for application purposes showed differences (Table 5): scenario analysis and conflict analysis for academics, environmental impact assessment and scenario analysis for research institutions, and data gathering and conflict analysis for governance authorities. Besides, communication was the main application purpose for NGOs and private consultancy firms. Research institutions did not report the use of DSTs for the aim of economic analysis.

Table 5: Tool application purposes for each user group (higher number of responses were represented in darker colour) and MSP steps to apply tools for each purpose

	User Group					
Application purposes	**Academics**	**Research Institution**	**Governance Authority**	**Others**	**Total per purpose**	**MSP Steps**
Uses conflict analysis	6	6	7	3	**22**	3,2,4
Scenario creation and analysis	6	7	5	2	**20**	3,4,2
Environmental impact assessment	3	7	4	3	**17**	3,2,4
Data gathering	1	5	7	3	**16**	2,5,6
Site identification	3	6	5	2	**16**	3,2,4
Governance assistance	4	6	3	2	**15**	1,3,7
Communication	1	5	3	4	**13**	1,3,7
Management plan proposal	2	4	5	2	**13**	3,4,5
Evaluation	2	3	4	2	**11**	5,6,7
Economic analysis	3	0	1	1	**5**	3,4,5
Social analysis	2	1	1	0	**4**	3,4,5
Total per user group	**33**	**50**	**45**	**24**		

3.4 Satisfaction level and development requirements

Respondents stated that 90% of the DST outcomes were used in an MSP implementation process. Regarding to specific tool characteristics, mean values for satisfaction levels ranged between 2.34 and 2.57, in a scale of 1 to 3 (low, moderate, and high), and diverse for each user group (Table 6). Besides outcomes (value 2.57), users were mainly satisfied by tool functions and cost (2.51 and 2.54, respectively). However, respondents scored lower satisfaction levels for ease of use and input data preparation (2.34 and 2.38, respectively). When comparing user groups, governance authorities were not satisfied by ease of use technical support, and academics were not satisfied by input data preparation and tool cost. Similar to these results, users defined cost of license, application difficulty, incapability of transferring data to other tools, and cost of data collection as the main reasons for not using DSTs (Table 6).

Table 6: Satisfaction levels (mean value, standard deviation and number of responses in parentheses) for tool characteristics by each user group. Users ranked each characteristic by scoring (1) low, (2) moderate and (3) high. (This analysis was performed by responses of DST users).

User Group	Outcomes	Cost	Functions	Technical support	Input preparation	Ease of use
Academics	2.66 ± 0.5 (6)	2.33 ± 0.5 (6)	2.50 ± 0.8 (6)	2.33 ± 0.8 (6)	2.33 ± 0.8 (6)	2.50 ± 0.5 (6)
Research Institution	2.58 ± 0.5 (12)	2.72 ± 0.5 (11)	2.50 ± 0.5 (12)	2.63 ± 0.5 (11)	2.45 ± 0.7 (11)	2.41 ± 0.5 (12)
Governance Authority	2.62 ± 0.7 (8)	2.75 ± 0.5 (8)	2.42 ± 0.8 (7)	2.37 ± 0.7 (8)	2.37 ± 0.7 (8)	2.12 ± 0.8 (8)
Others	2.50 ± 0.5 (6)	2.16 ± 0.7 (6)	2.66 ± 0.5 (6)	2.16 ± 0.7 (6)	2.33 ± 0.5 (6)	2.33 ± 0.8 (6)
Total	2.57 ± 0.5 (32)	2.54 ± 0.6 (31)	2.51 ± 0.6 (31)	2.41 ± 0.6 (31)	2.38 ± 0.6 (31)	2.34 ± 0.6 (32)

Respondents were asked to rank (low, moderate, and high) tool characteristics that they would desire to see in future tool developments (Table 7). In general, tool integrity (2.71), multi-functionality (2.64) and easy to use (2.62) were the main desired characteristics. Comparing user groups: academics and research institutions selected integrity, governance authorities selected multi-functionality and others selected easy to use as the characteristics for future tool developments. Integrity and multi-functionality were observed in the first two selection of all user profiles (Table 8). Less costly and temporally explicit tool characteristics were not desired as other ones. In this analysis, Kruskal Wallis test results showed no significant differences between users (p value was higher than 0.05 for each characteristics).

Table 7: Future tool characteristics scored by each user group. Users ranked each characteristic by scoring (1) low, (2) moderate and (3) high.

Field	Integrity	Multi-functionality	Easy to use	Temporally explicit	Less costly
Academics	2.62 ± 0.5 (8)	2.62 ± 0.7 (8)	2.50 ± 0.7 (8)	2.25 ± 0.9 (8)	2.12 ± 0.6 (8)
Research Institution	2.78 ± 0.4 (14)	2.46 ± 0.6 (13)	2.35 ± 0.7 (14)	2.38 ± 0.6 (13)	2.00 ± 0.7 (13)
Governance Authority	2.66 ± 0.7 (9)	3.00 ± 0 (9)	3.00 ± 0 (9)	2.55 ± 0.5 (9)	2.33 ± 0.5 (9)
Others	2.75 ± 0.5 (4)	2.50 ± 0.6 (4)	3.00 ± 0 (4)	2.50 ± 0.6 (4)	2.75 ± 0.5 (4)
Total	2.71 ± 0.5 (35)	2.64 ± 0.6 (34)	2.62 ± 0.6 (35)	2.41 ± 0.6 (34)	2.20 ± 0.6 (34)

Table 8: Ranking of future tool characteristics by each user group.

Ranking	Academics	Research Institution	Governance Authority	Others
1	Integrity	Integrity	Multi-functionality	Easy to use
2	Multi-functionality	Multi-functionality	Easy to use	Integrity
3	Easy to use	Temporally explicit	Integrity	Less costly
4	Temporally explicit	Easy to use	Temporally explicit	Multi-functionality
5	Less costly	Less costly	Less costly	Temporally explicit

4. Discussion

Over the past years, a broader use of DST for different planning tasks have been experienced (Bolman *et al.*, 2018; Janßen *et al.*, 2019). However, end user opinions and needs are not well-defined. The present research analyses DSTs users' perception on their capabilities, gaps and needs based on their experiences in real MSP implementation processes. Considerations and comments in this section refer to individual opinions and primary sources; therefore, they may have another interpretation in another sample of planners.

a. General opinions of end users

MSP is a fresh and dynamically evolving concept for many countries (Gissi *et al.*, 2019). Although it is a topic of increasing importance, there are limited number of completed plans and related working individuals (Frazão Santos *et al.*, 2018). However, it is expected to increase exponentially in coming years, since legislation is requesting countries to implement such plans (e.g. in Europe with the MSPD; 2014/89/EU) (European Union, 2014) or others in the rest of the world (Frazão Santos *et al.*, 2019)). Therefore, it can be considered that our study resulted with high participation (92 responses) and reflected opinions of diverse tool users around the world, compared with other surveys in similar studies (e.g. 77 respondents in Maguire *et al.* (2011); 42 in Elliott *et al.* (2018); or 59 in Janßen *et al.* (2019)). The questionnaire has reached tool users from both countries with completed and developing MSP processes. As it can be expected, highest participation was from countries with completed MSP implementation (e.g. United States, United Kingdom, Belgium). In contrast, there was a high interest to tools from plan developing countries such as Spain, Italy, Greece and Portugal, probably because of the implementation requirements after the European

MSPD. Most of the survey participants were middle-aged. Although it is hard to find concrete reasons for this fact, the need of MSP expertise, technical capacity or tool reliability can cause less participation from young or elder people.

Finding solutions with "problem-owners" is an essential method for participatory system dynamics, especially when the objective is environmental sustainability (Videira *et al.*, 2017). Several studies highlighted the importance of stakeholder opinions in environmental assessment, planning, and management activities (Gopnik *et al.*, 2012; Maguire *et al.*, 2011,2012; Olsen *et al.*, 2014a). Accordingly, respondents emphasized the importance of end user opinions and consultations for DSTs' efficiency. Although tools are automatized systems to make data-based decisions, it was mentioned that marine environment is highly sensitive and cannot be planned without knowledge-sharing activities and common visions, including expert judgment. Therefore, it was suggested that existing tools (e.g. participatory communication tools) can be used in development of new tools.

Regarding to user profiles, end user opinions and preferences showed similarities in terms of current application and future expectations purposes, as in Janßen *et al.* (2019). Research institutions and academics both asked for integrity and multi-functionality; and mainly applied tools for scenario analysis (Table 5). However, MSP participation level was lower than other groups for research institutions. Hence, it can be assumed that research institutions were more actively involved in pre-planning processes to analyse potential scenarios of planning actions (as in Ban *et al.* (2013)). In contrast to these two groups, governance authorities asked for ease of use, and applied tools for management plan proposal. Governance authorities place in the final stage of decision making processes, and can be seen as the key body to resolve conflicts and build consensus (Smythe, 2017). Respondents from this group showed high MSP participation and high tool application. Thus, developers should understand and consider the needs of governance authorities in future tool developments.

In general, most of the respondents perceived tools as robust concepts and scientifically meaningful. Satisfaction level for tool outcomes was considerably high and there was a positive opinion on tools' efficiency and practicality. Their overall perception can be taken as a sign that the tools will be used by planners in the future. Among others, stakeholder consultation and modelling tools can be expected to be applied to create hypothetical scenarios and strong caveats. However, there is a need to fulfil mentioned gaps in application process and make tools more meaningful and applicable for MSP.

b. Gaps and tool application challenges

In previous studies, tool functionality gaps and challenging topics were defined by analysing plan reports and tool outcomes (Janßen *et al.*, 2019). End user opinions may give a better understanding of these gaps and highlight main challenges based on MSP experiences and user profiles. Comparing to other issues, awareness of available tools, reliability of tool working principles, data availability/sharing, stakeholder engagement in tool applications, and application complexity were the identified prominent topics in this exercise.

Initially, participants defined internal issues that are directly related with tool performance and application process. It was declared that working principles of tools were complicated to understand, and existing tools require advanced validation functions for their outcomes. These facts caused reliability problems to use tool outcomes in real implementation processes (see also (Buhl-Mortensen *et al.*, 2016)). Therefore, DSTs could only be used to display spatial information and make broad assumptions. Besides tools' working principles and validation, users also had low level confidence on available data. Respondents stated that in many cases, planners could not use DSTs for concrete problems due to data reliability. It is declared that meaningfulness of tool results is dependent on data quality and availability (Coccoli *et al.*, 2018). Data coverage and resolution needs improvements especially when using tools across national borders (Jay *et al*., 2016). High quality, reliable, up-to-date and common formatted spatial information is hard to achieve for tool users since the main data providers (national administrations and institutions, academic bodies and European research projects), use different data collection and handling techniques. Moreover, there is a lack of awareness in poor scientific and insufficient data including data from surveys or observational data from individuals (Parsons and Wright, 2015). Frequent responses for this concern highlighted the need of quality data collection effort, especially for environmental components. Respondents stated the requirement of clear spatial distribution of environmentally sensitive areas which should be considered in planning process.

In addition to technical gaps, participants stated that there are not many tools considering the human side of the equation. Social importance of marine areas, non-digital data, and future needs of marine communities could be included by participatory plan developments. Regarding to this concern, it was said that human factor was not well considered in previous tool development processes. Social landscape of marine environment was seen as the missing-layer problem in integrated planning efforts (St. Martin and Hall-Arber, 2008). Therefore, it is required to increase applicability of tools to develop spatial representation of stakeholders. However, DSTs are complicated to describe to all stakeholders who have lack of time, skills to use them and financial power. Current tools are hard and challenging to apply without the support of tool experts for such users in governance authorities. Since many tools use Geographic Information System (GIS) background, there is a lack of simple tools with guiding and explanatory interfaces.

5. Conclusions and recommendations for future developments

The present questionnaire outcomes have allowed identification of user opinions, gaps and desired future requirements for tool developments. Initially, it was recommended to increase tool-user interaction from development to application stage. It was required to be involved in tool development processes from the beginning to identify desired features and functions. Also, it was mentioned that risk identification and prioritization should be done by end users. Although tool development is necessary to support different MSP tasks, human intervention is still needed due to the limitations of computer-based mechanisms. It was advised to have user-developer meetings and workshops to identify real requirements to avoid spending time and money for experimental products and to guarantee fit to purpose tools.

In terms of technical characteristics, integrated tools with more functionalities are recommended. Users have asked to scientist and tool developers to bring effort together to create applicable and effective tools and for urgent MSP requirements. Tool developers need to achieve clear integration with existing regulatory demands, and they need to have better understanding for existing legal mandates to increase usefulness. Hence, MSP steps should be adopted as the baseline of the tools' working flow and to focus on a publicly accepted MSP review cycle. In parallel with this, tools should be made more visible for policy makers and create awareness by good practices and guidance examples.

A frequent requirement for the future DSTs was the availability of comparing alternative planning decisions. For this purpose, better scenario analysis capabilities with high-quality visualisation are needed. More online and open access tools are needed to increase application process transparency and to engage more stakeholders in the present MSP processes. Regarding data availability, new efforts on environmental data collection are needed to enable ecosystem-based approach in MSP. In order to overcome the limited data, and following, the comments from respondents, tools should consider integration of expert judgement to increase human factor in decision making process. Regarding to data sharing, a common data aquarium (an open data sharing platform that allows users to upload data) for everyone to reach the high quality and updated data, is envisaged. Environmental, economic and social data should be aggregated and stored in a single administrative body for each sea basin while the data quality procedures should be determined in an updateable and transparent format.

In conclusion, this study identified that DSTs are worldwide accepted and being used in real MSP processes, mostly by research institutions and governance authorities. DSTs are mainly implemented in regional and legally binding planning activities. At present, tools are mostly used in the beginning stages of MSP implementation processes, and users demand tools for upcoming stages such as evaluation and monitoring. In general, end users require development of interactive, practical, reliable, open source and online tools providing transparency and user-friendly interface. Accordingly, developers should make an effort in creating new integrated and multi-functional tools, and engaging stakeholders in the tool development process. Given these characteristics, it seems difficult to consider all mentioned recommendations in a single tool. However, these concepts and innovations highlight the expected development trends and general end user opinions.

CHAPTER 3

A modelling approach for offshore wind farm feasibility with respect to ecosystem-based marine spatial planning

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1. Introduction

Global demand for energy is rising in parallel with industrialization and globalization. International and national energy policies and agreements are promoting the use of environment friendly renewable energy sources (European Union, 2009; United Nations, 1992b,2016), with the aim to reduce or eliminate the negative environmental impacts from traditional energy production methods, including climate change (Baban and Parry, 2001; Michaelides, 2012; Panwar *et al.*, 2011). One of the novel and promising areas for renewable energy production is the offshore wind energy. This sector has experienced an annual growth of 101% in 2017 in Europe (Kim *et al.*, 2012; Wind Europe, 2017). Although financial difficulties and legal constraints have limited the transformation of ideas into practices, offshore wind platforms are being developed and established in many countries around the world (Bilgili *et al.*, 2011; Keivanpour *et al.*, 2017). Europe has a total installed capacity of 15,780 MW from 4149 grid-connected wind turbines, and 81 offshore wind farms in 10 countries (Wind Europe, 2017). By 2024, it is expected to reach 29.8 GW, expanding at a Compound Annual Growth Rate (CAGR) of 12% (Credence Research, 2017). In relation to this, in Europe, offshore wind energy industry supplies 260,000 high-skilled jobs and 60 billion € turnover (European Commision, 2017a). It is expected that this trend will gain speed with the promotion of Blue Growth (FAO, 2013), and provide up to 560,000 jobs in 2030 (Wind Europe, 2017). While the main developments of wind farms is held in northern countries, offshore wind energy production interest is expanding to all countries in Europe (Rodríguez-Rodríguez *et al.*, 2016).

Although there is a record growth in the sector, the installation of wind farms is constrained to a set of factors that limits their technical and economic viability (Weiss *et al.*, 2018). In recent years, areas like the North Sea have experienced the highest development of this sector due to a set of conditions such as energy resource, shallow and smooth continental shelf and large sedimentary seafloor. The combination of these kind of conditions makes the installation of fixed wind platforms feasible and cheaper with the present technology. More recently turbines installed on floating platforms seem to create new opportunities for this sector, as wind farms installation could be expanded to areas where fixed-foundation turbines are not feasible (Bento and Fontes, 2019). This opens the door to new opportunities of growth of this sector, as expands the suitable areas to a broader scale. However, nowadays, there are just a couple of operational examples of floating wind farms around the world such as Wind-Float in Portugal (Roddier *et al.*, 2010) or the Hywind in Scotland (Myhr *et al.*, 2014). Although floating turbines can provide new opportunities, barriers such as technological maturity, high installation cost, space competition with other activities, and potential environmental impacts hinders the development of this new industry (Kausche *et al.*, 2018). Despite these barriers, expansion of this activity must be taken into account by managers and decision makers in the development process of marine plans.

In this context, EB-MSP (Degnbol and Wilson, 2008; European Union, 2014; Katsanevakis *et al.*, 2011) can contribute to the sustainable integration of wind energy platforms into the marine environment. EB-MSP aims to promote the sustainable growth of the maritime economies under environmental limits (Buhl-Mortensen *et al.*, 2016). Thus, EB-MSP concept should be considered in Blue Growth strategies and management of socio-economic activities in offshore areas integrating the environmental and economic pillar (European MSP

Platform, 2018). An efficient and integrated planning process of floating wind energy platforms needs to consider complex morphological conditions, environmental constrains, technical requirements and dynamic nature of the ocean (Göke and Lamp, 2012; Jay, 2010). Thus, it is key to develop plans integrating technical, environmental and socio-economic aspects, as well as, considering present conditions and future-oriented potential scenarios, to make them applicable for long-term plans and avoid obsolescence.

The development and implementation of decision support tools (DSTs) can assist planners, decision makers, industry and investors when developing and operationalising EB-MSP. DSTs are software-based tools and approaches integrating economic, environmental and social dimensions, as required in EB-MSP processes. They can adopt the role of intermediaries that provide support in evidence-based decision-making process (see Chapter 1). Examples of their successful use can be found in the identification of most suitable areas for the establishment of certain activities, trade-offs for different management alternatives (Gimpel *et al.*, 2018b), to provide alternative solutions for spatial and temporal conflicts between activities (Coccoli *et al.*, 2018), environmental effects (Menegon *et al.*, 2018a) or future scenarios generation (Stelzenmüller *et al.*, 2010). Among other approaches, Bayesian Belief Networks (BBN) have the capacity of integrating and relating different factors (Levontin *et al.*, 2011) that interplay in the aforementioned functionalities. By definition, BBN is a probabilistic model that is capable of causal reasoning and scenario definition and analysis (Landuyt *et al.*, 2013; Stelzenmüller *et al.*, 2015). Models can be used to create conditional probabilities by integrating quantitative or semi-quantitative data, and expert judgement in data limited situations (Pascual *et al.*, 2016). Such capabilities make this approach suitable and applicable in marine research and multidisciplinary approaches.

Although BBN application in marine science is getting popular, there are still few BBN examples for environmental models compared to other disciplines: management processes (Stafford *et al.*, 2016), habitat suitability analysis (Douglas and Newton, 2014; Smith *et al.*, 2007), risk and environmental impact assessment for water quality management (Abaei *et al.*, 2018; Castelletti and Soncini-Sessa, 2007; Xue *et al.*, 2017) and fisheries management decisions (Fernandes *et al.*, 2013; Schmitt and Brugere, 2013; van Putten *et al.*, 2012). Besides, this approach was also performed to make spatially explicit analysis producing output maps (Ban *et al.*, 2015; Coccoli *et al.*, 2018; Stelzenmüller *et al.*, 2015). Above-mentioned functionalities and application fields make BBN a valuable and appropriate approach to integrate and analyse different dimensions of marine environment, which is needed for EB-MSP (Domínguez-Tejo *et al.*, 2016; Marcot and Penman, 2018).

In this context, this research provides a novel EB-MSP DST approach for an integrated and spatially-explicit offshore wind farms site feasibility identification. Hence, our objectives are: (i) the development of a BBN that integrates most relevant technical, economic, environmental and social dimensions of offshore wind energy development; (ii) operationalize the model constructing a spatially explicit BBN DST; (iii) implement the model at the Basque Country (North of Spain) scale, as case study; (iv) define and develop the most reliable future scenarios and their analysis; and (v) expand the model to the North East Atlantic and Western Mediterranean regions. This approach can facilitate site identification process for offshore wind developments in the framework of EB-MSP.

2. Methods

2.1 Development of a spatially explicit model framework

To achieve these objectives, we built a spatially explicit model framework, through three consecutive steps (Figure 8), as explained below.

2.1.1 Conceptual model development

First step includes the identification of relevant components, definition of the model structure and the relationships between model components. Relationships between model components were defined by experts and literature review. Relationships and selection criteria were used to establish conditional probability tables (CPTs) which demonstrate marginal probability of a change in a single variable with respect to a change in other one (Göke and Lamp, 2012; Jay, 2010; Kim *et al.*, 2016; Myhr *et al.*, 2014; Rodríguez-Rodríguez *et al.*, 2016). To define these conditional probability tables, the research team brainstormed and connected components to represent expected relationships using their collective expert judgment. (see selection criteria in Appendices, Table A3). As the selection criteria, the model designated sedimentary and low-cost energy production areas, while avoiding conflictive (presence of marine activities and high visibility) and environmentally significant areas (areas with high biological value for related ecosystem components).

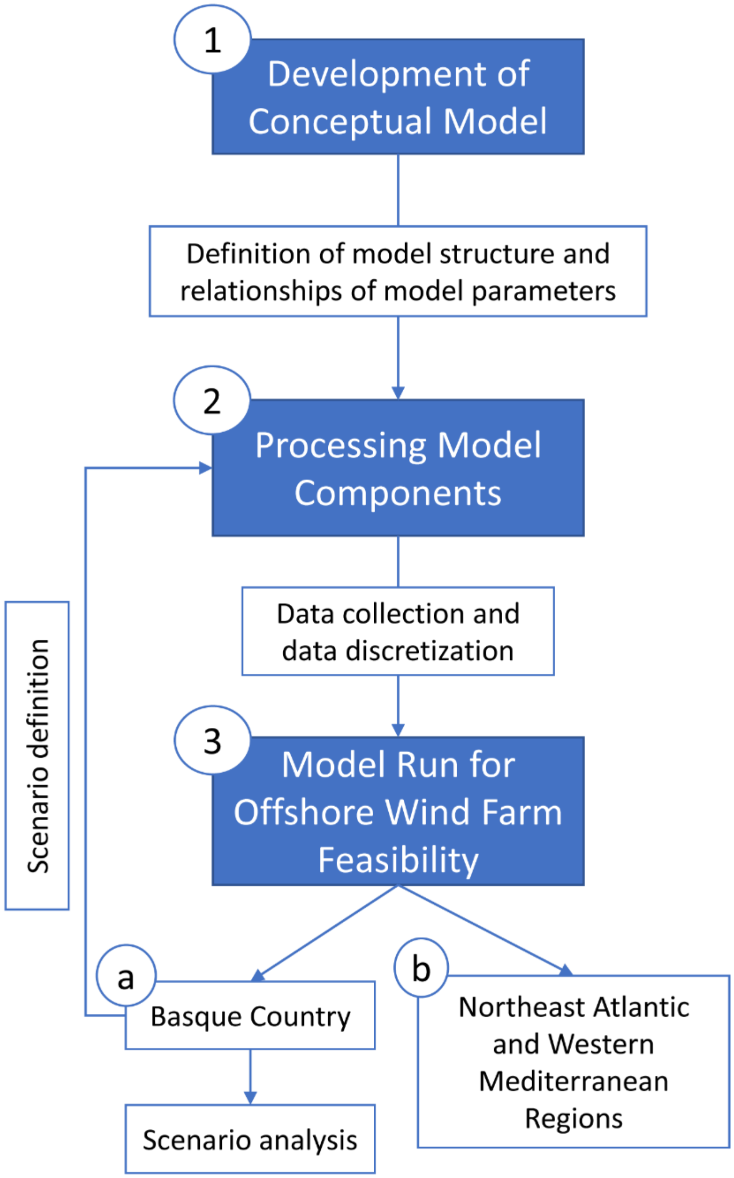


Figure 8: Modelling framework applied for the integrated and spatially explicit feasibility analysis of offshore wind platforms.

