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The impact of climate change on marine spatial planning and the blue economy: vulnerability assessment and implications for a sustainable use of the ocean services

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Abstract

Marine Spatial Planning (MSP) arose with the aim of promoting a better management and governance of the ocean, seeking to plan temporal and spatially the ocean uses, trying to reduce conflicts and arranging compatibility between uses. In the past 30 years, policy-makers have dedicated increasing attention to this issue, and MSP has become an important instrument, being currently under development in 70 countries, representing 45% of all coastal states. With the intensification of climate change, new threats are emerging for the marine and coastal environment, but also for the goods and services on which so many human populations depend. This poses numerous problems for the uses and activities that rely on these ecosystems, requiring effective adaptation. This adaptation could bring new conflicts, legal problems and new impacts on the environment, therefore affecting the Blue Economy (BE). Thus, recognizing the challenge that climate change will bring to MSP and to the BE is part of the solution to ensure a long-term vision of a sustainable ocean use. So far, few studies have applied a comprehensive approach to estimate and discuss the effects of climate change on marine spatial plans and on BE as well as integrating them within the process. For this reason, a review of the existing literature on Vulnerability Assessments was conducted to support the development of an MSP and BE vulnerability index for the European Union (EU) coastal Member States, as regards climate change. The obtained results and the implications they may have for the MSP and the BE, are discussed in this thesis. Our comprehensive Vulnerability Assessment can inform policy-making in coastal Member States, by identifying the ocean uses more vulnerable to climate change, considering social, economic and productivity factors. Moreover, the assessment also allows us to identify the marine spatial plans and BEs most vulnerable to climate change, emphasizing the importance of integrating climate change in future ocean management plans.

Keywords

Vulnerability Assessments - Marine Spatial Planning - Blue Economy - Climate change - EU coastal Member States

Resumo

O ordenamento do espaço marítimo (OEM) surgiu com o objetivo de promover uma melhor gestão e governança do oceano, procurando gerir espacialmente e temporalmente os usos do oceano, reduzindo conflitos e promovendo compatibilidades entre os diversos usos. Nos últimos 30 anos, muitos decisores políticos começaram a concentrar atenção neste tema, e os planos de ordenamento do espaço marítimo, tornaram-se um importante instrumento político, estando atualmente em desenvolvimento em 70 países, representando 45 % de todos os estados costeiros. Com o aumento dos fenómenos provocados pelas alterações climáticas, novas ameaças ao ambiente marinho e costeiro irão surgir, como também aos bens e serviços de que a população humana depende. Isto, trará inúmeros problemas no que respeita aos usos e atividades económicas correspondentes que dependem destes ecossistemas, sendo necessário medidas de adaptação efetivas. Estas adaptações, poderão provocar novos conflitos, problemas legais e novos impactos ambientais, afetando o crescimento da economia azul. Assim, reconhecer o desafio que as alterações climáticas irão trazer para o OEM e para a economia azul é fundamental para assegurar uma visão a longo prazo de um uso sustentável do oceano. Atualmente, são poucos os estudos que aplicaram uma abordagem holística para estimar e discutir os efeitos das alterações climáticas nos planos de ordenamento e na economia azul, bem como integrá-los nos processos. Por esta razão, este trabalho consiste na revisão da literatura existente sobre estudos de avaliação de vulnerabilidade no ambiente marinho, e no desenvolvimento de um índice de vulnerabilidade do OEM e economia azul dos Estados-Membros costeiros da União Europeia (UE), face às alterações climáticas. Os resultados obtidos e as implicações que poderão ter no OEM e na economia azul, são discutidos no âmbito desta tese. O presente estudo de avaliação de vulnerabilidade pode servir como suporte às políticas dos Estados-Membros costeiros da União Europeia, informando quais os usos do oceano mais relevantes em termos socioeconómicos e, simultaneamente, mais vulneráveis, como também, quais os planos de ordenamento e economias azuis mais vulneráveis às alterações climáticas. Servindo, assim, como reconhecimento da importância da integração das alterações climáticas nos futuros planos de gestão e ordenamento do oceano.