2.1.2. Processing model components

The second step was processing model components retrieved from the conceptual model structure (Figure 9). In this stage, data collection and data discretization were performed for technical, economic, environmental and other uses components. The empirical data for the model was retrieved from several sources (see Appendices, Table A5 and A6 for the detailed description of data sources and characteristics). Afterwards, all spatial data were discretized and continuous data for model components were transferred into discrete counterparts (e.g. low, moderate, high) (Appendices, Table A8). Finally, data was transformed into a 1-km^2 grid-cell and input data matrix including categorical values for each model component was prepared. Primary model components referred to a GIS layer or attribute, and each ID in the input data matrix referred to a specific grid cell in the study area.

In the conceptual model, technical-economic, environmental, and other uses feasibility components were connected to a final integrated feasibility component. An equal importance for each of the afore-mentioned dimension was given in the model and areas with both high technical, high environmental and high other uses feasibility were shown highly feasible in this final node.

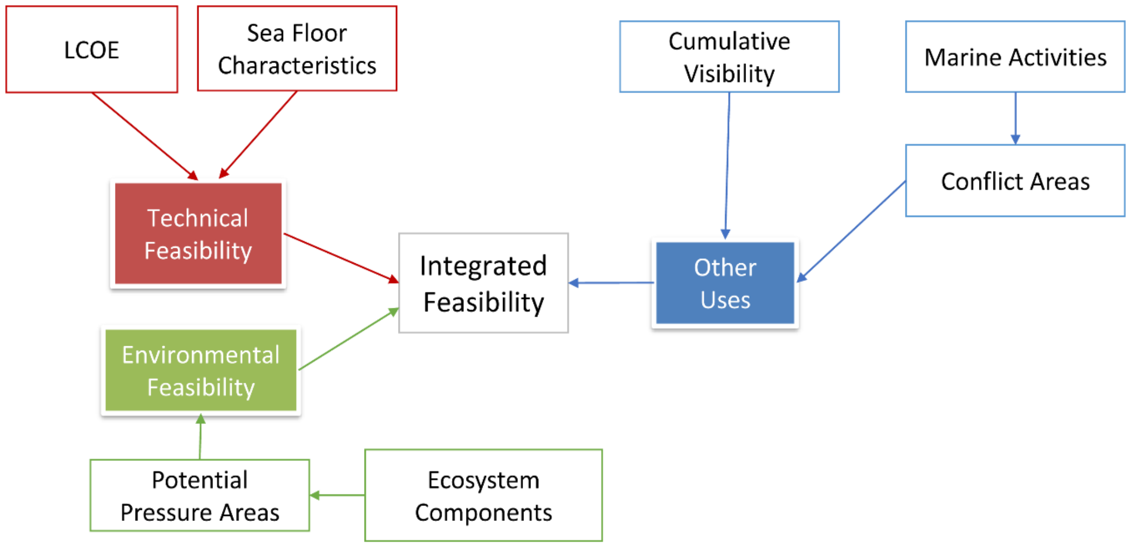


Figure 9: Conceptual model structure showing model components and their relationships in conceptual model. Note: LCOE - Levelized Cost of Energy.

The description of the process adopted for each set of components are given below:

- **Technical / economic factors**

These components represent the first part of the integrated feasibility analysis. It was considered that profitability, productivity and operationality of offshore wind energy platforms are the essential factors to select most feasible wind farm locations (Kim *et al.*, 2016). This section is composed by two components. Levelized cost of energy (LCOE), and seafloor characteristics were used to determine the suitability of an area from technical-economic point of view. LCOE (€/kWh) is an economic assessment of the average total cost to build and operate a power-generating asset over its lifetime divided by the total energy output of the asset over that lifetime. More specifically, LCOE is considered as the break-even cost to generate the energy in offshore wind farm projects (Bruck *et al.*, 2018). For further detail on the LCOE formulation, model datasets and modelling procedure we refer to Table A3. Regarding the discretization of LCOE, we used the market price range for the household consumers derived from report of Eurostat (2018) for EU countries (below 0.18 €/kWh market price without taxes, and 0.18 - 0.24 €/kWh when the taxes are included). Then, LCOE data was discretised to compare cost per grid cell with the average market price range (as shown in Table A8). In terms of sea floor characteristics, sedimentary seafloor was considered as being the most suitable for floating offshore wind turbines anchorage. Sedimentary seafloor proportion was calculated for each grid cell in the study area to assign a sea floor score (Discretization values for model components can be seen in Table A8). Finally, these two components were connected to technical feasibility that shows "high" state for areas with lower production cost than market price and high and very high sea floor scores.

- **Environmental factors**

These components considered environmental limitations that could be represented as the pressures that can generate impacts over different marine ecosystem components. Depending on the magnitude of the project and the sensitivity of the ecosystem components affected, this constrains could be an important limiting factor for the project making it even unacceptable. Pressures of offshore floating wind projects were framed in the context of the Marine Strategy Framework Directive 2008/56/EC pressure list of Annex III: physical loss, physical damage and other physical disturbance (Table 9) (Bailey *et al.*, 2014; Bailey *et al.*, 2010; Cazenave *et al.*, 2016; Thompson *et al.*, 2013; Williams *et al.*, 2015). These are related with the physical presence of the devices, the physical presence of moorings, mooring lines and supporting structures, the dynamic components of the devices (the moving parts of the devices can lead to "blade strike") and the acoustic effects during deployment, routine servicing and operation of devices, and decommissioning, which were the main actions or pressures identified by Boehlert and Gill (2010) in relation to marine renewable energy projects, together with chemicals used in the devices and the electromagnetic field generated during transmission of the produced electricity through the submarine cables.

The main ecosystem components considered in this study are: (i) marine mammals (changes in marine mammal behaviour, barrier to movement and displacement of activities such as feeding, mating, rearing, or resting habitats, collision and entanglement risk, disturbance and avoidance behaviour during construction and operation stage due to underwater noise generated), (ii) sea birds (collision risk with blades), and (iii) macrobenthos (increase of sea bottom habitat heterogeneity and biodiversity of sessile and mobile benthic organisms due to the addition of hard substrata coming from moorings, foundations and cables, changes in biogeographic distribution of hard substrata species and introduction pathway of invasive species, dragging or rubbing of materials such as chains, wires, ropes or cables across the seabed and changes in sediment transport regime and the morphology of sandy areas, artificialisation and change in proportion of hard/soft substratum in the installation area) (Bailey *et al.*, 2014). Environmental feasibility definition was based on the Biological Value (BV) given in each cell based on a previous study undertaken by Pascual *et al*. (2011). Then, these components were connected to potential pressures of an offshore wind farm project. Finally, higher BV was assigned to a lower environmental feasibility.

Table 9: Sensitive ecosystem components, and corresponding pressure themes and generic pressure elements from Marine Strategy Framework Directive (MSFD), Annex III).

Sensitive Ecosystem Components	**Pressures Theme (MSFD, Annex III)**	**Generic elements (MSFD, Annex III)**
Sea Birds, Macrobenthos	Physical damage	Changes in siltation
		Abrasion
Macrobenthos	Physical loss	Smothering
		Sealing
Marine Mammals, Sea Birds	Other physical disturbance	Marine litter
		Underwater noise

- **Other uses factors**

These components address spatial conflicts of wind farms with existing and future marine activities and cumulative visibility. First, excluding areas due to other marine uses were defined in the model. High fishing activity areas, high marine traffic density areas, submarine cables, MPAs, gas pipelines, aquaculture areas, wave energy converters, harbour service and sand extraction areas were defined as not compatible activities with wind farms, and thus their spatial distribution was added and classified as high conflict areas in the model.

The second component or factor of the other uses component is the visual impact of offshore wind through the calculation of a Cumulative Visibility Index (CVI). CVI is the phenomenon of sighting an object or infrastructure from multiple observation points (Wheatley, 1995) and is frequently applied for offshore wind energy sightings (Depellegrin *et al.*, 2014; Griffin *et al.*, 2015). The CVI identifies areas of the sea space of highest visibility and therefore can incorporate visibility concerns into infrastructure siting from coastal landscapes. The CVI is an aggregated index composed by five coastal resources: (i) CVI_{LU} - coastal urban land use based on CORINE land cover (2012) for continuous and discontinuous urban fabric of coastal settlements, representing visibility of residential houses in the study area; (ii) CVI_{Pop} coastal areas of high population density (JRC, 2015); (iii) CVI_{Beach} - visibility from bathing areas based on the bathing water quality sites for the year 2016 (EMODNet, 2016) buffered for 500 m; (iv) CVI_{N2000} - visibility from valuable Natura 2000 sites (EU Sea Atlas, 2016); and (v) CVI_{PUD} – visibility from popular sightseeing areas based on a visitation rate expressed in average photo user days (PUD; period 2005-2014) modelled with InVEST Visitation Rate (Natural Capital Project, 2018). For further detail on the CVI formulation, model datasets and modelling procedure we refer to (Appendices, Table A4).

2.1.3. Model runs for case study areas

In the third and final step of the framework, the conceptual model was implemented in Netica software as a BBN (www.norsys.com). The model was feed with real data and run for two different case study areas: the Basque Country and the Northeast Atlantic and Western Mediterranean Region. Results were visualised in maps by using ArcGIS software (www.esri.com).

- Basque Country case study

The Basque Country continental shelf was adopted as pilot case study because the characteristics of this area can be representative to other areas in the Atlantic in which offshore wind energy development is also being analysed and promoted. In addition, this is a rich area in terms of data availability (Borja and Collins, 2004) and can be used as a test site for the method proposed, before expanding it to other areas.

The total length of the Basque coast is approximately 150 km, and the continental shelf is narrow (Figure 10a), occupying a total area of 2355 km^2. The shallowest area is characterized by a belt of rocky substratum and sandy sediments mostly in the mouths of estuaries (Galparsoro *et al.*, 2015). Below 200 m depth, continental shelf has steep slopes and canyons leading to abyssal plains (Galparsoro *et al.*, 2010).

Diverse range of marine activities take place in the Basque coastline (Buhl-Mortensen *et al.*, 2016; Pascual *et al.*, 2013). The narrowness of the continental shelf brings the potential conflicts in present and future spatial allocation of these activities. Besides traditional activities such as artisanal and pelagic fisheries, pelagic purse seiners, and recreation, there are ongoing gas development, marine renewable energy projects (the Biscay Marine Energy Platform) (Galparsoro *et al.*, 2012) and an offshore aquaculture initiative. Moreover, there are two designated protected areas covering 225 km^2.

In addition to the present feasibility level in the Basque Country, the model was also used to project future scenarios of offshore wind feasibility depending on potential spatial allocation of new activities and adoption of management plans that are incompatible with wind farms. In this study, scenario analysis was performed by including new input layers of potential spatial distribution.

Two incompatible activities expected to be placed in near future were analysed in the study area: (i) new underwater cable connection between Spain and France, and (ii) new MPAs proposals by WWF (2005) in front of Bermeo and Getaria (Figure 10a). There are four different alternative routes for the new underwater cable connection. For each cable route alternative, 500 m buffer zone was considered in the spatial analysis. Each cable route and corresponding conflict were analysed to identify the most feasible areas for offshore wind farms. Then, second scenario analysis was performed to analyse feasibility changes when new MPAs are included as a constraint.

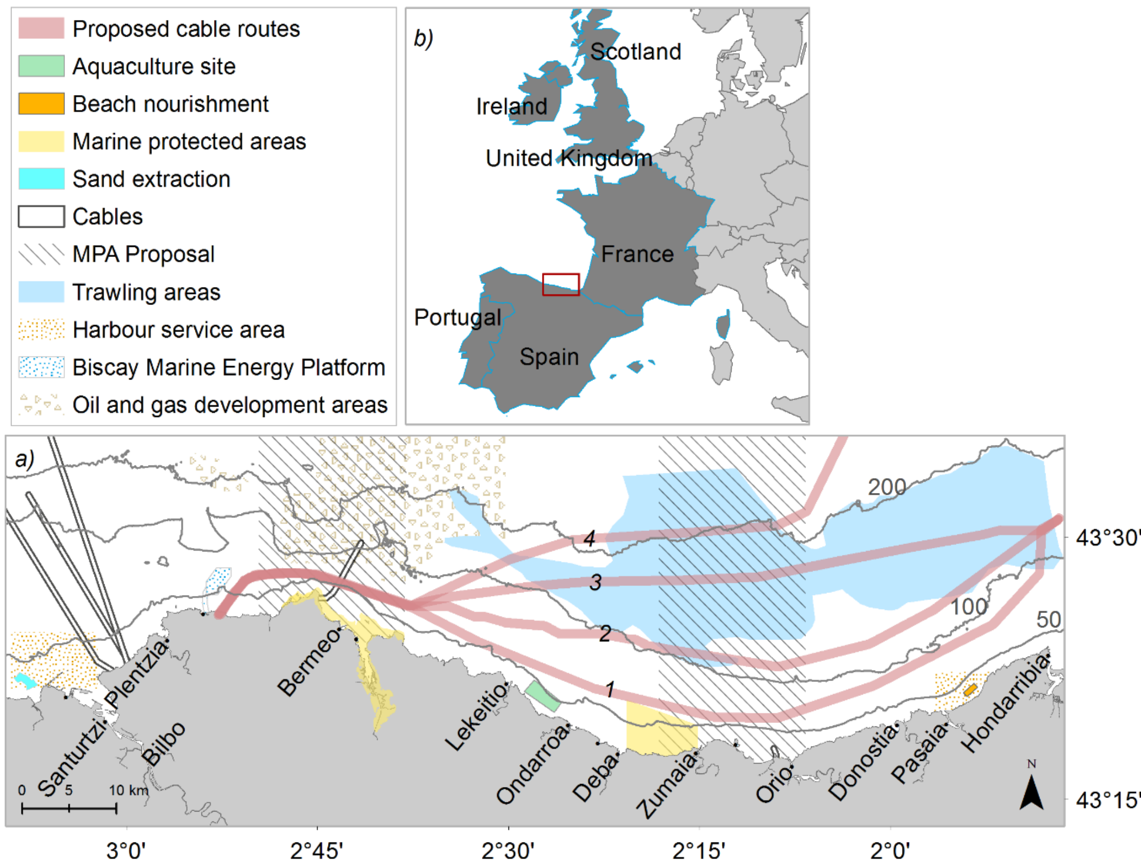


Figure 10: a) Current and planned human activities in the Basque Country, and b) North East Atlantic and Western Mediterranean regions and the location of Basque Country.

- **Northeast Atlantic and Western Mediterranean Regions**

In order to see if the model is able to run adequately in extensive areas with less information that in the Basque Country, the model scope was expanded to the Northeast Atlantic and Western Mediterranean offshore areas, covering five European countries including Ireland, United Kingdom, France, Spain and Portugal (Figure 10b). The outer limit of the study area was established at 24 nautical miles from the shoreline, covering 601,000 km^2.

In terms of offshore energy platforms, the case study area is considerably rich and one of the pioneer areas in Europe. There are 27 operational wind farms (26 in United Kingdom and 1 in Ireland) (checked in August 2018). UK built half of Europe's offshore wind power in 2017 (53% of the net 3.15 GW of capacity installed across Europe) (Wind Europe, 2017). Currently, there is a cumulative capacity of 15.78 GW of offshore wind in the country, which is predicted to reach 25 GW by 2020. Longer term, the UK is expected to retain its top spot by 2030.

In contrast to the Basque Country case study, there was a lack of data for some of the model components within the size of the study area and 1 km^2 spatial resolution. Due to this constraint, model was run with six input components derived from publicly available information including: (i) wind power density for 100 m height wind platforms, (ii) seafloor characteristics, (iii) bathymetry, (iv) marine traffic, (v) fishing intensity, and (vi) MPAs (see Appendices, Table A6 for detailed description of the data sources and characteristics). To perform the model with the best available data for the extensive study area, we used the wind power density for 100 m height wind platforms considering orography, roughness and roughness change effects, for the larger scope model run (http://globalwindatlas.info).

From the technical perspective, model was run to find the most feasible areas: highest wind power density, sedimentary seafloor and a limit of 100 m depth. Besides, in terms of other uses and potential conflicts, model avoided areas including MPAs, high fishing activities and high marine traffic. In this second run, environmental components were not included due to lack of data availability. Besides the current feasibility, the model was also run for a future scenario allowing floating wind farms to be established up to 200 m water depth due to expected technological advancements and potential capacity.

3. Results

3.1 Wind farm opportunities in the Basque Country

The integrated feasibility obtained by the integration of the most relevant technical/economic, environmental and other uses factors for the windfarms, shows the feasibility level in the Basque Country case study. The model outline and results could be seen in Figure 11 and the description of the different components are given below.

To begin with technical – economic components, the LCOE was higher than the average market price in all grid cells and 14% of the study area was classified as moderate cost; and 74% of the area was classified as high cost areas. Following, 34% of the area has high sea floor score (100% sedimentary soft bottom seafloor). According to results, only 6% of the study area showed moderate technical feasibility for offshore floating wind platforms (Appendices, Figure A1). These feasible areas were equal to 130 km^2 and they were located between Bilbo and Lekeitio and 3 km far from coastline. These areas were found in four separate groups. Results showed that most of the eastern offshore areas has low technical feasibility.

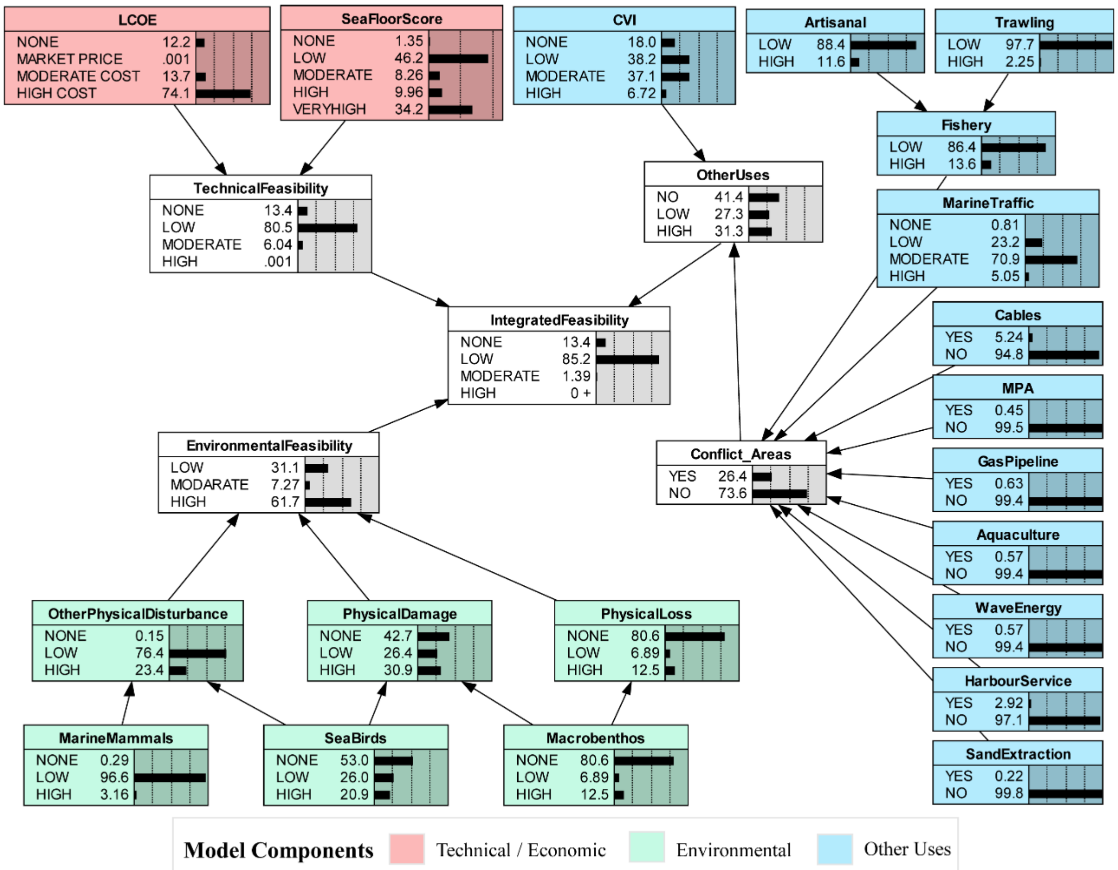


Figure 11: Basque Country Bayesian Belief Network model for the Basque Country integrated feasibility for offshore wind platforms. (CVI: Cumulative visibility index, MPA: Marine Protected Area).

The environmental feasibility results highlighted potential areas that could be under pressure with the presence of floating wind platforms. The percentage of potential pressure areas for marine mammals, sea birds, and macro-benthos were 3%, 20% and 12%, respectively. According to spatial distribution of these ecosystem components, 23% of the area can be potentially affected by physical disturbance, 31% of the area under physical damage and 12% of the area under physical loss type of pressures. Results showed that 62% of all study area has low potential for pressures produced by wind platforms and thus high feasibility for offshore wind farms installation (Appendices, Figure A1). These areas were equal to 1,791 km^2. However, 30% of the study area has low environmental feasibility due to high potential for environmental pressure. In the map, these areas were mostly seen in the coastal areas up to 5 km. Additionally, 7% moderate feasibility was seen in the east side of the study area.

In the sense of the CVI, the 7% and 37% of the study area has high and moderate potential visual impact (Appendices, Figure A1). These areas were mostly seen in western coast of the study area, in front of the city of Bilbo. Other visibility concerns can be found in eastern coast of the study area and in central area between Lekeitio and Zarautz.

With regards to feasibility in the context of other maritime activities held in the area; it was observed that 26% of the study area was occupied by marine activities that were incompatible with offshore wind farms. By adding high visual impact areas, 34% of the area can be considered as in conflict with wind farms (Appendices, Figure A1).

These two components (i.e. conflict level with marine activities and cumulative visibility) were connected to a combination component, showing the final results of “other uses” component. There is no potential conflict in 41% of the study area, and low conflict in 27% of the study area. In contrast, 31% of the area (730 km^2), has high conflict potential caused by other existing marine activities and cumulative visibility. Output map for conflicting areas showed that high conflict areas would mostly occur in the western side of study area.

In terms of the integrated estimation of feasible areas for offshore wind energy platforms in the study area, a total of 1% (23 km^2) of the study area show a moderate feasibility. These moderate feasibility areas are located at 3 to 5 km far from coastline in the coastal areas between Bilbo and Lekeitio (Figure 12).

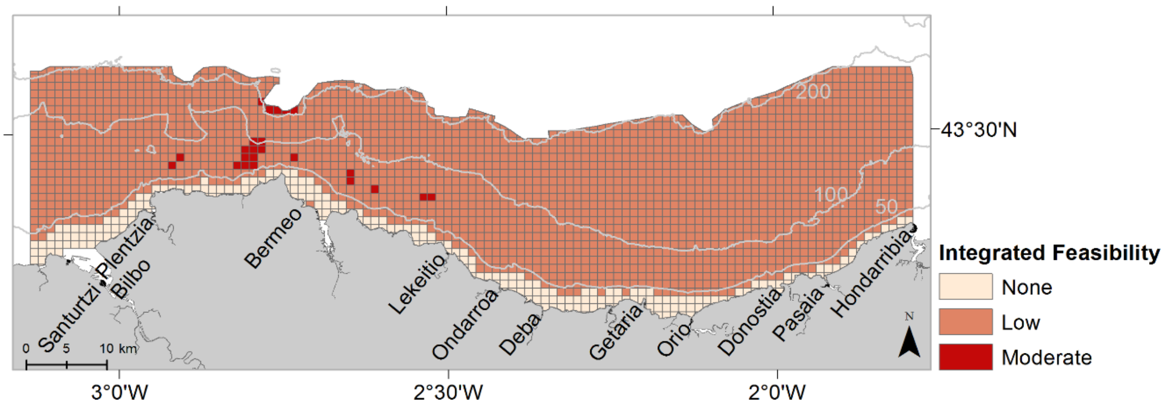


Figure 12: Integrated wind energy platforms foundation feasibility map within the Basque continental shelf.

3.2 Effects of potential future activities on offshore windfarm feasibility in Basque Country

Two scenario analysis were performed: (i) new underwater cable connection routes, and (ii) new proposed MPAs. Among four alternative routes for cables, route 1 has the longest length and it goes closer to the Basque coastline. However, inclusion of route 2 and route 3 cause a bigger decrease in the feasibility results (11 and 9 km^2 decrease in moderate feasibility areas respectively) (Table 10). Besides these two scenarios, route one and four also passes by the moderate wind farms feasibility areas (8 km^2 decrease on moderate feasibility areas).

The second scenario results showed that considerable amount of moderate feasibility areas would be affected with the designation of new MPAs, and consequently decreasing the feasible areas for offshore floating wind development (18 km^2 decrease in moderate feasibility areas).

Table 10: Integrated feasibility results of spatial scenarios including four underwater cable routes and marine protected areas (MPAs) and their effect on integrated feasibility (feasibility in km^2 and percentage of the total area in parentheses).

Integrated Feasibility levels	**Current feasibility**	**Scenario: Cable 1**	**Scenario: Cable 2**	**Scenario: Cable 3**	**Scenario: Cable 4**	**Scenario: MPA Proposal**
Low	2052 (87.1 %)	2060 (87.4 %)	2063 (87.6 %)	2061 (87.5 %)	2060 (87.4 %)	2070 (87.8 %)
Moderate	23 (0.97 %)	15 (0.63 %)	12 (0.50 %)	14 (0.59 %)	15 (0.63 %)	5 (0.21 %)
None	280 (11.8 %)	280 (11.8 %)	280 (11.8 %)	280 (11.8 %)	280 (11.8 %)	280 (11.8 %)
Total	2355 (100 %)	2355 (100 %)	2355 (100 %)	2355 (100 %)	2355 (100 %)	2355 (100 %)

3.3 Offshore wind farms feasibility within the Northeast Atlantic and Western Mediterranean regions

For the extensive study area, the model outline and results could be seen in Figure 13. The integrated feasibility levels for floating offshore wind farms highlights that 4% of the study area (21,600 km^2) shows very high, 5% of the area (30,000 km^2) has high, 5% of the area

(30,000 km^2) has moderate and 86 % of the area (522,000 km^2) has low feasibility for floating offshore wind platforms.

In terms of wind power density for 100 m height wind turbines, study area has very high, high, moderate and low wind areas 12%, 15%, 16%, and 19%, respectively. Furthermore, 18% of area has suitable shallow water areas (below 100 m depth) and 18% of area has rocky seafloor which makes it unfeasible for floating wind farms. In the sense of other activities, marine traffic is very high and high in 5% and 8% of the study area, respectively. In 28% of the area there are operational MPAs and in 2% of the are there is high density of fishing activity.

Visualisation of these results demonstrated that feasibility areas were concentrated in the northern coastline of the study area, in the Atlantic (Figure 14). More specifically, very high feasibility areas were found in the northern coasts of Scotland and Ireland. In addition, high feasibility areas were found in eastern and western coastlines of United Kingdom and in eastern coastline of Ireland. Apart from this, high and moderate feasibility areas were identified in the Gulf of Lions, France. In terms of moderate feasibility, model demonstrated areas in English Channel and north-eastern coastline of France. In contrast to these results, there are no areas showing high or moderate feasibility in the two southern countries including Spain and Portugal.

Furthermore, scenario results demonstrated a significant increase in feasibility areas due to the change in bathymetric limitation from 100 m to 200 m water depth (Appendices, Figure A2). As a result of this change, "very high" and "high" feasibility areas were increased by 1.4% (8,400 km^2) and 2% (12,000 km^2), respectively. These new "very high" and "high" feasibility areas were identified in Galicia (northwest coast of Spain), and Atlantic coast of Ireland and Scotland.

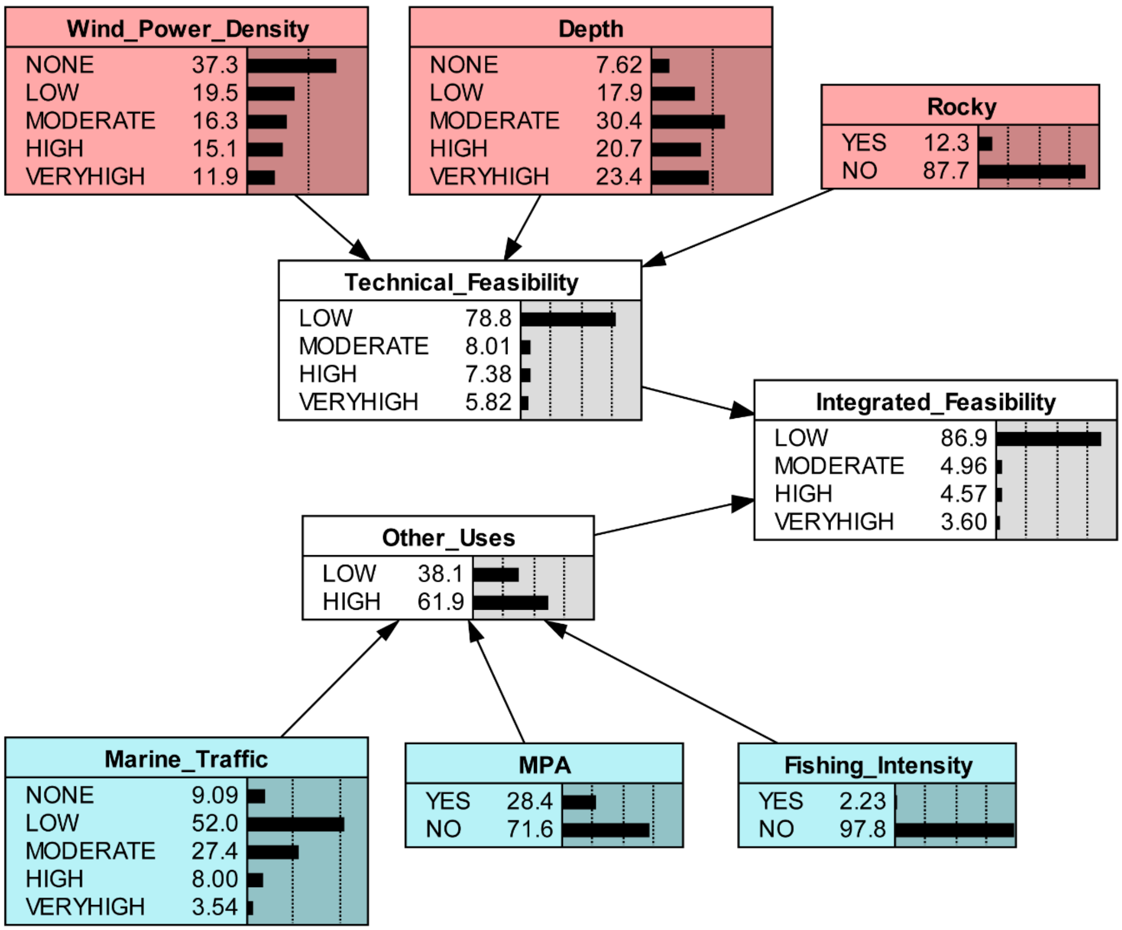


Figure 13: Bayesian Belief Network model for integrated feasibility for offshore wind platforms within the Northeast Atlantic and Western Mediterranean regions. (MPA: Marine Protected Area).

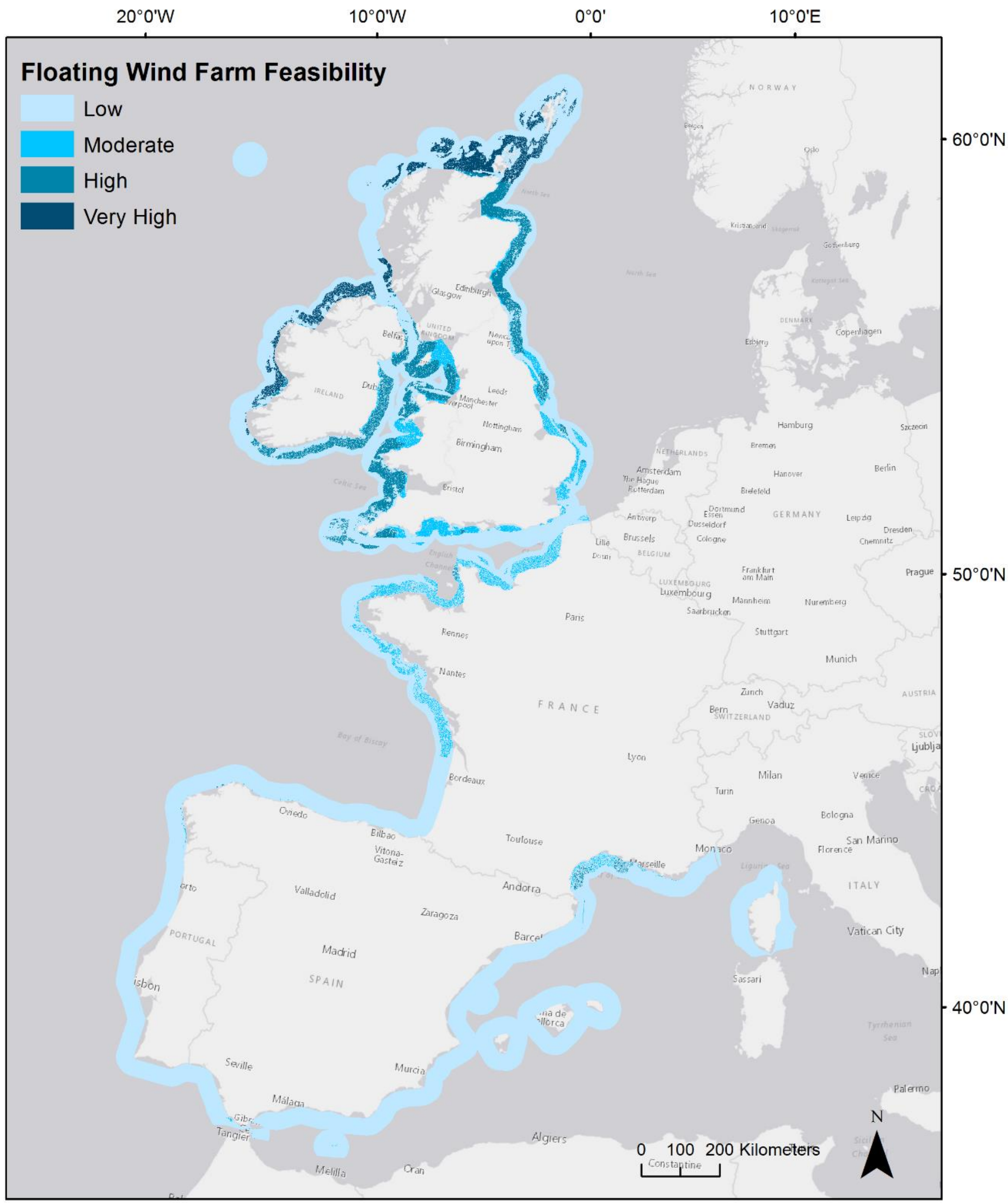


Figure 14: Integrated wind energy platforms foundation feasibility map within the Northeast Atlantic and Western Mediterranean regions.

4. Discussion

Our research provides a novel EB-MSP DST approach for an integrated and spatially-explicit offshore wind farms site feasibility identification. By implementing this approach, users can identify feasible locations for wind farms, in addition to incorporating maritime activities and environmental considerations. The applied model is capable of running at different levels of complexity and scale, whilst still producing valid results. Local and European scale analysis both provided expressive feasibility results reflecting the current limitations and future scenarios. Using the Basque Country as an example, model results did not demonstrate any high feasibility areas due to high production cost, low level of wind power and narrow continental shelf. In the previous studies, Colmenar-Santos *et al.* (2016) also pointed out geophysical characteristics of the area as the reason of low feasibility of offshore wind technology. Since it is likely to have lower feasibility areas with higher model complexity, inclusion of environmental factors (3 ecosystem components and pressures) and competition for space with other uses (10 marine activities) reduced the overall integrated feasibility and space availability for windfarms. In contrast to the first model run, European scale analysis showed high and very high feasibility areas. Model was operational despite issues with data availability, model assumptions and simplification. In larger scale analysis, depth, MPAs, and seafloor characteristics were identified as the main factors limiting the available space for wind farm development (6%, 4%, and 3% decrease in high and very high feasibility areas respectively).

In addition to these model outcomes and feasibility limitations, two model structure showed differences due to data availability. In comparison with first model run with 15 model components, European scale model could be operational with six input components derived from publicly available information. While analysis in Basque Country gave local and detailed spatial outcomes considering cost of production, technical and environmental components and marine activities, European scale analysis could show less detailed but promising outcomes considering three technical components and three limiting marine activities. Model outcomes showed a strong equivalence between projected feasibility and developed or proposed wind farms (Table A9). Thus, the model operates at varying spatial scales, with the ability to alter the complexity of the model in accordance with data availability, thus adding value to planning processes at multiple scales.

It is acknowledged the need of incorporating potential conflicts in addition to environmental constraints in planning process (Gimpel *et al.*, 2018b; Varela-Vázquez and Sánchez-Carreira, 2017), especially when allocation of new activities is analysed. Our approach incorporates aspects of EB-MSP through the integration of ecological, social and economic aspects into feasibility assessments, rather than solely technical limitations. An additional component of the model is the integration of a cumulative visibility index (CVI), that includes the concept of cumulative viewshed from multiple observation points as criteria to improve visibility evaluation for infrastructure siting (Llobera, 2003). Visibility aspects belong to the most relevant social impacts from offshore wind farm development (Bishop and Miller, 2007; Kaldellis *et al.*, 2016) as they can affect local communities and economic activities depending on coastal landscapes resources (Depellegrin, 2016). Furthermore, our framework allows for flexibility by incorporating specific ecosystem components through various data sources. The consideration of environmental and economic factors in addition to technical limitations allows users to incorporate the complexity of marine environment in BBN, further refining results for their specific context depending on data availability. Recently, several studies on site selection for offshore wind energy (Göke *et al.*, 2018; Kim *et al.*, 2016; Weiss *et al.*, 2018) were published. In contrast to other aim-specific EB-MSP DST approaches solely focusing on a specific planning element, the applied modelling framework allows users to include and relate each planning element in an integrated way. The approach presented here, integrates all dimensions of marine environment and demonstrates their relationships in an extensive network. This capability of BBN modelling approach can make a significant contribution to planning processes by gathering all factors in one broad model (Pascual *et al.*, 2016). Thus, the model works at varying levels of complexity and data availability, with further application in modelling different scenarios.

In this way, use of future scenarios underpins adaptive management, allowing consideration of changing spatial allocations and management decisions with time (Mahmoud *et al.*, 2009). For example, due to EU biodiversity targets for 2020 (Amengual and Alvarez-Berastegui, 2018) in accordance with Aichi Biodiversity Targets (e.g. at least 10% protected marine areas) (Hagerman and Pelai, 2016; United Nations, 1992a,2010), the development of future offshore wind farm areas will be increasingly challenged with the allocation of new MPAs (Börger *et al.*, 2015). In this context, significant impact of conservation scenarios on site feasibility was observed within the Basque Country case study. The analysis was performed by using MPA proposals, and the same approach could be applied for different conservation targets. However, co-allocation opportunities of MPAs and windfarms could be also considered in the future conservation scenarios (Ashley *et al.*, 2018). From exclusion to co-allocation, different conflict levels could be defined in the scenario analysis. As seen in the scenario with underwater cables, construction and buffer zones will reduce feasibility and are accounted for within model results. Moreover, present feasibility conditions are constrained by bathymetry, where current technologies limit floating offshore wind farm development to 100 m water depth. However, the broad-scale model incorporated possible advances in technologies where floating wind farms may overcome these bathymetric limitations and can be established up to 200 m water depth. According to this scenario, technological advancements may create new opportunities and increase feasible offshore space for countries like Spain and France in the future.

Application of scenario analysis, thresholds and resilience thinking can expand awareness of the potential outcomes of planning decisions, as well as of the probabilities and consequences (Polasky *et al.*, 2011). Therefore, scenario-based applications and trade-off analysis can inform and improve the decision-making processes and help space and resources use optimisation to reduce overall losses for marine uses. Moreover, these applications can also be beneficial to analyse strategic targets such as the ones defined in Blue Growth strategy (Rodríguez-Rodríguez *et al.*, 2016). Burgess *et al.* (2018) defined the initial step of Blue Growth strategy as clear objectives, quantified trade-offs and maximum likelihood of finding win-win solution. Spatial scenarios regarding to economic activities such as wind energy, aquaculture, fishery or tourism, can identify space requirements to achieve Blue Growth targets. Further, broad-scale feasibility analysis may highlight transboundary management options considering individual and common planning priorities for countries.

A challenge for BBN modelling is the requirement of data discretization. Although discretization has advantages such as faster computation or easy demonstration of results (Chen and Pollino, 2012), the process leads to a loss of information. Thus, users must be aware of how data is discretized and recognize how feasibility results and model performance may be affected. Discretization could also incorporate cut-off values from legislations and stakeholders, to better integrate local knowledge of the activity at different spatial scales. Another important challenge for any modelling approach is data quality and availability (Stelzenmüller *et al.*, 2010), where reliability of feasibility results from the present approach are data dependent. In the applied framework, feasibility is spatially constrained by ecosystem components and maritime activities, where the absence of data may cause an increase in feasibility. Similarly, low data quality for marine activities results in less spatial conflict which may lead to an increase in feasibility. However, the framework may account for these deficiencies through updating the model with new data as they become available. In this context, developments on online data provision are significantly important for the model utility and reliability. Although there are recent developments in broad scale data sharing such as European Atlas of the Seas[1] () and EMODnet[2] (), data portals with high resolution spatial data on environmental components and marine activities are required.

5. Conclusions

Our BBN approach has allowed incorporating socio-economic and environmental elements, in addition to technical limitations, to determine feasibility for floating offshore wind farms in the context of EB-MSP. Through operationalizing this approach by a spatially explicit BBN model, both at local (Basque Country) and regional (North East Atlantic and Western Mediterranean) scales, we have demonstrated the operationalisation of the model in large areas. It was acknowledged that regional scale analysis can support decision makers by

[1] https://ec.europa.eu/maritimeaffairs/atlas/maritime_atlas
[2] http://www.emodnet.eu

providing a big picture of the potential feasible areas, then the local scale analysis is required using more detailed and reliable data for concrete decision making. In addition, the BBN model allowed to define and analyse future scenarios which can enhance or compromise the feasibility of floating wind farms allocation, assisting managers and policy-makers in taking the best management decisions in MSP. Future works should also consider technological improvements in floating wind farms, which overcome present technical constraints.

CHAPTER 4

Visioning for a transboundary and ecosystem-based maritime spatial planning in the Bay of Biscay

SUBMITTED AS

Pınarbaşı, K., I. Galparsoro, N. Alloncle, F. Quemmerais-amice, Á. Borja, Visioning for a transboundary and ecosystem-based maritime spatial planning in the Bay of Biscay (Submitted)

1. Introduction

Increased competition for marine resources and space requires coherent management of oceans. Among other measures, the European Parliament and the Council developed a Directive to establish a common framework for Maritime Spatial Planning (MSPD) (European Union, 2014), which should be transposed into Member States' national legislation, and requiring spatial plans to be established by March 2021. The objective of the directive is to support sustainable development and growth in maritime sectors, applying an ecosystem-based approach (Articles 3 and 14), and to promote the coexistence of relevant activities and uses. Furthermore, it requires Member States to take into account enhanced cross-border cooperation in order to consult and coordinate plans (European Union, 2014). Another European Union directive, the Marine Strategy Framework Directive (MSFD), aims to protect more effectively the marine environment across Europe and to achieve Good Environmental Status (GES), by 2020 (European Commision, 2008). Like MSPD, MSFD also declares that "Member States are required to cooperate to ensure the coordinated development of marine strategies for each marine region or subregion". Diversification and intensification of maritime activities can derive stress and environmental pressures. Therefore, dynamics of marine environment and resources, human activities and associated pressures, opportunities and policy priorities should be taken into account in transboundary ocean governance in line with an ecosystem-based maritime spatial planning (EB-MSP) (Flannery *et al.*, 2015; Jay *et al.*, 2016).

The ecosystem-based management (EBM) is "the integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thus achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity" (OSPAR Commision, 2003). In sectoral perspective, EBM was used as an approach that takes major ecosystem components and services into account in managing activities such as fisheries and aquaculture (FAO, 2013). Such approach requires to balance the human activities according to ocean's capacity to provide ecosystem services, to integrate ecological, economic and social perspectives into planning process, and to support environmental management as well as the political regulations (Katsanevakis *et al.*, 2011). It is suggested that strategic and iterative process for EBM should be followed in three main phases: (i) visioning, (ii) planning, and (iii) implementation (Agardy *et al.*, 2011). In order to have successful planning and implementation phases, a clear visioning should be realized, and an ecologically sound visioning may emphasize how to put EBM into practice and how to measure its success. Although the need for EBM was mentioned in most literature and policy documents on marine management, its implementation and evaluation with MSP were not fully realized due to the broad characteristics of its principles (Ansong *et al.*, 2017).