Palavras-chave

Avaliação de Vulnerabilidade - Ordenamento do Espaço Marítimo - Economia Azul - Alterações Climáticas - Estados-Membros costeiros da UE

Resumo alargado

O ordenamento do espaço marítimo tem sido desenvolvido em todo o mundo, com o objetivo de promover um uso sustentável dos oceanos, através da gestão espacial e temporal dos seus usos, de forma a reduzir conflitos e a procurar uma maior compatibilidade entre usos, e entre estes e o ecossistema. O ordenamento do espaço marítimo está a ser implementado em 70 países, representando 45% de todos os estados costeiros, e de entre os principais desafios que existem no desenvolvimento e implementação do ordenamento do espaço marítimo, as alterações climáticas têm sido identificadas como um dos maiores. Com a intensificação das alterações climáticas, novas ameaças vão surgindo para o ecossistema marinho e para os bens e serviços de que tantas populações humanas dependem. Isto impõe inúmeros problemas para os usos e atividades que dependem dos ecossistemas marinhos e costeiros, exigindo uma adaptação efetiva. Esta adaptação poderá trazer novos conflitos, problemas legais e novos impactos no ambiente, que irão afetar o crescimento da economia azul, tão desejada pelos *stakeholders* e decisores políticos, como evidenciado na Estratégia Nacional para o Mar 2021-2030. Por esta razão, reconhecer o desafio que as alterações climáticas irão trazer para o ordenamento do espaço marítimo e para a economia azul é fundamental para assegurar uma visão a longo prazo de um uso sustentável do oceano. Até agora, são poucos os estudos que aplicaram uma abordagem holística para estimar e discutir os efeitos das alterações climáticas no ordenamento do espaço marítimo e na economia azul, bem como integrá-los no processo.

Reconhecendo este desafio, este trabalho tem como foco dois objetivos distintos. O primeiro pretende perceber de que forma e com que intensidade as diferentes dimensões de vulnerabilidade (*i.e.* exposição, sensibilidade, capacidade adaptativa), os diferentes usos do oceano (*i.e.* pesca; aquacultura; energia renovável; conservação marinha; transporte marítimo; turismo e mineração), as palavras ordenamento do espaço marítimo e economia azul, e os diferentes fenómenos climáticos (*i.e.* aquecimento da temperatura das águas; acidificação, desoxigenação e subida do nível médio do mar; fenómenos extremos; mudanças na circulação dos ventos e correntes; mudanças na distribuição da biodiversidade; e *blooms* de algas e doenças nocivas) estão presentes nos estudos de avaliação de vulnerabilidade e de risco realizados no ambiente marinho. Para isso, foi realizada uma revisão de literatura através da plataforma *Web of Knowledge*, utilizando duas pesquisas por conceitos-chave escolhidos no âmbito deste projeto. Tais pesquisas, permitiram perceber que mais de 50% dos estudos referem adequadamente todas as dimensões de vulnerabilidade, que o uso do oceano mais estudado em projetos deste tipo é o uso pesca, e que os fenómenos climáticos mais referidos/considerados são os fenómenos extremos, o aquecimento e subida do nível médio do mar. Importa ainda destacar, que apenas um estudo acabou por referir todos os usos do oceano.

O segundo objetivo, procura determinar três tipos de vulnerabilidade socioeconómica (*i.e.* com base no emprego, no valor acrescentado bruto e na produtividade) do ordenamento do espaço marítimo e da economia azul face às alterações climáticas, nos Estados-Membros costeiros da União Europeia e no Reino Unido (o Reino Unido aquando da realização deste projeto ainda pertencia à União Europeia). Assim, procurou-se desenvolver um índice de vulnerabilidade, adaptando os trabalhos desenvolvidos pelo *Intergovernmental Panel on Climate Change* sobre as alterações climáticas e outros trabalhos preliminares focados neste tema. Para o cálculo da vulnerabilidade, foram seguidas as orientações do modelo do *Intergovernmental Panel on Climate Change* de 2007, sendo aquele que é mais usado nos estudos de conservação, e por ser aquele que possui a definição mais reconhecida e referida de vulnerabilidade. Reconhecemos, assim, que neste trabalho o cálculo da vulnerabilidade é resultado conjunto da exposição, sensibilidade e capacidade adaptativa de um sistema às alterações climáticas.