The first step of an EBM approach is to identify the relevant geographic area for planning and key issues from environmental perspective. This step is called "visioning" (Agardy *et al.*, 2011). In this context, the Bay of Biscay has well-known physiographical boundaries and significant ecological value, within the North-East Atlantic (Borja et al., 2019) (Figure 1). The bay is located in the temperate North-east Atlantic Ocean and positioned off the western coast of Europe and bordered by France and Spain (Figure 1). In France, regions of Aquitaine, Poitou-Charentes, Pays-de-la-Loire, and Brittany, and in Spain, regions of Galicia, Asturias, Cantabria and Basque County have coastline to the Bay of Biscay. Total population in these regions is almost 19 million people (7 million in Spain and 12 million in

France) and it equals to 14% of Spain and 18% of France population. In terms of economic power of the coastal regions in the Bay, average gross domestic product (GDP) per capita is 90% of EU average in France regions and 83% of EU average in Spain regions in the Bay of Biscay. Furthermore, unemployment rate is 8% in France regions, and 12% in Spain regions in the bay (Eurostat: https://ec.europa.eu/eurostat).

Actual surface area is about 175,000 km^2 (i.e. 103,000 km^2 (59%, of the total area of the Bay of Biscay) in France, and 72,000 km^2 (41% of the total area) in Spain exclusive economic zones (EEZ)) and a maximum depth of 4,800 meters (Borja *et al.*, 2019a). Regarding to ocean floor, France has considerably larger continental shelf (64,000 km^2, 63% of its EEZ in the bay) than Spain (14,000 km^2, 20% of its EEZ in the bay). Besides, it has vital seafloor habitats as spawning and feeding grounds for several fish species (e.g. hake, megrim, anchovy, mackerel, etc.) as well as for species of birds and cetaceans (García-Barón *et al.*, 2019b; Pascual *et al.*, 2013; Waggitt *et al.*, 2020). In terms of benthic habitats, France EEZ in Bay of Biscay consist of sublittoral sediment (60%), deep-sea bed (34%), circalittoral (5%) and infralittoral (1%) rock habitats. In contrast, a large proportion of Spain EEZ in the bay consist of deep-sea bed habitat (83%). Besides, sublittoral sediment (12%) and circalittoral rock (5%) habitats take place in a smaller area compared to France. Main human activities are shipping (with important commercial harbours, e.g. Nantes-Saint-Nazaire, Bordeaux, Bilbao, Gijón,), fishing (both pelagic and demersal, including recreational, traditional and industrial fishing), tourism, coastal discharges and dredged sediment disposal (Borja *et al.*, 2019a). Besides, renewable energy exploitation and offshore aquaculture are emerging activities (SIMNORAT, 2018b).

Its specific and temperate biogeographical conditions and biological richness (e.g. around 400 species of fish, 100 species of copepods, and 28 species of cetaceans) makes it different than other regions around the bay (Valdés and Lavín, 2002), presenting species adapted to warmer conditions compared to the surrounding areas of Brittany to the north and Galicia to the west regions presenting species adapted to cold waters due to the upwelling areas in these regions. Thus, considering the above-mentioned particular biogeographic characteristics, the Bay of Biscay could be defined as one management unit in EBM. This particular consideration of the bay as one planning unit provides opportunities to improve sectoral and environmental management by integrating whole ecosystem considerations, and it requires a transboundary visioning. Further, mobility of human activities across borders and ecological conditions make it essential to enhance cross-border regulations, strategies and cooperation to ensure coherence across biogeographical boundaries and to use common knowledge on changing conditions of marine environment (Valdés and Lavín, 2002).

Considering above-mentioned characteristics, this research aims to identify the key issues and challenges in order to raise recommendations for a transboundary EB-MSP in the Bay of Biscay for achieving socio-economic and environmental objectives based on a holistic vision of economic, environmental and social settings, and present management practices.

Table 11. International conventions, organizations, agreements and directives which may support a transboundary ecosystem-based maritime spatial planning in Bay of Biscay.

Name	Type/Focus	Focus	Description
The United Nations Convention on the Law of the Sea (UNCLOS)	International Convention	Environmental	UNCLOS is the legal basis to signing parties for international marine regulations and duties.
Convention on Biological Diversity (CBD)	International Convention	Environmental (Conservation)	CBD aims the conservation of biological diversity; the sustainable use of its components; and the fair and equitable sharing of benefits arising from genetic resources.
International Maritime Organization (IMO)	International Organization	Sectoral (Marine traffic)	IMO provides rules, regulations and bases for marine safety, efficiency of navigation, and control of marine pollution from ships.
Food and Agriculture Organization of the United Nations (FAO)	International Organization /	Environmental / Sectoral	FAO is a specialized agency of the United Nations that leads international efforts to defeat hunger.
Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention)	Regional Convention /	Environmental	OSPAR aims international cooperation on the protection of environment and elimination of marine pollution of the area.
Atlantic Strategy	Regional Strategy and Initiative	Sectoral	It aims to promote entrepreneurship and innovation; and to improve accessibility and connectivity (https://atlanticstrategy.eu). Accordingly, an action plan was developed in the five Member States with Atlantic coasts (Ireland, the United Kingdom, France, Spain and Portugal) to realize the implementation of this strategy.
Maritime Spatial Planning Directive (MSPD)	EU Directive	Sectoral	MSPD aims to support sustainable development and growth in the maritime sectors, applying an ecosystem-based approach, and to promote the coexistence of relevant activities and uses.
Marine Strategy Framework Directive (MSFD)	EU Directive	Environmental	MSFD aims to achieve good environmental status (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend.
Water Framework Directive (WFD)	EU Directive	Environmental	WFD aims to expand the scope of water protection to all waters, surface waters and groundwater achieving "good status" for all waters by a set deadline
Habitat and Bird Directives (HBD)	EU Directives	Environmental	The Habitats Directive ensures the conservation of a wide range of rare, threatened or endemic animal and plant species. The Birds Directive aims to protect all the 500 wild bird species naturally occurring in the European Union.

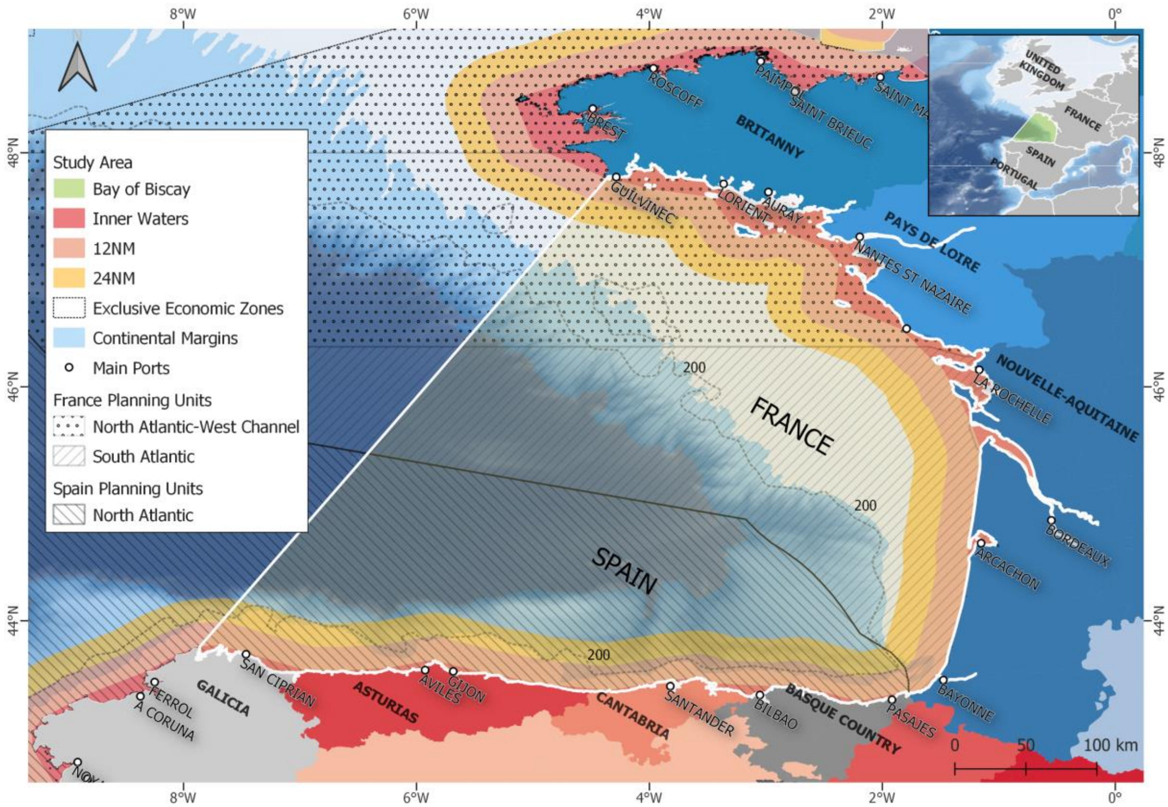


Figure 15: Geographical boundaries of the Bay of Biscay according to International Hydrographic Organization (IHO), exclusive economic zones of France and Spain and the maritime spatial planning units defined by each country.

2. Methods

2.1 Maritime Spatial Planning in France and Spain

MSP is not entirely in place at any of the two countries at the time of this research, but in both cases, MSP implementation process was started by the transposition of the MSPD into national legislation. MSPD was transposed into French legislation through the entry into force of article 123 of law n° 2016-1087 for the 2nd "reconquest of biodiversity, nature and landscapes". Ministry for an Ecological and Solidarity Transition is the national authority in charge of the overall planning process. Regarding to planning efforts; "National Strategy for the Sea and Coast" provides a strategic framework for marine and maritime issues in France (Ministère de la Transition écologique et solidaire, 2017). The strategy clarifies sectoral priorities, national interests, and potential planning actions. According to 6th priority action of this strategy, it is recommended to "build maritime spatial planning to reconcile uses, seek synergies between activities and integrate new activities". To do so, strategic documents are built for each of the four planning areas are used in France (called "façades" in French): (i) East Channel-North Sea; (ii) North Atlantic-West Channel; (iii) South Atlantic; and (iv) Mediterranean. Long- and short-term objectives for each region were defined in these documents, which have been designated as the official MSFD implementation documents. Besides these integrated management objectives, diagnosis of the state on coastal and marine environment, priorities in human activities, environmental impacts and associated activities, main issues, and emerging needs were presented for each coastal region (Ministère de la Transition écologique et solidaire, 2017).

In Spain, the MSPD was transposed through the "Royal Decree 363/2017 of 8 April, establishing a framework for the management of maritime space" and the Ministry of Ecological Transition as assigned as the responsible authority. Previous to transposition of the directive, for the coordination between the ministerial departments of the national government, an Inter-Ministerial Commission on Marine Strategies (CIEM, in Spanish) was created in 2012. A specific working group derived from the commission is currently working for maritime space ordination, and meeting regularly since 2017.

Currently, a regional planning process has been launched, and five sub-regions ("demarcaciones", in Spanish) (North Atlantic, the one covering the present study area, and

South Atlantic, Alborán Sea, Levantine - Balear, and Canary Islands) were defined for which, plans will be developed. Marine strategies for these five marine sub-regions are being developed and these include spatial protection as part of the specific measures for achieving the GES defined by the MSFD (Suárez de Vivero and Rodríguez Mateos, 2012). Regarding to specific sectors ordination, only the aquaculture activity was adopted (JACUMAR, 2019).

2.2 Visioning for Ecosystem-based Maritime Spatial Planning

Formulation and implementation of MSP should start with pre-planning activities (such as specifying area boundaries and goals), and analysis and definition of current conditions (Ehler and Douvere, 2009). Similarly, development of an EBM vision might be facilitated by regional outlooks for complex economic, environmental and social issues and development of a common understanding of the ecosystem (Agardy *et al.*, 2011). Moving towards a clear vision and recommendations for EB-MSP, it is significant to acknowledge situation and weaknesses in existing management and to identify the value of a comprehensive approach. Key stages to accomplish this phase are: (i) settings of the area with economic, environmental and social dynamics, (ii) existing management measures and conservation practices, (iii) identification and analysis of measurable objectives, and (iv) identification of critical issues with recommendations for planning and implementation phases.

To begin with the background analysis and literature review, existing policy and planning documents from both countries, related EU directives and their implementation process (EC, 2017), deliverables from transboundary MSP projects, scientific publications (Flannery *et al.*, 2015; Janßen *et al.*, 2019), and existing transboundary MSP frameworks were reviewed to get an understanding of the current situation in the study area. In addition, existing transboundary planning studies were collated to analyse different methodologies (Jay *et al.*, 2016; Wright *et al.*, 2019). Afterwards, a four executive stages framework was defined for the visioning for EB-MSP in the Bay of Biscay (Figure 2).

Figure 16: Applied visioning steps to reach critical issues and recommendations for a transboundary and ecosystem-based maritime spatial planning (EB-MSP) applied in the Bay of Biscay. MSFD: Marine Strategy Framework Directive.

Spatial distribution of maritime activities and their contribution to national economy were collated and analysed for defining the current conditions. In this stage, external economic databases were used (Eurostat: https://ec.europa.eu/eurostat). According to policy papers and planning documents, potential spatial expansions and economic growth for marine activities were analysed. Outcomes of this stage supported the understanding of shared values and overlapping socio-economic and environmental objectives.

In terms of environmental context, Member States shall, in respect of each marine region or subregion, identify the measures which need to be taken in order to achieve GES in their marine waters (European Commision, 2008). In this context, MSFD progress of France and Spain in the Bay of Biscay were analysed by using first cycle of program of measures (PoM) reported declarations to European Commission. As of 2019, the countries have proposed their programmes in 2017–2018, while they perform the assessment of GES (the first assessment was performed in 2012, and the second cycle assessment status is ongoing). Each PoM was classified according to their geographical scope and then, case study related measures were filtered. Later, these measures were categorized according to related marine activity and focusing ecosystem component. Results of this analysis were used to explain the relationship of the PoM, socio-economic and environmental objectives, and stakeholder expectations.

Following, socio-economic and environmental strategic objectives were collated to analyse the future conditions and to compare both countries. First, socio-economic objectives from both countries were placed in two categories, according to their specificity (strategic and specific objectives). Later, each objective was categorized in terms of focusing MSP dimensions (economic, social and environmental), geographical scale, spatial explicit or not, transboundary value and expected environmental impact. A comparison matrix was filled with the information collected from national policy documents for related marine activity, national MSP documents, and SIMNORAT project deliverables (SIMNORAT, 2018a,b,2019a,b). In addition to above mentioned categories, stakeholder opinions were added for each related socio-economic objective (SIMNORAT, 2019b). As the final category, conservation relationship of each objective was identified in the matrix. As the second task of this stage, strategic and specific environmental objectives were listed from each countries' policy documents. In addition, stakeholder expectations for impacts of each socio-economic and environmental objective to marine ecosystem were collected from the consultation report of French national planning document (Direction interrégionale de la mer Sud-Atlantique, 2018). These expectations were used to analyse and compare environmental and socio-economic objectives from policy documents.

Finally, each information in matrices was used to identify potential issues and challenges that could be faced in the framework of implementing a transboundary EB-MSP. Identified socio-economic objectives, blue economy indicators, future expectations, potential environmental impacts, taken measures and stakeholder opinions were synthesized to reach main critical issues and possible future scenarios that should be undertaken in the further planning exercises. Beside above-mentioned collected information, outcomes of existing planning documents and projects (SIMNORAT, 2019a), were used to define issues and challenges. According to these issues and challenges, recommendations were derived for a transboundary EB-MSP implementation in the Bay of Biscay.

3. Results and discussion

3.1 Social and economic setting

In general, shipping and fishery make the main contribution to both countries' national blue economy with high employment and turnover values (European Commision, 2017a). Important commercial harbours such as Bordeaux, Nantes-Saint-Nazaire, La Rochelle Bilbao, Gijón, (Figure 1), play an important role in constant increase of shipping activity in the bay. Future projections indicate that shipping activity is expected to increase, as in the international context, global demand for maritime shipping is expected to grow 300% by 2050, according to recent projections (ITF, 2019). Although the capacity of harbours in the bay are much smaller comparing to harbours in Northern Europe (e.g. Rotterdam and Hamburg), according to the estimations by SIMNORAT project (SIMNORAT, 2019a), the Montoir-de-Bretagne / Gijón lane is expected to have strong growth and to be labelled as "highway of the sea" in the near future. According to latest data for the Bay of Biscay region (Eurostat: https://ec.europa.eu/eurostat), French ports handled 48 million tonnes of goods, while Spanish ports handled 100 million tonnes of goods in 2015.

Another important and historical activity, fishery (pelagic, benthic and demersal, including industrial, artisanal and recreational fishery) provides a significant contribution to employment and turnover in the Bay of Biscay (Borja *et al.*, 2019a; Pascual *et al.*, 2013). On the other hand, spatial distribution of fishing effort shows heterogeneity in the area due to geographical conditions. While, the wide, shallow and predominantly sedimentary continental shelf in French coast attracts fishers from both countries, the narrow, deep and predominantly rocky continental shelf of Spanish coast limits the available space for industrial fishing activity.

In addition to these traditional human activities, new activities are also emerging in the area such as offshore aquaculture, offshore renewable energy production and electricity transmission cables. Initially, aquaculture activity makes a large contribution to blue economy of the two countries (1.5 billion euros in total). Both, in French and Spanish coast, shellfish and finfish aquaculture activity takes place in very coastal areas, which may have conflicts with fishery, yachting, tourism and other coastal activities, as well as with conservation. Research activities for site suitability and production alternatives for offshore aquaculture are taking place in recent years, and it is expected to have more offshore aquaculture farms in the sea basins of both countries (JACUMAR, 2019). In addition, offshore renewable energy is another emerging activity in the area. France has an offshore wind farm project which is planned to be operational by 2022 in the coast of Nantes, Saint-Nazaire (80 wind platforms, with 480 MW expected capacity) and others are to be planned in the coming years. Besides wind energy, wave energy converters (e.g. Waveroller in Brittany) are in a prototype test process to be the first offshore wave energy facility of France. In Spain, offshore energy projects are also testing their application capability in real ocean environment in BIMEP test site. According to projection of Wind Europe (2017), France will have the capacity of producing 7 GW, and Spain 200 MW by offshore energy platforms in 2030. Another planned activity is the installation of an underwater electricity cable between the two countries. The interconnection cable project between France and Spain in the bay will be consist of 2x1000 MW direct current link which will run mostly underwater (www.inelfe.eu). This project will contribute to 10% interconnection ratio target of Horizon 2020 of European Union.

3.2 Program of measures and conservation practices

Both countries have prepared and reported the first cycle of MSFD PoM declarations to the European Commission. From the total number of measures, 76 from France and 319 from Spain are applied in the geographical scope of the Bay of Biscay. Remarkably, concentration of both countries' PoMs showed similarity in terms of related MSFD descriptors (Figure 3). To begin with, 22% of France and 27% of Spain measures were related with descriptor 1, which aims to maintain the biodiversity. Next, descriptor 4 (elements of food webs ensure long-term abundance and reproduction) was the second ranking descriptor of both countries with 15% of France and 21% of Spain measures. After that, descriptor 6 (the sea floor integrity ensures functioning of the ecosystem) was the third ranking descriptor with 12% of France measures and 21% of Spain measures. Like most concentrated descriptors, less concentrated ones were also similar for both countries. Less than 10% of measures are dealing with descriptor 2 (non-indigenous species do not adversely alter the ecosystem), descriptor 5 (eutrophication is minimised), descriptor 7 (permanent alteration of hydrographical conditions does not adversely affect the ecosystem), and descriptor 11 (introduction of energy does not adversely affect the ecosystem).

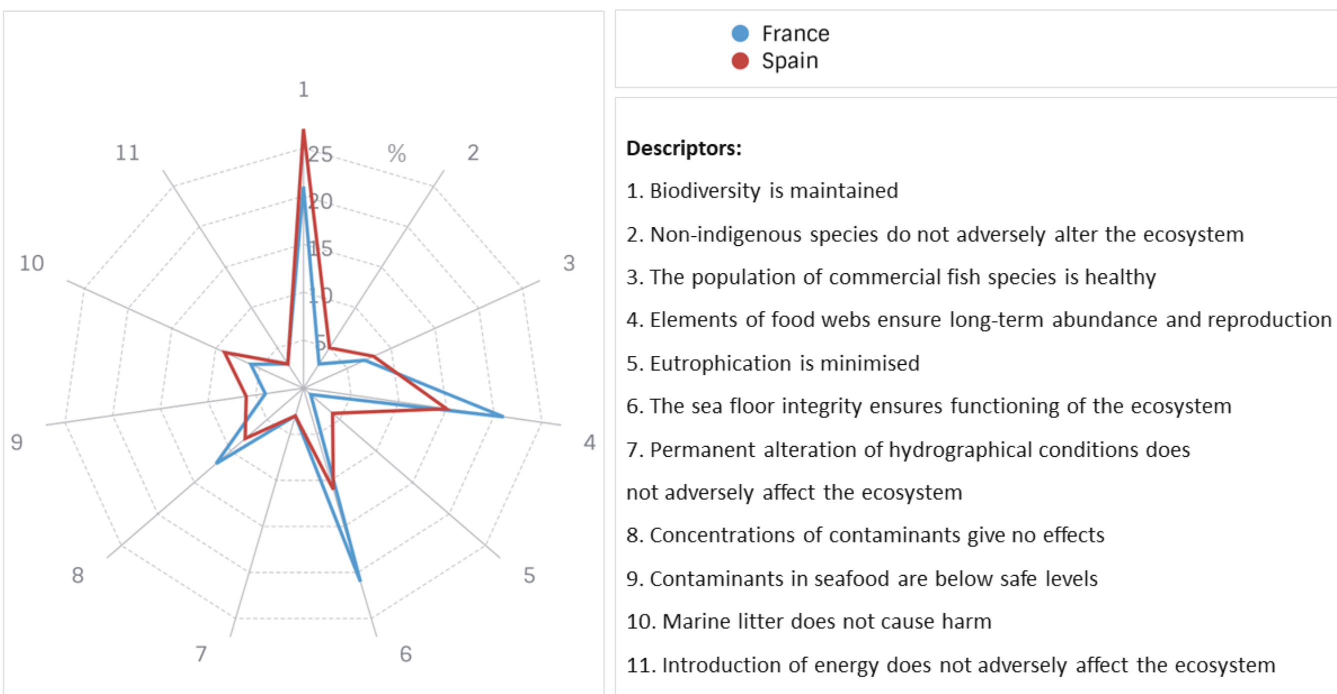


Figure 17: Percentage of Marine Strategy Framework Directive program of measures and the descriptor it applies for Spain and France in the scope of the Bay of Biscay.

In addition to descriptors, each measure was classified according to focus topics including human activities and pressures. Results of this classification showed that France measures were mainly focused on topics related with pollution (15%), fisheries (15%) and management plans (15%). Next measures were related with protected areas (10%), marine extraction (9%), and conservation (7%) (Figure 4). Topics such as regulation, air quality, water quality, noise, aquaculture, environmental awareness, construction and sediment had tackled by less than 5% of measures. In Spain, measures were mostly related with conservation and protection purposes (Figure 5). Main topics were restoration and conservation of marine ecosystems (17%), marine litter (15%), spatial protection (9%), fishing and other exploitation (8%) and research and innovation (8%). In contrast, pressure-related topics such as physical loss, physical damage, energy inputs, nutrient enrichment or waste-water treatment species were tackled by less than 2% of total measures in Bay of Biscay.

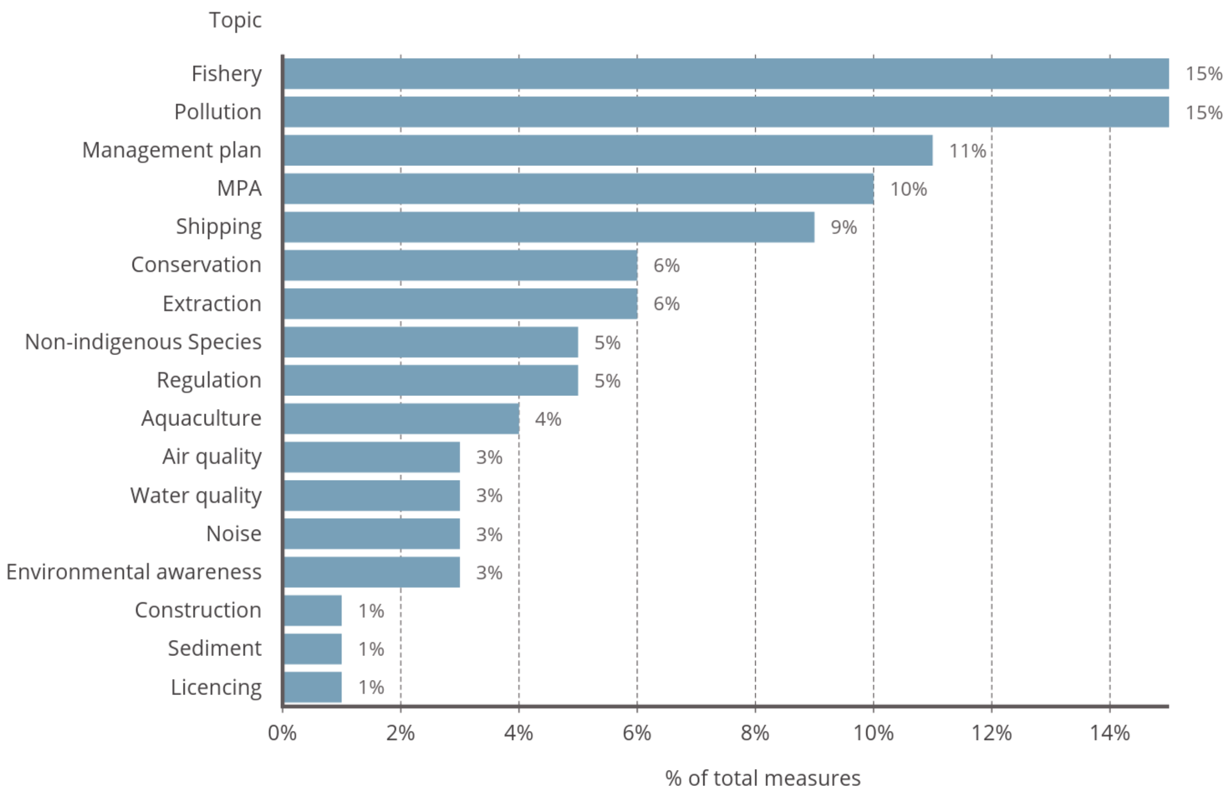


Figure 18: Proportion of focus topic for Marine Strategy Framework Directive programme of measures reported for the Bay of Biscay by France (MPA: marine protected area).

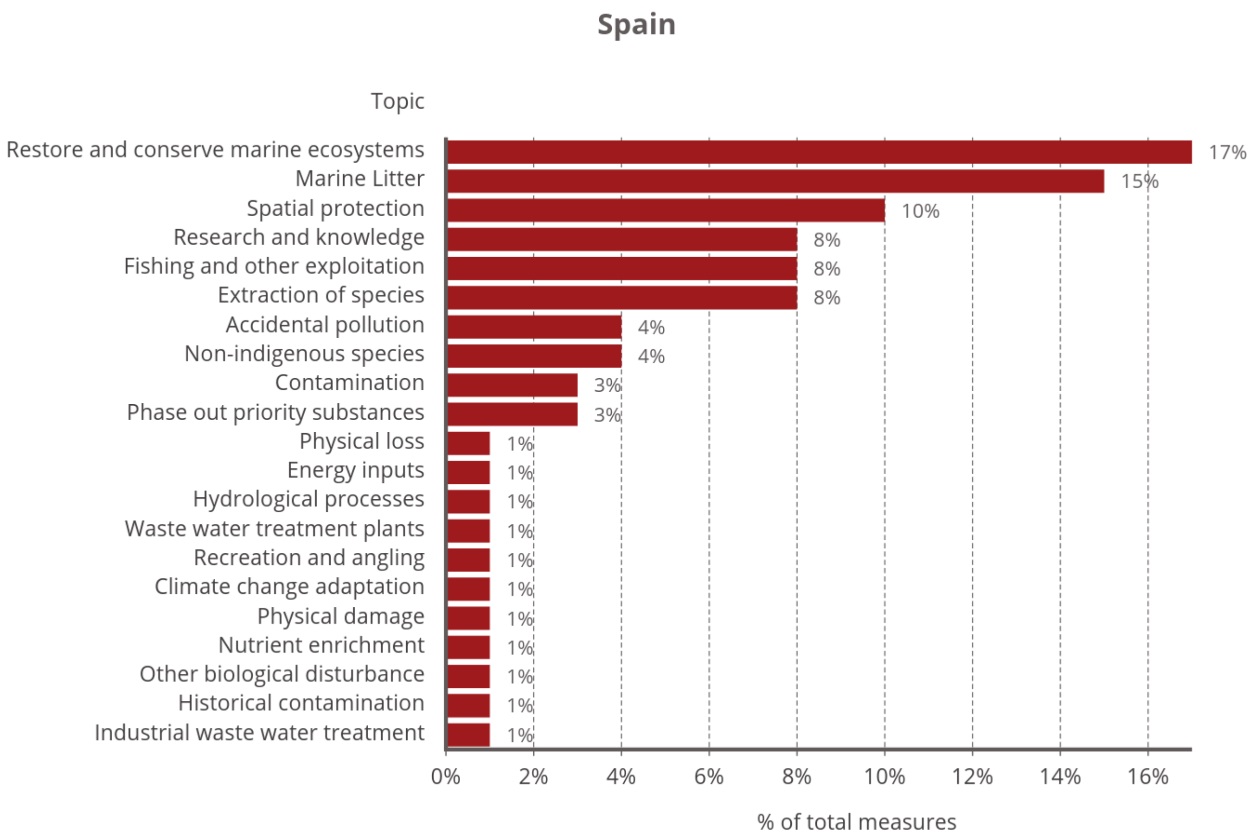


Figure 19: Proportion of focus topic for Marine Strategy Framework Directive programme of measures reported for the Bay of Biscay by Spain.

In terms of conservation activities, there are protected areas designated in the Bay of Biscay for several species (Figure 6). As of 2019, around 64,700 km^2 area (63% of total EEZ in the bay) in France, and around 7,200 km^2 area (10% of total EEZ in the bay) in Spain were designated as Natura 2000 sites (EUNIS Database, www.eunis.eea.europa.eu). These areas are classified as special protection areas and special community importance in Natura 2000 ecological network (Council Directive, 1992). Special protection areas represent 38% of France and 2% of Spain EEZ in the bay, and sites of community importance represent 24%

of France and 8% of Spain EEZ in the bay. In terms of targeting species, sea birds' protection takes the largest space among other species. Although there are large proposed and designated areas for protection, several human activities such as shipping, fishing or aquaculture take place in these areas with respect to their regulations and management plans. As an important example, "El Cachucho" or "Le Danois Bank" takes place in Bay of Biscay in December 2008. It was proposed to be a site of community importance due to the presence of the reef's habitat (Habitat type code: 1170), and in 2009, it was included in the OSPAR network of MPAs. Management plan of the site does not restrict all fishing activity but prohibits the use of bottom-fishing gears to protect vulnerable benthic habitats (Rodríguez-Basalo *et al.*, 2019). Besides El Cachucho, France proposed a large area "Talus du golfe de Gascogne", as site of community importance in December 2017 due to reef habitat (1071) (https://natura2000.eea.europa.eu Site Code: FR5302015). In consistent with SCI, the area was also proposed as a Special Protection Area in 2018 (Site Code: FR5212016). This large area covers marine space up to EEZ border of France and Spain, can make an important impact on protection of living resources. In addition to existing MPAs, recent research activities stated that the present conservation measures are not sufficient to guarantee the proper conservation of the area for cetaceans (García-Barón *et al.*, 2019a).

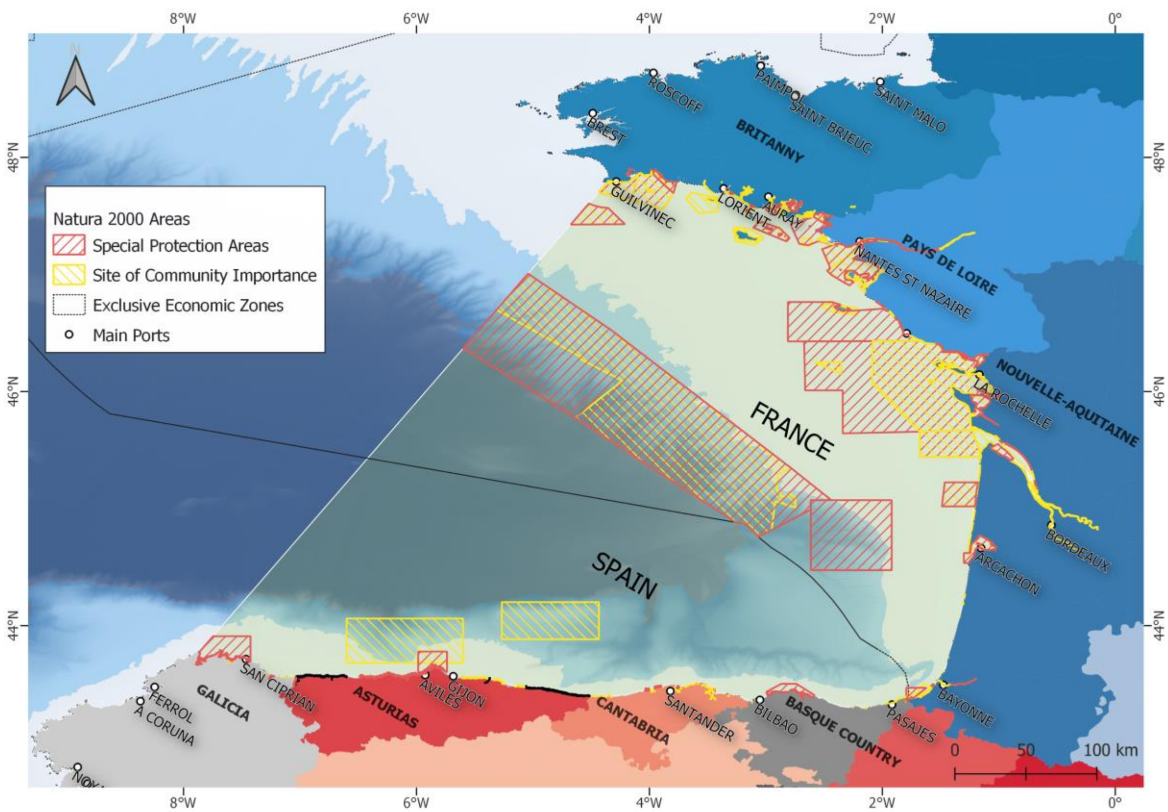


Figure 20: Natura 2000 sites in the Bay of Biscay and the type of the sites (Special Protection Areas and Sites of Community Importance).

3.3 Strategic objectives and future conditions

As a part of its nested maritime strategy, France has identified strategic and specific objectives for its marine space in the Bay of Biscay in order to serve as basis for the 2nd cycle of MSFD implementation process (Direction interrégionale de la mer Sud-Atlantique, 2017). With regards to shipping, main socio-economic objective of France is to ensure the competitiveness and complementarity of ports, and to improve their service and promote modal shift. Accordingly, France aims to foster competitiveness and synergies between Atlantic ports. Besides, it is expected to realize port development schemes consistent with the evolution of economic sectors and ecological and land issues. Similarly, Spain has declared expected increase in the freight transport and port capacities (SIMNORAT, 2019a). Currently majority of ports are not capable to host ships with a capacity greater than 18,000 TEU (Twenty-foot equivalent units - standardized containers). Authorities aim to adapt their ports for ships that might reach capacities of around 24,000 TEU. Potential investments are planned for the purpose of port maintenance (5,000 million €) and network of road and rail access to the ports (400 million €) between 2021 and 2031.

Although there is high growth expectation, there are current environmental concerns in the area. Increasing shipping density brings higher likelihood of strikes (particularly affecting baleen whales and large odontocetes such as sperm and fin whales) (García-Barón *et al.*, 2019b). Besides, shipping is seen as the reason of a growing threat of the introduction of non-indigenous species through ballast waters which can in turn transmit new pathogens to the indigenous species of the bay. France has declared specific environmental measures which are directly related with shipping activity: (i) to reduce or avoid pressure generating direct mortality and disturbance of marine mammals and turtles, and (ii) to limit noise emissions in the marine environment to levels that do not impact marine mammals. Although socio-economic objectives encourage ports extension and economic growth, France has declared environmental objectives that aim to limit coastal artificial infrastructures in order to protect environment.

In terms of fishing activity, socio-economic objectives focus on increasing fishing productivity by modernizing fishing fleet - gears, and management of resources. France aims to develop the fishing fleets while preserving diversity of metiers, including fisheries craft. More specifically, authorities aim to renew and modernize fishing fleets and shore facilities, and to enhance the products and by-products of the fishery. In order to have sustainable fishery and maintaining the resource, they aim to keep resource exploitation at Maximum Sustainable Yield for Common Fisheries Policy stocks and according to sustainability principles for those under local management, with consideration of habitats (Zimmermann and Werner, 2019). In Spain, authorities aim to extend the adoption of best practices in the development of fishing activity to ensure environmental and socio-labour sustainability. According to feedbacks from industry representatives, fishery objectives of Spain mainly focus to get better fisheries possibilities. This means not to increase the number of the vessels but to get better quotas from European Union (SIMNORAT, 2019a).

Three of strategic environmental objectives of France can make direct positive impact to fishing activity. According to these objectives, France aims: (i) to limit pressure on vulnerable or endangered fish species, or even promote their restoration and limit the level of pressure on important fisheries functional areas, (ii) to reduce or eliminate the intake of chemical contaminants in the marine environment, whether of terrestrial or marine origin, chronic or accidental, and (iii) to promote the exploitation of fish and shellfish stocks at sustainable maximum sustainable level. Besides, objectives on contamination, waste, and physical pressures can indirectly contribute to health of fishery activity. In both countries, fishery industry is involved is being promoted to include their vision in the elaboration and development of MPA management plans in the last years. In France, fishery stakeholders were directly involved in designation of protected areas.

Regarding to aquaculture activity, France aims to improve water management to ensure the sustainability. For this purpose, specific objectives focus to improve the quality of water in the aquaculture context, to preserve environmental parameters adapted to the farming cycle of cultivated species, and to limit health and zoo-sanitary risks. Besides, they aim to control shellfish waste (Concession Cleaning and Shellfish Equipment) and to reduce the risk of introduction and spread of non-indigenous species in order to continue transition to ecosystem-friendly aquaculture. On the other hand, Spain aims to simplify and homogenize the legal and administrative framework and strengthen the representativeness of the sector (JACUMAR, 2019). Besides, it is aimed to increase Spanish aquaculture production, based on the improvement of sectoral planning and the selection of new areas of aquaculture interest. Closer relations between the scientific community and the sector will be designed to reinforce the competitiveness of the sector trough Research and Development (R & D). As of 2019, two new offshore aquaculture interest areas were declared (Basque Country and Asturias) in the aquaculture activity planning document. According to this planning document, it is expected to "increase Spanish aquaculture production, based on productive investments and the improvement of sectoral planning within the framework of integrated management of coastal zones".

In addition to the above-mentioned activities, both countries refer to renewable energy sector in their policy documents, and they will keep supporting industry R & D for deployment of these technologies. France also declared their intention to integrate sediment extractions into a sustainable development approach that meets the needs of sectors and territories.

France published detailed documentation of strategic objectives and these objectives were consulted by related stakeholders, evaluated through the Strategic Environmental Assessment (Sud-Atlantique, 2017), and submitted to the stakeholders by public consultation. In this consultation, stakeholders were asked to select specific socio-economic and environmental objectives which they consider that can have positive and negative impact to targeting ecosystem features and pressures (Figure 7). According to these selections, it was projected that environmental objectives were mainly targeting food webs, commercial species, fish and cephalopods, coastal structures, benthic habitats, sea birds, mammals and turtles, and noise pressure (Figure 3). However, there were not many objectives targeting contamination, non-indigenous species, hydrodynamic conditions, eutrophication, and waste. On the other hand, main negative impacts of socio-economic objectives were related with coastal structures, contamination, and impacts on benthic habitat and seabirds. Beside these negative impacts, a couple of positive impacts of socio-economic objectives were expected mainly on contamination, benthic habitat and waste.

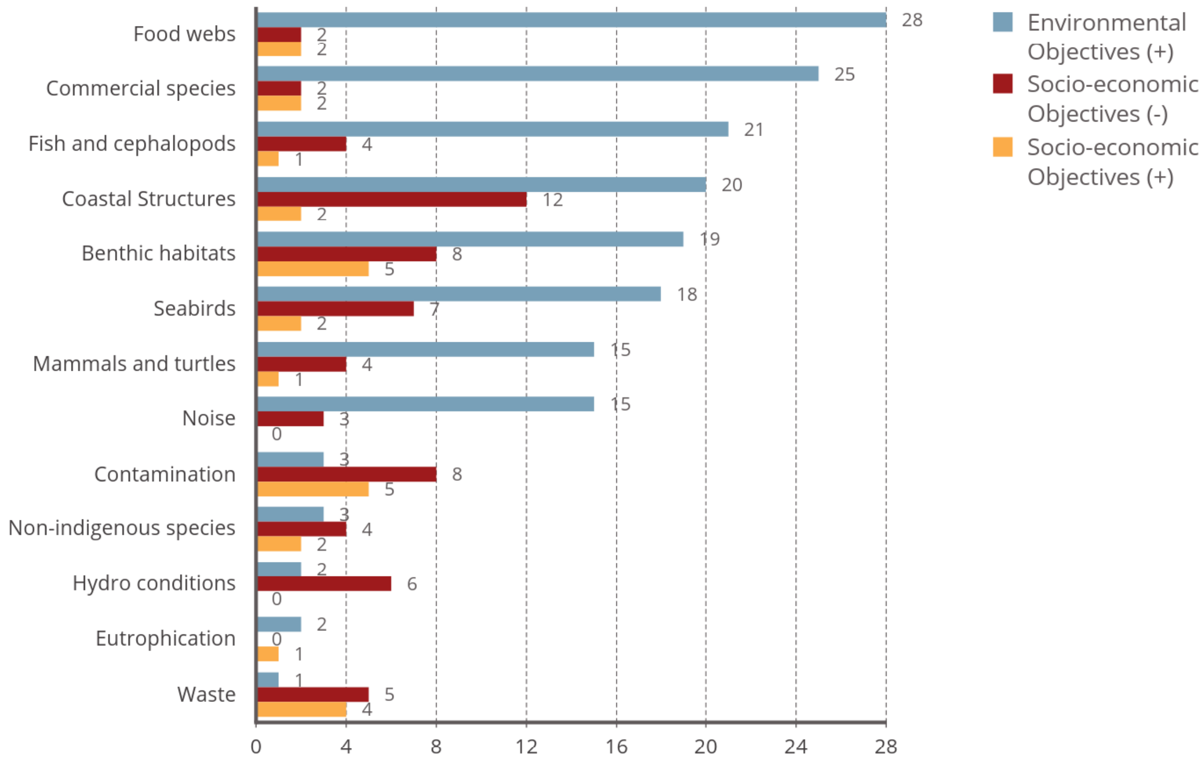


Figure 21: Number of impacts of environmental and socio-economic objectives of France on ecosystem features and pressures, defined by stakeholders in the planning process (positive impacts by environmental objectives and negative and positive impacts by socio economic objectives) (adapted from the environmental consultation report of Direction interrégionale de la mer Sud-Atlantique (2018)).

4. Critical issues and recommendations

Fishing, aquaculture, marine traffic, sand extraction and waste disposal were the main activities causing pressures to marine ecosystem in the Bay of Biscay in the early 1990s according to Lorance et al. (2009). However, fishing appeared to be the only activity having documented and widespread impacts on this ecosystem, while other impacts were classified as local. Since those years, several studies were performed on the existing and potential human activities and related pressures (Borja *et al.*, 2019a; García-Barón *et al.*, 2019b; Mérillet *et al.*, 2018; Pascual *et al.*, 2013) along with the assessment studies for environmental status (Borja *et al.*, 2011; Borja *et al.*, 2019b; MITECO, 2019) in the Bay of Biscay. Recently, new challenges such as coastal artificialization and new industries (renewable energy platforms) are expected to create conflicts in terms of environmental risks and available space. Besides, increasing use of coastal areas for tourism purposes can be considered as an important problem. Considering aforesaid developments and challenges, six key issues were identified and discussed in order to promote EB-MSP in the Bay of Biscay.

- **Space conflicts caused by limited space in the continental shelf**

Along with analysis of existing and planned human activities, sectoral space conflict on fisheries were identified related with the geographical conditions of the bay. It can be said that transboundary interactions can cause resource competition, which may affect fishing stocks mainly in French continental shelf. According to stakeholders, historical fishing border should remain respected in the bay, and Spanish and French fishery representatives should agree on fishing quotas (SIMNORAT, 2019b). Besides current fishing activity, separation of United Kingdom from European Union can stress these cross-border interactions through a transfer of the fishing effort. Therefore, impacts of Brexit on fishery activity should be analysed and discussed by the authorities of both countries (Boyes and Elliott, 2016). On the other hand, there is a significant reduction in the number of fishing vessels in both countries due to EU regulations (Engelhard *et al.*, 2015).

Moreover, potential protected areas along the border, should be discussed further with fishery industry from both countries in order to address cross-border risk assessment. Changes in historical fishing borders should be analysed in order to see potential future environmental risks. Demands from fishery stakeholders such as more adequate and acceptable quotas from EU and expectations of new protected areas should be considered, and future projections of these management measures should be shared. However, all stakeholders should be informed that designation of Natura 2000 areas is to achieve or maintain a favourable conservation status of habitats and species named in the EU Birds and Habitats directives. As management measures, these areas are likely to lead to a reduction and/or change of fishing pressures. Although that can cause an initial decline in catches from the site itself, this measure could increase local populations and potentially even improve carrying capacities through effects on habitats (Pedersen *et al.*, 2008).