Estudos de avaliação de vulnerabilidade como estes podem ser usados para reconhecer a fraqueza de um sistema, focando-se na ameaça a esse sistema, para alertar as pessoas para o risco e para novas oportunidades que possam advir desse risco, e para melhorar e identificar medidas efetivas de adaptação,

contribuindo para uma melhor capacidade adaptativa. É, também, um meio para reconhecer e perceber como os diferentes setores, e economias e comunidades dependentes desses setores, podem ou conseguem enfrentar a problemática das alterações climáticas. Assim, foram considerados no cálculo da vulnerabilidade nove usos do oceano (*i.e*. pesca; aquacultura; energia renovável; portos; construção naval; transporte marítimo; turismo; mineração e conservação marinha) e oito fenómenos climáticos (*i.e*. aquecimento, acidificação e desoxigenação da água; subida do nível médio do mar; fenómenos extremos; mudanças na circulação dos ventos e correntes; mudanças na distribuição da biodiversidade; e *blooms* de algas e doenças nocivas), provenientes do *European Union Blue Economy Report* de 2019 e 2020, e de trabalhos preliminares na área.

Para a determinação da vulnerabilidade, em termos de exposição, foram utilizadas três variáveis: (i) o número de postos de trabalho de cada atividade económica ligada aos usos do oceano, (ii) o valor acrescentado bruto de cada atividade económica ligada aos usos do oceano, e (iii) a produtividade de cada atividade económica ligada aos usos do oceano. De referir, que todos estes dados são provenientes dos *European Union Blue Economy Reports* de 2019 e 2020. Para o uso relativo à conservação marinha, a exposição foi calculada a partir de diferentes critérios, nomeadamente a percentagem de áreas marinhas protegidas e o valor da biodiversidade no índice da qualidade do oceano em cada país. Para a sensibilidade, foi usado o impacto dos oito fenómenos climáticos nos nove usos do oceano, adaptando os resultados provenientes de trabalhos preliminares sobre o tema. Por fim, para a capacidade adaptativa, foram recolhidos dados que serviram como *proxy* das dimensões propostas nos trabalhos de Cinner *et al*. 2018 sobre capacidade adaptativa.

O índice obtido permitiu, assim, determinar quais os usos do oceano mais importantes e vulneráveis, ao nível socioeconómico, bem como quais os planos de ordenamento e respetivas economias azuis mais vulneráveis, permitindo reconhecer a importância que terá a inclusão das alterações climáticas nestes processos políticos. Com os nossos resultados, é possível determinar que os usos pesca, aquacultura e conservação marinha são dos mais vulneráveis às alterações climáticas. É possível identificar os países Reino Unido, Espanha, Itália e França como os mais socialmente vulneráveis, os países Reino Unido e França como os mais economicamente vulneráveis, e os países Dinamarca, Reino Unido, Bélgica, Holanda e França como os mais produtivamente vulneráveis, a nível do ordenamento do espaço marítimo e economia azul. Os resultados obtidos, permitem um maior conhecimento das implicações que as alterações climáticas irão provocar no ordenamento do espaço marítimo, bem como nas suas economias.

O nosso estudo de revisão de literatura servirá de contributo à comunidade científica para um melhor entendimento da complexidade associada a estudos de avaliação de vulnerabilidade, identificando quais as áreas menos abrangidas nestes estudos, para o ambiente marinho, permitindo um maior desenvolvimento numa área cada vez mais em crescimento. O nosso estudo de vulnerabilidade do ordenamento do espaço marítimo e economia azul às alterações climáticas, permitirá servir de apoio a futuras políticas da União Europeia, contribuindo com dados sobre os usos, planos de ordenamento e economias mais vulneráveis em determinado país, servindo de fonte de informação para futuras decisões de gestão do oceano. Para além disso, este estudo reforça a ideia da necessidade do reconhecimento e inclusão das alterações climáticas nos futuros planos de gestão dos oceanos, num mundo onde cada vez mais existe a noção do impacto que os fenómenos climáticos terão nas espécies, processos ecológicos, ecossistemas, atividades e infraestruturas.