- **Development of offshore wind projects and its economic impact**

According to estimations in France, first large wind farm project will produce 480 MW energy in 2022 in Saint-Nazaire (http://parc-eolien-en-mer-de-saint-nazaire.fr). The planned production is equivalent to covering the equivalent of 20% of the electricity consumption of the Loire-Atlantique region. Although it is not expected to have a high regional economic impact, project capacity highlights the potential of the Bay of Biscay for similar renewable energy projects. New offshore projects can be expected in the bay since Member States are targeting 32% of renewable energies in its final energy consumption by 2030 (del Río *et al.*, 2017). On the other hand, geographical conditions of Spanish coast is not suitable for large scale renewable energy projects with current technology (Pınarbaşı *et al.*, 2019). Due to the deep waters of the bay, it would be recommended that research activities should focus on floating technologies.

- **Environmental threats and recommended joint risk assessment**

Significant bycatch mortalities on the common dolphin and harbour porpoise (Lassalle *et al.*, 2012), increasing probability of collision of cetaceans, oil spill by vessels, marine litter caused by fishing and shipping activities (van den Beld *et al.*, 2017), and noise (Pirotta *et al.*, 2019) can be listed as the main environmental threats in the bay. Besides, recent accidents (e.g. Modern Express in 2016 and Grand America in 2019) in the bay, point out high level risk of shipping for marine environment due to rough weather characteristics of the area. Besides pressures from ocean-based activities, anthropogenic pressures coming from land takes an important place in environmental risks. As it was seen in France, coastal and MSP measures can be merged to understand land-sea interactions and take actions accordingly (Schlüter *et al.*, 2020).

According to results, France (10%) and Spain (27%) have published significant proportion of their measures related with conservation and protection of marine areas. Besides, according to recent studies new and transboundary MPAs should be considered in the bay to protect marine mammals, seabirds and seafloor habitats (García-Barón *et al.*, 2019a). However, declaration of new MPAs are not enough for above-mentioned potential environmental threats by human activities. It can be recommended to perform a comprehensive and cross-border environmental risk assessment in the bay to identify threats and their potential magnitude, and to promote sustainable development through the integration of environmental considerations into the planning process as it was performed in other sea basins (David et al., 2013; Piet et al., 2019). In national planning processes, Strategic Environmental Assessment (SEA) which would supplement the existing provisions on environmental impact assessment in a transboundary context (Directive 2001/42/EC), should be performed as a systematic decision support process, aiming to ensure that environmental and possibly other sustainability aspects (Rehhausen *et al.*, 2018).

- **Increasing concern on marine litter in the Bay of Biscay**

Another concern is continuously increasing marine litter in the Bay of Biscay. In both countries 15% of the measures were related with marine litter or pollution topics. Recently, several studies were performed to understand the source, distribution and type of the litter in the area (Lopez-Lopez *et al.*, 2017). According to van den Beld *et al.* (2017) the main source of marine litter could be linked to fishing activities, major shipping lanes and river discharges. Due its dynamic characteristics, marine litter is a cross-boundary issue (Basurko et al., 2015). As such, authorities from both countries must work together to tackle this particular problem. As a semi-enclosed area, Bay of Biscay is an important accumulation zone where the concentration of floating marine litter is higher in comparison to other European regions (Lebreton *et al.*, 2012). Since 2003, local authorities have supported active fishing for floating marine litter, and it is recommended to continue financing fishers to catch floating marine litter. Besides, new studies should be undertaken to improve knowledge on types and impacts of the litter in order to create efficient solutions to marine pollution problem and prevent its occurrence.

- **Management measures and strategic objectives**

The PoMs of the two countries in the Bay of Biscay are difficult to compare and the lack of relevant information does not allow a complete understanding of how each programme will contribute to achieve the GES of the sub-region (Cavallo et al., 2018). Besides, there is a high difference between number of measures from France and Spain which makes it essential to analyse by percentages. According to analysis of measures, biodiversity, fishing and pollution related issues were highlighted to reach GES in the bay. Following PoM, measures from the first MSFD cycle implementation, environmental objectives, part of the second cycle implementation, are focused on the similar problems. However, it was seen that objectives from both countries were very broad and difficult to measure. EBM requires measurable objectives in visioning and planning phases to monitor their applicability (Agardy et al., 2011). It is recommended to have clear and quantitative objectives in the further planning efforts to both countries, however it is difficult to achieve because of existing political and economic objectives. As it was seen in planning documents from France, environmental targets should be based on pressure and impacts of human activities since this is the most effective way to achieve GES (Cavallo et al., 2016). In this context, impacts of socio-economic objectives and focus areas of environmental objectives showed differences in France. In order to consider socio-economic objectives, potential impact of coastal structures, contamination and impacts on benthic habitat derived by socio-economic activities and objectives should be considered in environmental objectives preparation.

- **Governance: Cross-border cooperation and need for process leaders:**

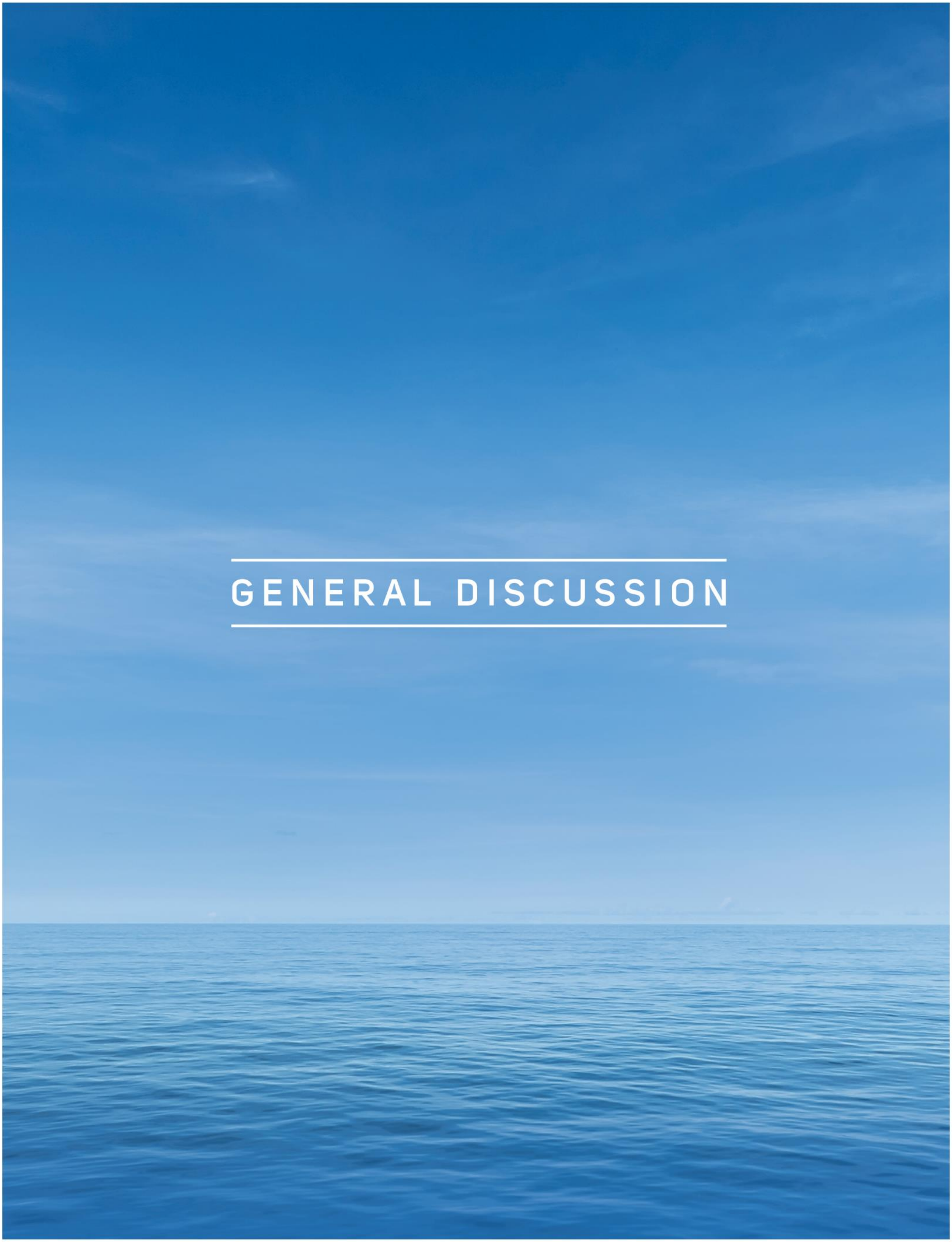
As it was mentioned in directives, Member States' commitments should be achieved through voluntary agreements, reached by consensus amongst the relevant stakeholders. Transboundary thinking has become vital in the management of shared seas and implies various types of cross-border collaboration (Morf *et al.*, 2019). Information sharing; administration sharing; agreed joint rules; and combined organisation should be used in transboundary partnership working (Kidd and McGowan, 2013). In order to manage and solve above-mentioned issues, several actors should be involved in EB-MSP process in Bay of Biscay. There are examples of sectoral cross-border cooperation such as the regional advisory councils (RACs) which are stakeholder-led organisations that provide recommendations on fisheries management matters. In Bay of Biscay, South West Waters Advisory Council (SWWAC) brings together all actors who have an interest in Fisheries Management to put forward opinions to the European Commission and the Member States on the management of the fisheries in the South Atlantic (www.cc-sud.eu). However, scope of these councils covers large maritime space, which gives broad recommendations for several sea-basins. Therefore, local advisory councils for specific areas such as Bay of Biscay can be beneficial to focus area specific issues.

Among other governance related needs, there is a need to foster MSP by integration of process leaders, working groups and responsible regional authorities. Around the world, there are several examples of cross-border MSP cooperation (e.g. HELCOM, www.helcom.fi, and OSPAR, in the Atlantic, covering the Bay) which recommend transnational policy measures, promote a dialogue with sector institutions, support projects by working groups, and enhance stakeholder participation by forums and discussion. Considering existing MSP efforts in the Bay of Biscay, it is required to have common platforms and organizations to share ideas and concerns from both countries' authorities and stakeholders.

5. Conclusions

A common understanding of the ecosystem and management practices is the initial step of an EB-MSP. In order to reach this understanding, economic, environmental and social settings, and present management practices are needed to draw a holistic vision for an EB-MSP in regional seas. Moreover, existing information produced by other directives such as MSFD can constitute significant input for MSP processes in terms of understanding of environmental perspective and main concerns. In a general perspective, France and Spain focused on the similar critical issues such as biodiversity, long-term abundance of food webs, sea floor integrity and marine litter in the Bay of Biscay.

However, there are different socio-economic objectives for the same region which may pose difficulties in the implementation of EB-MSP. It is essential to further analyse these objectives and expectations by planning authorities in order to avoid future conflicts. Potential space conflict caused by limited continental shelf, Brexit and potential protected areas should be analysed. Further, since both countries promote the use of new coastal structures such as offshore energy platforms, potential negative impacts on marine environment should be avoided. Therefore, it is recommended to perform regional scale joint risk and environmental assessments. Currently, there is no transboundary stakeholder platform to share knowledge from both countries. Such platforms may lead accurate data sharing to be used in ecosystem-based planning processes. Other marine regions (Baltic or North Sea Stakeholder Platforms) may constitute examples for such cooperation. Considering these expectations and current concerns, there is a need to foster transboundary and EB-MSP by integration of process leaders, working groups and responsible regional authorities in the Bay of Biscay.



GENERAL DISCUSSION

General Discussion

It has been discussed elsewhere if productive, clean and healthy oceans require an environmental management approach that recognizes the full array of interactions within an ecosystem, including humans (Ansong *et al.*, 2017; Kirkfeldt, 2019). Ecosystem-based approach (EBA) provides an integrated management approach of land, water and living resources that promotes conservation and sustainable use in an equitable way (Domínguez-Tejo *et al.*, 2016). Therefore, priorities and benefits of society should be well considered in ocean governance under EBA framework (Douvere, 2008). After performed analysis and reached outcomes in this thesis, a general ecosystem-based framework including socio-economic and socio-ecologic perspectives of ocean governance, and corresponding management actions was provided (Figure 22). This framework represents the economic and environmental sides of ocean governance equation, which at the end aims balancing economic, ecologic and social goals. Under the EBA umbrella, reaching a balance between economic and ecologic priorities is a difficult and complicated task. While Blue Growth initiative of EU requires smart, sustainable and inclusive growth of activities and fosters blue economy, increasing number of human activities create pressure for marine environment and its living resources (Elliott *et al.*, 2017; European Union, 2012). Besides, emerging human activities create new conflicts due to limited available marine space. In order to manage these activities, MSPD emerges as an important management tool, which requires spatial distribution and management plans of human activities from each EU member state (European Union, 2014). Although MSP was presented as the best way to ensure both ecosystem conservation and development of human activities, many implementation experiences showed that main focus was on blue growth and fostering blue economy (Frazão Santos *et al.*, 2014).

There are several studies discussing the position and role of MSP in ecosystem-based ocean governance (Gissi *et al.*, 2019; Katsanevakis *et al.*, 2011; Schlüter *et al.*, 2020). Although MSP was provided as a solution to activity-based conflicts and pressures, it is a public process which requires several tasks which could be difficult to accomplish. In this context, this thesis discussed and analysed advances in MSP, under an EBA, by reviewing and analysing existing DSTs in Chapter 1 and 2, and by developing and implementing DSTs in Chapter 3 (Figure 23).

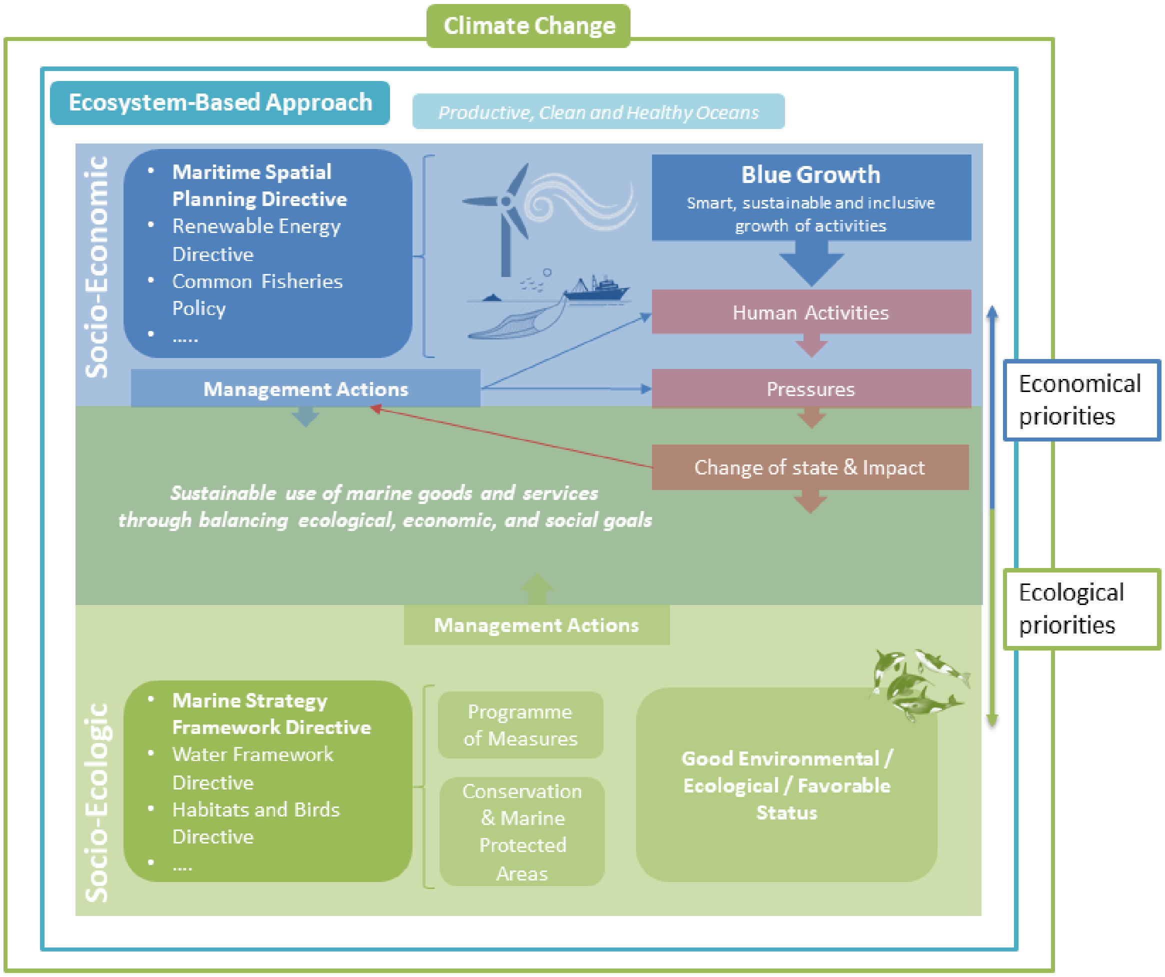


Figure 22: An ecosystem-based framework of ocean governance including socio-economic and socio-ecologic management actions and priorities (blue areas represents socio-economic management actions and green areas represent socio-ecologic management actions, whilst the intermediate area represents the balance between both and minimizing it the activities at sea are more sustainable).

On the other side of the framework, there are environmental regulations and directives aiming to achieve GES and to protect living resources (Figure 1). These regulations were used for minimising the environmental degradation due to new activities, increasing economic interests and new environmental pressures (Elliott *et al.*, 2018). Existing implementations showed that these actions and regulations (program of measures of MSFD and WFD, and marine protected areas and other conservation measures of HD and BD) stabilize the state of environment and decrease / manage impacts coming from human activities (European Commission, 2016; Smith *et al.*, 2016). In this thesis, orientation and benefits of these management actions in ecosystem-based MSP implementation were analysed and discussed in Chapter 4 (Figure 24).

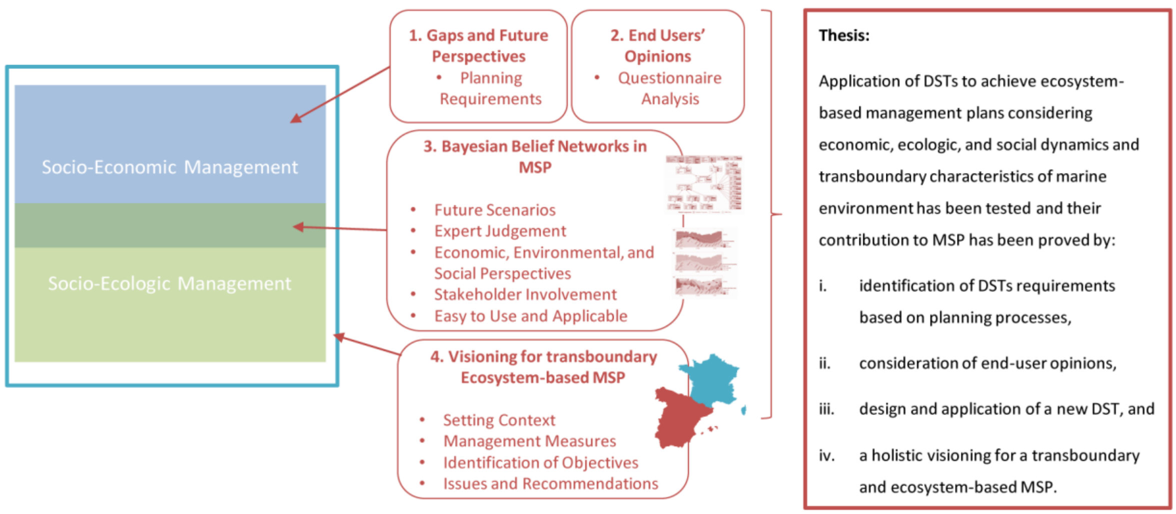


Figure 23: Contribution of the thesis chapters in the ecosystem-based framework of ocean governance including socio-economic and socio-ecologic management actions and priorities. MSP: marine spatial planning; DST: decision support tool.

1. Socio-Economic Management Perspective

As outlined in the framework, several emerging and existing activities create pressures and impacts on marine ecosystem and measuring and managing these impacts on environment and society can help to guide policy and management decisions. Beside other sectoral directives and regulations, MSP provides an integrated tool covering many aspects and tasks in socio-economic management (European Union, 2014). In the MSP process, planners benefit supportive mechanisms in order to make computing power needed and complicated decisions (Stelzenmüller *et al.*, 2013b). However, there was a lack and necessity of a complete review on tool applications in literature. In order to fill this gap, this thesis made a detailed review on tool applications in MSP processes in Chapter 1 and Chapter 2, identifying tool application trends, tool development trends and tool user profile.

- **Decision Support Tools: Their Application, Development and Users**

As an important contribution to current MSP research field, outcomes of this thesis identified tool application characteristics around the world by explaining what, where, when, for what and by which users' tools were applied. Since there were only few research undertaken on this purpose (Bolman *et al.*, 2018; Göke *et al.*, 2018; Janßen *et al.*, 2019; Stelzenmüller *et al.*, 2013b), analysis of tool applications by several sources could highlight the further steps in tool developments. Existing research on this topic was mainly considering a bunch of tools selected by authors according to their experiences. Outcomes of Chapter 1 and Chapter 2 represent direct input from MSP experiences from all around the world and users' opinions and expectations. Classification of application purposes, application timing in terms of MSP steps, and the plan types were analysed, which can be beneficial for tool developers.

In terms of application purposes, tools analysed in Chapter 1 were mainly applied to identify issues, conditions and constraints. DSTs were used for site selection tasks to analyse large amount of data and to perform integrated site suitability analysis. Although other scientific researches identified main contributions of tools to policy and stakeholder integration (Gee *et al.*, 2019), analysis from Chapter 1 and responses of end-users from Chapter 2 demonstrated that DSTs were mainly used for: (i) uses conflict analysis, (ii) site selection for maritime activities, (iii) scenario analysis, and (iv) communication. As an important purpose of MSPD (European Union, 2014), tools helped planners to identify conflict areas and potential solutions to share marine space in a sustainable way (Noble *et al.*, 2019). However, there is a common opinion of planners for the limitation of capabilities of the tools. Although tools support planners for the difficult tasks, such as data analysis or modelling, there is an important uncertainty problem in tool applications (Gissi *et al.*, 2017; Menegon *et al.*, 2016), and tools are not 100% capable to solve conflicts. Researchers proposed to increase communication, human integration and transparency (Morf *et al.*, 2019) in order to overcome the limitations of tools capacities. Thus, management plans should not rely only on outputs of DSTs, and expert knowledge and communication with stakeholders should be considered in plan development (Stelzenmüller *et al.*, 2015).

Furthermore, outcomes of Chapter 1 and Chapter 2 demonstrated that tools are being applied in the beginning stages of MSP. This may have several reasons including: (i) the slow progress in MSP implementation in many countries (Frazão Santos *et al.*, 2019), (ii) limited functionalities and complexity of available tools for final MSP steps (Janßen *et al.*, 2019) or (iii) the perception of tool application as an unnecessary concept. This demonstrates that development of tools will be needed for the further steps such as plan evaluation and monitoring. However, DSTs were seen as a robust and useful concept by many planners according to the outcomes of Chapter 2. Planners mentioned that initial steps of MSP process, such as data gathering for spatially-explicit databases, are the most time consuming tasks of whole process (Ehler and Douvere, 2009). Therefore, they preferred to benefit tools in these beginning steps according to outcomes of Chapter 1 and 2.

Besides when and why tools were used, outcomes of Chapter 1 showed that DSTs were frequently used in MSP related research projects and activities. However, application of tools in legally binding and national MSP processes was not so evident. In contrast to these outcomes of Chapter 1, outcomes of Chapter 2 showed that many planners applied DSTs in a legally binding planning process in Chapter 2. Therefore, although national plans and reports do not mention tool use, it can be considered that planners benefit them in the implementation of legally binding plans without reporting tool use. Although science driven models give beneficial information, they do not address the basic problems and challenges of decision making in real planning processes (Bolman *et al.*, 2018). Therefore, even authorities mentioned that they took research projects into consideration in planning process, it is difficult to make radical decisions which may affect existing spatial structure in the sea.

- **Tool Development Trends**

Both Chapters 1 and 2 provided important inputs for tool developers and their future production. In contrast to other scientific reviews (Gee *et al.*, 2019; Janßen *et al.*, 2019), analysis in Chapter 1 and 2 was not focused on a selected bunch of tools. These researches can be considered as one of the initial DST listing, and outcomes of these chapters demonstrated high number of tools available in the field of MSP. Many of them were developed for the same purposes, and even with the same functionalities. In addition, most of MSP related research projects created their own tools to satisfy their specific requirements. There are only few tools applied in different geographical areas such as Marxan and InVEST

(Ball and Possingham, 2000; Natural Capital Project, 2018). Besides, mass tool production caused many tools in databases which most of them are not existing or not functional anymore. Most of research projects are funded for a limited time period. Therefore, most of the web pages and the tool sources were closed at the end of the project funding period (Janßen *et al.*, 2019). In order to overcome this issue, tool developers should consider having web hosting services for at least 10 years period which allows users to keep using DSTs in an efficient and continuous way.

In order to keep the continuous use of the tools, developers should also consider the outcomes of Chapter 1 and 2 on desired tool characteristics (Figure 24). According to identified gaps and issues in tool applications, supported by users' perspectives, future developments in tools should be focusing on the future needs of MSP processes. Since many countries will start their evaluation stages, DSTs evaluation and monitoring functions will gain importance (Frazão Santos *et al.*, 2018). Attractive innovations and strategies for the future position of MSP would make future tools more demanding for the planners. Mainly, new functions were asked from developers such as future projection and scenario analysis. In terms of climate change, clear visualization and scenario analysis functions could help planning and management to overcome constraints and increase solution capacity by offering accessible information and communication (Glaas *et al.*, 2017). In a broad definition, DSTs with capacity of scenario analysis, socio-economic aspects, communication / visualisation features are desired by end-users and these new DSTs may trigger the demand for tool application. Besides these functionalities, integrity, multi-functionality and ease of use are the main characteristics desired by end-users in Chapter 2.

In terms of existing tools and their weaknesses, literature review and end-users' participation highlighted the similar points. Among other gaps, limited functionality was identified as an important reason to infrequent usage of tools in real MSP processes. Besides, imbalance of tools' main focus for economic, environmental and social issues were explained. Stakeholder and social focused DSTs may increase the ownership and ease of acceptance of tools by planners (Videira *et al.*, 2017). In both chapters, importance of human intervention was mentioned due to limitations of computer-based mechanisms.

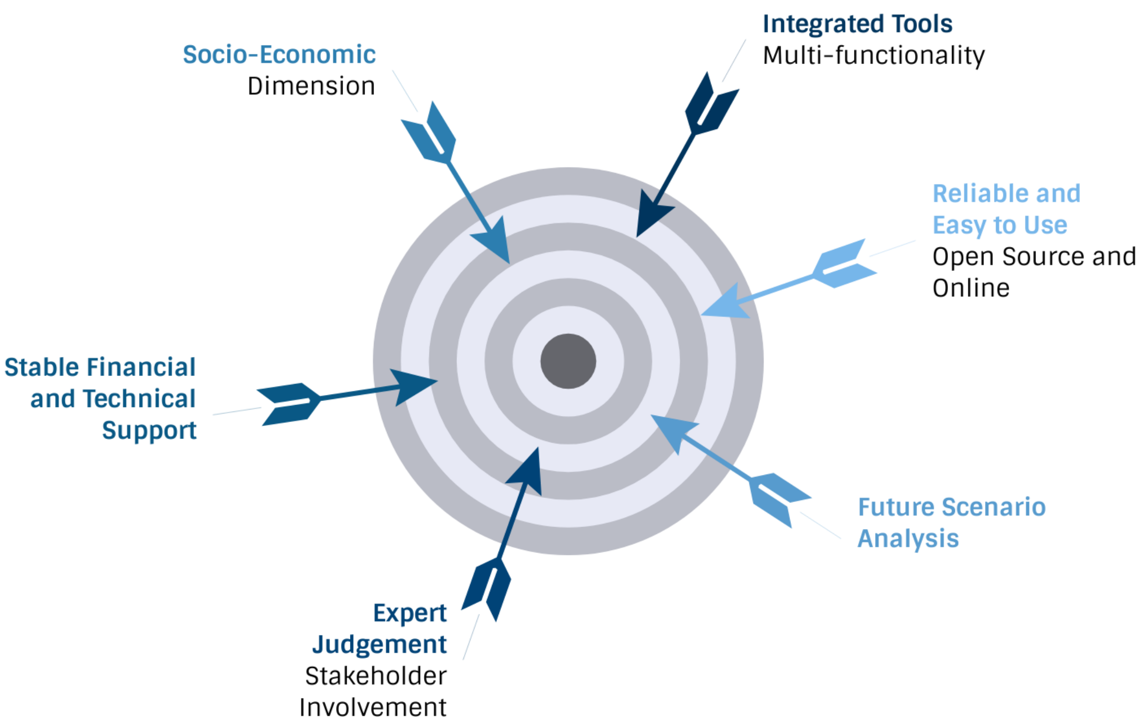


Figure 24: Desired future tool characteristics and functionalities based on the outcomes of analysis in Chapter 1 and Chapter 2.

- **Tool User Profile**

Another important outcome of this thesis was drawing the profile of tool end-users. In contrast to the outcomes of Chapter 1, questionnaire results demonstrated that an important portion of tool users were from government authorities (22% of all participants). Although there were many identified tool users from academics and research institutions, other MSP stakeholders such as governance authorities, private consultancy companies, NGOs and marine industry represented the 48% of the whole participants. This can be assumed as the high diversification of stakeholders involved in tool application. Inputs from Chapter 2 showed that legally binding MSP participation rate of people from research institution was low compared to other user groups. According to this result, it can be said that position of science in the plan development processes should be improved (Foley *et al.*, 2010).

As it was expected, tool users were mainly from countries which can be considered as the pioneers of MSP idea. Similar to this result, origin of new tool developments was also mainly from these countries. Among others, United States, Australia and Northern European countries were identified as the main tool application areas. Besides these pioneers, countries such as Spain, Italy, Greece and Portugal have shown high interest to this research. The reason behind this interest can be related with the implementation deadline of MSPD, and tool related requirements. According to user profile drawn in Chapter 2, developers should aim to involve planners in the tool application processes. It was observed that DST users from technical backgrounds such as engineering and mathematics were considerably low. Besides, ease of use should be considered as an important point since tools were not used often by elderly people.

- **Tool Design and Implementation: Bayesian Belief Network Models**

According to outcomes of the initial two chapters, desired tool characteristics were mainly identified as integrated, flexible, multi-functional and easy to use. As a result of this identification, in Chapter 3, BBNs were selected as the appropriate tool which fits with the identification of required tool for MSP process. As an example of application, an integrated model was designed to find the most feasible areas for offshore wind farms. Similar to above-mentioned ecosystem-based framework, functions and limitations of the BBN allowed to incorporate socio-economic and socio-ecologic components to the model structure (Figure 4). Besides, technical limitations such as seafloor habitat types were added as a component into the model. Although this model was a partial model focusing on a specific human activity, it gave insights for a potential complete model representing all related drivers and activities in MSP process.

As it was seen in Chapters 1 and 2, several researches focused on site selection for offshore wind farms based on technical and environmental factors in parallel with its increasing popularity (Arrambide *et al.*, 2019; Ashley *et al.*, 2018). Different than other approaches, the model presented in Chapter 3 integrates whole site selection process and related parameters in one tool. Integration of all these factors in one model gives several advantages to the planners, such as: broad analysis of technical suitability, potential conflict levels and areas due to other maritime activities, proportion and spatial allocation of environmentally sensitive areas, and social concerns, such as visibility and aesthetic considerations.

Besides the advantage of integrated analysis, BBN tools can be developed with support of stakeholders since they are capable to integrate expert knowledge by its conditional probability feature. In quantitative and semi-quantitative data situations, expert judgement was used in existing applications (Pascual *et al.*, 2016). Since MSP promotes the coherent and integrated pattern of sea use (Elliott *et al.*, 2018), DSTs can be produced by inclusion of opinions and prioritization of all significant actors and stakeholders. MSP workshops, forums and stakeholder meetings can be used to promote the tool development process and collect inputs.

Although they were not included in this Thesis, other tool developments and applications were performed as a part of this research period in AZTI, for other Blue Growth sectors, such as (i) the design and application of a GIS-based tool identifying suitable locations for aquaculture activity (Gimpel *et al.*, 2018a), and (ii) a BBN based tool analysing potential conflict between fisheries and aquaculture activities (Coccoli *et al.*, 2018). They complement and reinforce the research undertaken during the Thesis. As in Chapter 3, related environmental, economic and social parameters were used for GIS-based aquaculture suitability analysis tool and applied in several European case studies as a part of AquaSpace project (www.aquaspace-h2020.eu). Moreover, in another BBN application which was similar to the model presented in Chapter 3, expert judgement was used to identify fisheries characteristics in a proposed aquaculture site, and to propose new fishing sites (Coccoli *et al.*, 2018).

BBNs were used in several marine issues related analysis (Uusitalo *et al.*, 2016). In this research, its novel spatially explicit methodology allowed to use model for several purposes such as site selection, conflict analysis, avoiding environmentally sensitive areas and social concerns. Although this initial attempt was focusing on offshore wind farms, the same methodology can be applied for other maritime activities such as wave energy platforms or aquaculture, as shown in the abovementioned examples (Coccoli *et al.*, 2018; Gimpel *et al.*, 2018a). Future studies should focus on developing existing approaches to include other factors and updated data. Particularly, outcomes of studies related with environmental components and pressures by human activities can be included in that model structure (Arrambide *et al.*, 2019).

- **Floating Offshore Wind Farms: Expected future**

Feasibility conditions presented in Chapter 3 were mainly constrained by bathymetry due to the current technological limitations up to a certain water depth (Weiss *et al.*, 2018). However, advancement in new floating technologies allow allocation in areas up to 200 m water depth, increasing the amount of available space for these offshore developments. Floating offshore wind technology can be considered as more than the extension of offshore wind industry, creating a new technology on its own right (Bento and Fontes, 2019). Its development is continuous in a different and broader environmental, technological and geographical context. This expected new technology present a high potential to increase application of offshore wind farms and to reduce emissions in electricity sector (Wieczorek *et al.*, 2015). However, this sector is dealing with several technological and institutional challenges (Firestone *et al.*, 2015). According to outcomes of Chapter 3, Spain and France marine space has suitable conditions to develop their floating offshore wind farms as United Kingdom did in the past (Weiss *et al.*, 2018). The world's largest offshore wind turbine on a floating platform (the first Wind Float Atlantic unit) has departed for its final destination off the Portuguese coast of Viana do Castelo in October 2019 (www.edp.com/en/windfloat).

Since it is expected to see the use of this new technology more often in near future, planners should analyse potential impacts on marine ecosystem components and coastal societies.

2. Socio-Ecologic Management Perspective

While MSP and sectorial directives focus on fostering blue economy and reaching sectorial developments, socio-ecologic management actions intends to achieve GES and protect living resources, as shown in Figure 22. Among other environmental directives and regulations, MSFD represent a key position for MSPD which was highlighted in the directive itself. MSFD can be seen as the environmental stabilizer of Blue Growth oriented MSP implementations (Menegon *et al.*, 2018b), and has an important value in overall socio-ecologic management of oceans. In addition to socio-economic management perspective, Chapter 4 of this thesis took a step forward and identified key issues and challenges according to existing management actions in the Bay of Biscay and raised recommendations for transboundary and ecosystem-based MSP. Among other studies analysing MSP implementation experiences in other geographic areas (Buhl-Mortensen *et al.*, 2016; Flannery *et al.*, 2015; Olsen *et al.*, 2014b; Smythe, 2017), this research provides a new approach to set the context and understand the current conditions in the planning area in a transboundary and ecosystem-based context.

Different than existing studies on similar topic, this research benefits from the information produced in the MSFD (European Union, 2008). The programs of measures identified by France and Spain were analysed and classified by topics and maritime activities in order to understand main concerns and issues of both countries in an environmental perspective. Comparison of the outcomes with strategic objectives helped to understand the complete vision to achieve an EBA in the Bay of Biscay. This research demonstrated that existing available information can be very beneficial to understand the current situation in a planning area and to inform MSP decisions, especially in an environmental context (Borja *et al.*, 2013). Although, MSP itself was identified as an independent process, MSPD promotes the use of MSFD outcomes which was previously produced and identified necessary steps and main issues regarding GES (European Union, 2014).

Accordingly, this research highlighted the importance of methodology comparison for directive implementation to understand and benefit the way the other countries followed. In the scope of the Bay of Biscay, France represents a good example which followed a transparent and collaborative MSP process including multi-language documentation, clear visualisation for spatial allocation of activities, defined environmental concerns for management units, and a detailed and online consultation process (Ministère de la Transition écologique et solidaire, 2017). This example can be followed by Spanish authorities to achieve similar outcomes which may be matching for the regional sea planning. As an important outcome, it was seen that strategic objectives are very broad for both countries which should be more specific in order to serve for its purpose. Although expected growth and success were mentioned for each maritime activity in both countries planning and management reports, specific future actions were not mentioned which could inform stakeholders, coastal societies and investors.

Although it is natural to see different strategies and steps in directive implementations of countries, outcomes of analysis in Chapter 4 pointed out similar issues which may require transboundary solutions and common harmonized efforts. Among others, space conflicts caused by limited space availability in the continental shelf, development of new offshore wind projects and its economic impact, common environmental concerns, increasing marine litter, and management and transboundary governance were found as the main issues that require common effort and solution. In order to overcome these issues in the Bay of Biscay, both countries should show interest for a collaborative planning process which has been found positive in other sea basins (Gee *et al.*, 2011; Janßen *et al.*, 2018; Jay *et al.*, 2016). Data sharing, common data use, transboundary environmental protection, broad consensus on marine litter were recommended to planning authorities. Besides, the need for process leaders and clear governance were highlighted in order to tackle all these issues in a practical way.

- **Limitations, Challenges and Recommendations**

This thesis started with a broad literature review on DSTs in order to understand the current situation of tool applications around the world. Although this review ended with concrete results on tool applications and purposes, it was acknowledged that analysis of MSP reports was not entirely enough to understand the level of tool applications in legally binding planning processes. In order to clarify this issue, each tool web page, application reports, project outcomes and scientific literature were checked. It can be said that, outcomes of Chapter 2 supported the analysis done in Chapter 1 by adding end-users' inputs and experiences.

In Chapter 2, it was aimed to reach all planners who performed a tool application in MSP field. However, it was difficult to find desired target group to perform the questionnaire. Although a large mail list, MSP social platforms and networks, and social media were used to distribute the questionnaire, in many cases, personal effort was required to communicate participants to fill the questionnaire. Since there were other studies with similar purposes, it was significant to reach such high amount of responses to get meaningful and novel results on end-users' insights. Beside reaching to planners, identification of planners who were actively involved in the planning process was difficult since DST definition was not the same for each participant. Many approaches and GIS-based applications were considered as tools; therefore, we have explained the DST definition on this research prior to questionnaire.

Besides these points, other challenges and limitations were observed in Chapter 3. In order to design and perform a novel model for offshore wind farm feasibility, updated data in same spatial resolution was required. For this purpose, several databases for technical, environmental, and social data were searched. Although there are several sources such as EMODnet (www.emodnet.eu) that scientists can benefit free spatial data, all input data used in BBNs should be in same spatial resolution to perform the proposed model. Therefore, technical limitations of BBN may create further data availability challenges for more complicated planning models. In addition to spatial resolution, it is difficult to find accurate data for spatial distribution of ecosystem components or important areas for these components. As it was mentioned in Chapter 3, new data and sampling efforts should be undertaken in order to increase available data on marine ecosystem components. Another challenge was to define concrete conditions for the feasibility model based on expert opinion. Further model applications should perform a detailed expert analysis including workshops and quantitative questionnaires which may increase the accuracy of the model outcomes.

In Chapter 4, inputs from planning reports of two different countries were collated to draw a holistic vision on transboundary and EB-MSP in the Bay of Biscay. However, it is difficult to work with two different implementation strategies, methodologies and documentation styles for EU directives. Besides, different timing for different tasks in France and Spain caused unbalanced information flow in our analysis. Further analysis can be re-performed after the two countries complete their implementation of MSPD and MSFD, and provide clear documentation explaining undertaken steps and actions in planning process.

For the further research, it can be recommended to develop and perform new BBN models for other maritime activities such as offshore wave energy converters or aquaculture activity, as well as several activities at the same time, including traditional activities and new activities from the Blue Growth. It can be said that a large BBN model, including all important factors and parameters related with an MSP process, can demonstrate the big picture to all planning actors in a clear and transparent way. Inclusion of new components such as economic revenues of maritime activities, employment numbers, acceptance rates of stakeholders, or importance of ocean areas for coastal communities, can make the proposed model more integrated and comprehensive. Finally, there is a strong need for MSP to address climate change, which acts as an umbrella in the whole schema shown in Figure 22, and potential impacts on human activities (Gissi *et al.*, 2019). Further models and investigation should analyse potential future scenarios and effects on human activities according to climate change (Santos *et al.*, 2016).

Conclusion and Thesis

The aim of this thesis was setting the context of DSTs in MSP implementation process both by identification of required developments and analysis of end-user opinions, to design and apply a comprehensive DST considering economic, ecologic and social dimensions of marine environment and to identify issues and create recommendations for a transboundary and ecosystem-based MSP. This general aim was divided into specific objectives in parallel with the thesis chapters.

From the first objective, *"to characterize and analyse the present use of the DSTs in existing MSP implementation processes, to identify weaknesses and gaps of existing tools, and to propose new functionalities both to improve their applicability and to promote their application"* (Chapter 1), the conclusions are:

1. Most of the MSP reports did not explicitly state the application of DSTs. Thus, it is possible that this lack of specificity could lead to uncertainty regarding the DST outcomes in the management plans.
2. Tools were applied in the first stages of the MSP process, which reflects the fact that most countries have only just started to apply MSP in the time of research.
3. New DSTs should have the capacity to address future scenarios, socio-economic aspects, and improve communication and participation of stakeholders. Besides, availability of user-friendly tools with advanced functions and stable financial and technical support will facilitate further tool development and encourage decision makers to use them in the MSP process.

From the second objective, "*to capture and analyse DST end-user perceptions on their applications in MSP processes to draw recommendations and to give insights for future developments*" (Chapter 2), the conclusions are:

4. DSTs are worldwide accepted and being used in real MSP processes, mostly by research institutions and governance authorities in regional and legally binding planning activities.
5. DSTs were mostly used in the beginning stages of MSP implementation processes, and users demand tools for upcoming stages such as evaluation and monitoring.
6. In general, end-users require development of interactive, practical, reliable, open source and online tools providing transparency and user-friendly interface.
7. Accordingly, developers should make an effort in creating new integrated and multi-functional tools, and engaging stakeholders in the tool development process.

From third objective, *"to develop a model that integrates most relevant economic, environmental and social components to identify feasible areas and future scenarios for offshore wind farms and to apply it in different case study areas"* (Chapter 3), the conclusions are:

8. The BBN modelling approach allows to incorporate socio-economic and environmental elements, in addition to technical limitations, to determine feasibility for floating offshore wind farms in the context of EB-MSP.
9. Model used in regional scale analysis can support decision makers by providing a big picture of the potential feasible areas, then the local scale analysis is required using more detailed and reliable data for concrete decision making.

10. Future scenarios which can enhance or compromise the feasibility of floating wind farms allocation, can assist managers and policymakers in taking the best management decisions in MSP.
11. Future works should also consider technological improvements in floating wind farms, which overcome present technical constraints.

From fourth objective, *"to identify the key issues and challenges in order to raise recommendations for a transboundary EB-MSP in the Bay of Biscay based on a holistic vision of economic, environmental and social settings, and present management practices"* (Chapter 4), the conclusions are:

12. Economic, environmental and social settings, and present management practices can be benefit in order to draw a holistic vision for an ecosystem-based MSP in regional seas.
13. Information produced by MSFD implementation can constitute significant input for MSP processes in terms of understanding of environmental perspective and main concerns.
14. France and Spain, both focused on the same critical issues such as biodiversity, long-term abundance of food webs, sea floor integrity and marine litter.
15. Strategic objectives of both countries promote new coastal structures which may have negative impact on marine environment.
16. There is a need to foster MSP by integration of process leaders, working groups and responsible regional authorities in the Bay of Biscay as it was seen in other sea basins.

Finally, considering these conclusions, the hypothesis has been confirmed, being the thesis that:

Application of DSTs to achieve ecosystem-based management plans considering economic, ecologic, and social dynamics and transboundary characteristics of marine environment has been tested and their contribution to MSP has been proved by: (i) identification of DSTs requirements based on planning processes, (ii) consideration of end-user opinions, (iii) design and application of a new DST, and (iv) a holistic visioning for a transboundary and EB-MSP.

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Appendices

Table A1: Planning initiatives in which respondents have participated.

No.	Marine Spatial Plan Names	Geographical Area
1	Adriatic Ionian MSP project	Adriatic Sea
2	AMER - Adriatic Marine Ecosystem Recovery	Adriatic Sea
3	Great Sandy Marine Park	Australia
4	Australian National System of Marine Protected Areas	Australia
5	Belgian MSP	Belgium
6	Marine Spatial Planning as a tool for managing artisanal fisheries in Southern Coast of Brazil	Brazil
7	Eastern Scotian Shelf Integrated Management Initiative	Canada
8	Nova Scotia aquaculture	Canada
9	British Columbia Marine Planning Process (MaPP)	Canada
10	MaPP Marine Planning Process for the Northern Shelf Bioregion	Canada
11	Havplan Øresund	Denmark
12	ICZM Plan for Alexandria Governorate, including Lake Mariut	Egypt
13	ICZM Plan for the coastal stretch between El Sallum and Marsa Matruh	Egypt
14	Estonian MSP	Estonia
15	TransMasp (Be-France)	France
16	MSP and Aquaculture in Greece	Greece
17	Sulawesi Tenggara MSP	Indonesia
18	Maluku MSP	Indonesia
19	Papua Barat MSP	Indonesia
20	Proposed MSP for Ireland	Ireland
21	Transposing the MSP Directive in Italy	Italy
22	Program of Ecological and Territory Order of Yucatan Coast, Mexico	Mexico
23	North Sea 2050 Spatial Agenda (process leader/author)	North Sea
24	NorthSEE	North Sea
25	Portuguese Maritime Spatial Plan	Portugal
26	POEM (Portugal)	Portugal
27	ICZM Plan for the State of Qatar	Qatar
28	Romania's MSP	Romania
29	Shetland Marine Spatial Plan	Scotland
30	Scottish National Marine Plan & Regional Planning initiatives	Scotland
31	Implementation of the UNEP/COBSEA/Sida Coastal and Marine Spatial Planning Project	South Asia Countries
32	Planes de Gestión de ZEC	Spain
33	PST Costas de la CAPV	Spain
34	MSP in Spain (initial phase)	Spain
35	Action plan for fishery management in Santa Pola (Alicante)	Spain
36	Aquaculture zoning spatial plan	Spain
37	Dutch MSP 2016-2021	The Netherlands

38	Management system for Marine Protected Areas in Turkey	Turkey
39	Development of Foca SEPA Management Plan	Turkey
40	Integrated Coastal and Marine Zone Management of Gokova SEPA	Turkey
41	Strengthening Protected Area Network of Turkey: Catalyzing Sustainability of Marine and Coastal Protected Areas	Turkey
42	NESAP - North East Growth Area Marine Spatial Plan	UK
43	North West (England) marine plan evidence gathering	UK
44	Massachusetts Ocean Plan	USA
45	Florida Reefs	USA
46	Energy and mineral planning in the United States	USA
47	Marine Spatial Plan for Washington's Pacific Coast	USA
48	Northeast Regional Ocean Plan	USA
49	Rhode Island Ocean Special Area Management Plan	USA
50	Rhode Island Ocean Special Area Management Plan (Ocean SAMP) Five-Year Update	USA
51	Northeast Ocean Plan	USA
52	US Caribbean Regional Ocean Plan	USA
53	Oregon Sea Plan	USA
54	ADRIPLAN project	EU Project
55	BSR INTERREG III Balance project	EU Project
56	SYMPHONY	EU Project
57	SUPREME and SIMWESTMED project	EU Project
58	EU MSP Directive Council negotiations incl support study MASPNOSE	EU Project
59	MUSES - Multi Use in European Seas	EU Project
60	Aquaspace	EU Project
61	SIMCelt	EU Project
62	TPEA (EU)	EU Project

Table A2: List of decision support tools used by respondents.

Decision Support Tool	Number of responses
Marxan	11
Geographic Information Systems	9
SeaSketch	2
Marxan with Zones	2
GeoWeb portal Rijkswaterstaat	1
MAREE (Marine Ecological Emulator)	1
Relational coordination	1
HELCOM Map and Data service (regional data hub)	1
ODEMM	1
EcoTrust Marine Planner	1
Northeast Ocean Data Portal	1
UCINET, Netdraw - Social Network Analysis tool	1
NE Marine Corridor Digital Atlas	1
Impact assessment tools	1
MSP Challenge 2050	1
GRID	1
MIMES	1
Scenario Analysis	1
DEFINITE	1
EcoImpactMapper	1
Data portals	1
CONNIE3 (Connectivity Interface):	1
Cumulative impacts assessment tool	1
Biogeochemical model by CSIRO:	1
Attribute classification and typology	1
Application of COEXIST methodology	1
Marine Maps	1
Marine Cadastre	1

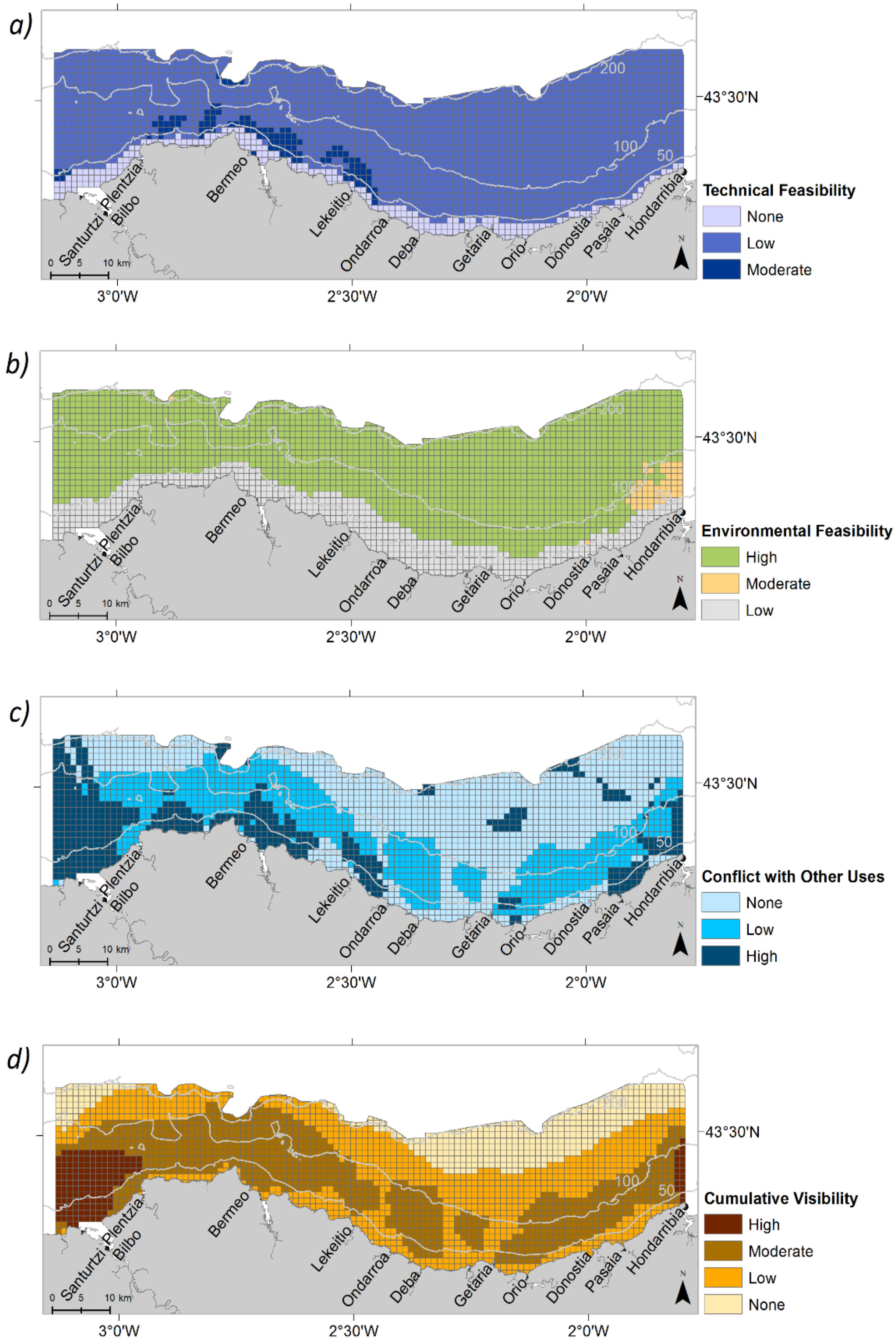

Figure A1: a) Technical- economic feasibility; b) environmental feasibility for floating wind farms; c) conflict areas for wind farm installation according to existing marine activities within Basque continental shelf; and d) cumulative visibility index.

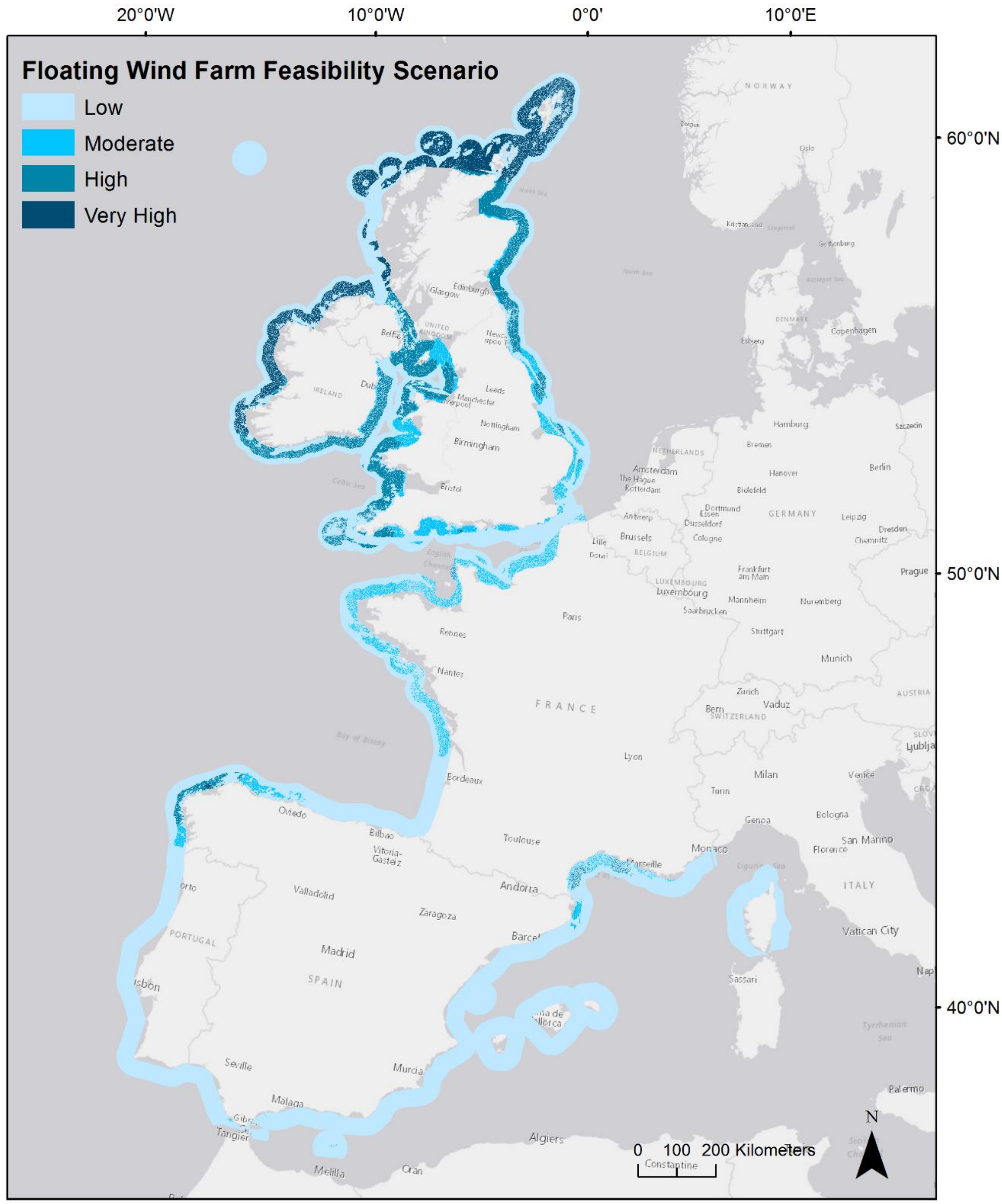

Figure A2: Floating Offshore Windfarms feasibility scenario which allows bathymetric limitation up to 200m water depth.

Table A3: Levelized Cost of Energy calculation.

LCOE calculation were used to determine the payback period of the installed capital costs and the profitability of the project (Miller *et al.*, 2017). In this study, applied LCOE formulation considers water depth, distance to shore in kilometres, number of wind turbines and a capacity factor that represents the average power generated, divided by the rated peak power, and was calculated for 8 MW wind turbines as follows:

$$LCOE = \frac{0.245 \cdot T^{-0.084}}{(3.216 \cdot CF + 0.0368)} + \frac{0.848 \cdot 10^{-3} \cdot T^{-0.6953}}{CF} \cdot (D-5) + \frac{2.022 \cdot 10^{-5} \cdot T^{-0.084}}{CF} \cdot (d-50)$$

Where:

CF capacity factor range 0.2 to 0.525
T number of 8 MW turbines, from 1 to 45 units
D distance to shore in kilometres, limited to 55 km
d water depth in meters, limited to 300 m

In this formulation, the capacity factor is defined as the annual equivalent hours of the wind turbine working at nominal power. A CF of 0.5 means that, in a given location, a given wind turbine, would generate the equivalent energy to be half of the hours of the year working at nominal power. Spatial distribution of LCOE was calculated for each spatial grid cell in the study area. The meteorological analysis was based on WRF (Weather Research and Forecasting) model. For the validation process of in the study area, observation data from a buoy installed in BIMEP project area was used in 2012.

Table A4: Cumulative Visibility Index calculation.

The CVIs were aggregated into an overall CVI for Basque Country coastal areas as follows:

$$OCVI = CVI_{LU} + CVI_{Pop} + CVI_{Beach} + CVI_{N2000} + CVI_{PUD}$$

and,

$$CVI = \sum d \; x \; CVI_i x \; p_{res}$$

whereas, d is the distance weighting factor assuming that visibility close to coastal areas has high visual impact, CVI is the cumulative visibility expressed in number of observation points per pixel for the i-th coastal resource and ppres is the priority weighting factor (1 – low priority to 5 – high priority) defining the protection priority of the coastal feature at stake in case of visual impact. The CVI was run for each coastal resource using ArcGIS Visibility Toolbox based on a EU Digital Elevation Model (EU-DEM, 2017) of 30 m x 30 m resolution. In total n = 3120 observation points were applied assuming an average observer height of h = 1.7 m. Maximum visibility distance was 15 km. The distribution of observation points was modelled with a regular point grid of 100 m intervals along the coastline.

Table A5: Input data for Basque Country Bayesian belief network conceptual model, data source, data format, processing method and selection criteria.

Input Data Type	Input Name	Data Source	Data Format	Unit and Processing Method	Feasibility Selection Criteria
Technical components	LCOE (Levelized cost of energy) (€/MW)	Tecnalia / calculation defined in A.1	Raster	Capacity factor, number of 8 MW turbines (from 1 to 45 units), distance to shore in kilometres (limited to 55 km), water depth in meters (limited to 300 m) were included in LCOE calculation. Discretization was made according to electricity market price.	Select low cost energy production areas
	Seafloor type	Galparsoro et al. (2010)	Polygon	Seafloor score for each grid was calculated according to preference for offshore platforms	Select high sea floor score sedimentary areas
Social component	Cumulative Visibility Index	Defined in A.5	Raster	Population, urban areas, beaches and Natura 2000 areas defined the coastal points for visibility analysis. Final index was classified as low, moderate and high.	Avoid areas with high cumulative visibility
Marine Activities	Artisanal Fishery	Pascual et al. (2013)	Raster	Discretised for Low – High fishing pressure areas	Avoid areas with high fishing density area
	Fishing intensity	JRC (https://ec.europa.eu/jrc/en)	Shapefile	Discretised for Low – High fishing pressure areas	Avoid areas with high fishing density area

Input Data Type	Input Name	Data Source	Data Format	Unit and Processing Method	Feasibility Selection Criteria
	Shipping	Benjamin Halpern, Melanie Frazier, John Potapenko, Kenneth Casey, Kellee Koenig, et al. 2015. Cumulative human impacts: raw stressor data (2008 and 2013). Knowledge Network for Biocomplexity. doi:10.5063/F1S180FS.	Raster	Discretised for Low – Moderate – High shipping density according to quartiles of raster data	Exclusion of high shipping density
	Cables	AZTI	Polygon	Presence / Absence	Exclusion
	MPAs	EEA database of protected areas: https://www.eea.europa.eu/data-and-maps	Polygon	Presence / Absence	Exclusion
	Gas Pipeline	AZTI	Polygon	Presence / Absence	Exclusion
	Harbour Service Areas	AZTI	Polygon	Presence / Absence	Exclusion
	Wave Energy Platforms	AZTI	Polygon	Presence / Absence	Exclusion
	Sand Extraction Areas	AZTI	Polygon	Presence / Absence	Exclusion
	Proposed MPA	World Wide Foundation	Polygon	Presence / Absence	Exclusion
Ecosystem Components	Marine Mammals	Pascual et al. (2011)	Shapefile (polygon)	Classified for biological value of area for specific component (0 to 5)	Avoid areas with high biological value
	Sea Birds	Pascual et al. (2011)	Shapefile (polygon)	Classified for biological value of area for specific component (0 to 5)	Avoid areas with high biological value
	Macro-benthos	Pascual et al. (2011)	Shapefile (polygon)	Classified for biological value of area for specific component (0 to 5)	Avoid areas with high biological value

Table A6: Input data for Northeast Atlantic and Western Mediterranean regions Bayesian belief network conceptual model, data source, data format, processing method and selection criteria.

Input Data Type	**Input Name**	**Data Source**	**Data Format**	**Unit and Processing Method**	**Feasibility Selection Criteria**
Technical components	Wind power density for 100 m height wind platforms	Data obtained from the "Global Wind Atlas 2.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU) in partnership with the World Bank Group, utilizing data provided by Vortex, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info"	Raster	1 km resolution data discretised for low-moderate-high-very high wind power density for 100m wind platforms	Select high wind power areas
Technical components	Bathymetry	EMODnet Data Portal	Polygon	Depth classification	Avoid areas with more than 100 m depth
Technical components	Rocky areas	EMODnet Data Portal	Shapefile	Presence / Absence	Avoid rocky areas
Social component	Marine Protected Areas	EMODnet Data Portal	Shapefile	Presence / Absence	Avoid areas with high cumulative visibility
Marine Activities	Fishing Intensity	JRC	Raster	Discretised for Low – High fishing areas	Avoid areas with high fishing density area
Marine Activities	Marine Traffic	Halpern *et al.* (2012)	Raster	Discretised for Low – High marine traffic areas	Avoid areas with high marine traffic

Table A7 a. Dataset for visibility modelling.

Geospatial datasets	Resolution	Unit	Data format	Reference
Digital elevation model (DEM)	30 m x 30 m	meter	Raster	EU-DEM, 2017
Regular Observation Point Grid	100 m intervals along the coastline	Human observer height 1.7 m	Point feature	Modelled using ArcGIS Visibility toolbox

Table A7 b. Dataset of human uses in the coastal area sensitive to potential visual change.

Geospatial datasets	Resolution	Unit	Data format	Priority weight	Reference
Corine Land Use 2012	100 m x 100 m	Coastal Urban Land Use including continuous and discontinuous urban fabric	Raster	3	CORINE, 2012
Population	1000 m x 1000 m	Inhabitant/km^2 for rasters cells	Raster	2	JRC, 2015
NATURA 2000 Sites	/	Presence/absence of the Habitat of Bird Directive site in coastal and marine areas	Polygon feature	5	EU Sea Atlas, 2016
Bathing Water Quality Beach	/	Presence/Absence of bathing water sites adjacent observation points within buffer 1000 m	Point features	4	EMODnet, 2016
Photo User Days	1000 m x 1000m; 2005-2014	Average annual visitation rate in coastal areas based on Photo-User-Days	Grid features	3	Natural Capital Project, 2018

Table A8. Discretization values for model components.

Technical components	
LCOE	**Index value per cell**
High Cost	0.24 – 0.30
Moderate Cost	0.18 – 0.24
Market Price	0.12 - 0.18
Seafloor score	**Seafloor characteristics**
Very High	More than 90% sedimentary
High	50% - 90% sedimentary
Moderate	20% - 50% sedimentary
Low	0% - 20% sedimentary
Environmental components	
Ecosystem Components (Marine Mammals, Sea Birds, Macrobenthos)	**Biological Value (Pascual *et al.*, 2011)**
High	3
Low	1 and 2
Other Uses components	
Marine Activities	**Take place in grid-cell**
Yes	Yes
No	No

Table A9. Operational wind farms in the Northeast Atlantic and Western Mediterranean regions, country, installation year, number of turbines, production capacity and result from the integrated feasibility model for the farm location. (ArcGIS Online, Offshore Wind Farm Locations)

Farm Name	Country	Year	Number of Turbines	Power MW	Model Feasibility Result
Arklow Bank	Ireland	2017	7	25,2	High
Barrow	United Kingdom	2017	30	90	High
Beatrice	United Kingdom	2017	84	588	High
Beatrice Demonstrator Site	United Kingdom	2015	0	10	High
Blyth	United Kingdom	2017	0	0	Low
Burbo Bank Extension	United Kingdom	2017	0	0	High
Greater Gabbard	United Kingdom	2017	140	504	Moderate
Gunfleet Sands Demo	United Kingdom	2017	0	0	Moderate
Gunfleet Sands I	United Kingdom	2017	30	108	Moderate
Gunfleet Sands II	United Kingdom	2017	18	65	Moderate
Gwynt y Mor	United Kingdom	2017	160	576	High
Humber Gateway	United Kingdom	2017	73	219	Moderate
Inner Dowsing	United Kingdom	2017	27	97	Moderate
Lincs	United Kingdom	2017	75	270	Moderate
London Array 1	United Kingdom	2017	175	630	Moderate
Lynn	United Kingdom	2017	27	97	Moderate
North Hoyle	United Kingdom	2017	30	60	High
Ormonde	United Kingdom	2017	30	150	High
Rhyl Flats	United Kingdom	2017	25	90	Moderate
Scroby Sands	United Kingdom	2017	30	60	Moderate
Sheringham Shoal	United Kingdom	2017	88	317	High
Teesside	United Kingdom	2017	27	62	Low

Farm Name	Country	Year	Number of Turbines	Power MW	Model Feasibility Result
Thanet	United Kingdom	2017	100	300	Moderate
Walney 1	United Kingdom	2017	51	184	High
Walney 2	United Kingdom	2017	51	184	High
West of Duddon Sands	United Kingdom	2017	108	389	High
Westermost Rough	United Kingdom	2017	35	210	High

ADVANCES IN **MARITIME SPATIAL PLANNING**

Due to increasing competition for ocean space, there is a significant need for a coherent maritime management and planning. While achieving social and economic objectives, marine ecosystems should be protected by balancing human activities and their spatial distribution. **In planning processes, development and implementation of decision support tools can assist planners, decision makers, industry and investors in order to implement ecosystem-based MSP.**

In this thesis, it has been aimed to characterise **existing DSTs,** capture and analyse DST **end-user perceptions;** to perform an example of the implementation of a DST by **developing a model** that integrates most relevant economic, environmental and social components to identify **feasible areas and future scenarios for offshore wind farms;** and finally to identify the key issues and challenges in order to raise **recommendations for a transboundary EB-MSP in the Bay of Biscay.**

The findings of this thesis can help researchers to better understand the links between DSTs and MSP processes and to contribute to MSP processes with required tools.

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