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List of Abbreviations

BE Blue Economy
EBM Ecosystem-Based Management approach
EEZ Exclusive Economic Zone
EU European Union
GNI Gross National Income
GVA Gross Value Added
HABs Harmful Algae Blooms
IPCC Intergovernmental Panel on Climate Change
ISI International Scientific Indexing
MPA Marine Protected Area
MSFD Marine Strategy Framework Directive
MSP Marine Spatial Planning
OECD Organisation for Economic Co-operation and Development
OHI Ocean Health Index
SIDS Small Island Developing States
UK United Kingdom
VA Vulnerability Assessment

1. Introduction

Marine Spatial Planning (MSP) has been developed worldwide aiming to promote a sustainable use of the goods and services provided by the ocean, through the spatial and temporal management of ocean uses, in order to reduce conflicts and seek greater compatibility between uses and between the uses and the ecosystem, allowing the achievement of ecological, social and economic targets specified by political processes [1-2]. MSP is being implemented in 70 countries, representing 45% of all coastal states [3]. Among the main challenges that exist in developing and implementing MSP, climate change has been identified as one of the biggest [4]. With the intensification of climate change, new threats emerge for marine and coastal ecosystems, but also for the goods and services provided, on which so many human populations depend [4-5]. This poses numerous problems for the uses and activities that rely on these ecosystems, requiring effective adaptation to climate change [5]. This adaptation will bring new potential conflicts, legal problems and new impacts on the marine environment, which will affect the development of the Blue Economy (BE) [6]. So far, a number of studies around the world have addressed and discussed the effects of climate change on MSP, as well as how MSP could integrate them and become more adaptive [7]. Still, in practice climate change tends to be neglected as a relevant factor in the majority of marine spatial plans and MSP initiatives [7-8]. Thus, finding practical ways to support the integration of climate change impacts into ocean plans is to ensure that MSP initiatives are viable and have a long-term vision for a sustainable ocean use [5, 7].

One of the identified pathways to "climate-proof" MSP is the development of climate vulnerability and risk analyses (focused on social, economic, cultural or ecological dimensions, or on a combination of them) [7].

In accordance to such information, the main goal of this essay is to investigate three types of vulnerability of ocean uses and activities to climate change and examine their implications on MSP initiatives and the BE. This will be achieved by developing and applying an MSP and BE vulnerability index to climate change, using European coastal countries as a case study. The present work is based on guidelines from the 4th and 5th Assessment Reports by the Intergovernmental Panel on Climate Change (IPCC), guidelines by the Organization for Economic Co-operation and Development (OECD) on constructing composite indicators, and a preliminary approach on assessing ocean planning and BE vulnerability to climate change [5, 9-14]. Additional objectives of the present work, to be achieved through the development of a literature review, pertain to estimating how (and to what extent) vulnerability dimensions, ocean uses and activities, and climate drivers are incorporated in Vulnerability Assessment (VA) studies related to the marine environment. Achieving these objectives will provide a significant contribution to project OCEANPLAN (Marine Spatial Planning under a Changing Climate; PTDC/CTA-AMB/30226/2017; www.oceanplan-project.com), under which the present work is developed.

In order to provide a deeper knowledge on the concepts related to the topic, the introductory section is divided into four different sub-sections: (i) MSP in the world and Europe; (ii) Blue Growth; (iii) the challenge of climate change; and (iv) the importance of climate-related VA studies.

1.1. MSP in the World and Europe

Marine and coastal ecosystems provide numerous goods and services that are essential for human wellbeing and livelihoods ensuring food, cultural identity, jobs and income generation [15]. At the same time, these areas are deeply affected by anthropogenic stressors [15-17]. With a global human population of over seven billion people, a third of which living within 100km of the coast, and a variety of human activities, such as fishing and offshore industries, producing cumulative pressures on the environment, ensuring a sustainable use of the ocean is a major challenge [15-17]. Planning of marine areas arose with the aim of promoting better management and governance of the ocean, seeking to organize the distribution of ocean uses in time and space, and trying to reduce conflicts and promote compatibility between uses [5]. Over the past 30 years, many decision-makers around the world have dedicated increasing attention to MSP, and MSP has become an important instrument and approach to support sustainable ocean use and conservation [3, 5]. The spatial management of ocean uses and activities, implies licensing procedures, the development of regulations, and the allocation of space to a variety of human activities that occur in the maritime space [4, 5, 18]. This, brings political, social, economic, scientific and environmental challenges, involving trade-offs between the different sectors and dedicated balance between socioeconomic development and environmental protection [4, 5, 18]. Figure 1.1. presents a glimpse into the general MSP framework. It is important to have in mind that MSP includes both biophysical and human dimensions, which often makes it difficult to capture effectively the entire complexity of factors inherent to the process [4]. In addition to this, political and institutional settings are an important part of planning initiatives [4]. Therefore, MSP, like any other planning instrument, is influenced by changes in governmental structures leading in many cases to considerable delays in the development of plans or even to their abandonment [4, 19-20].

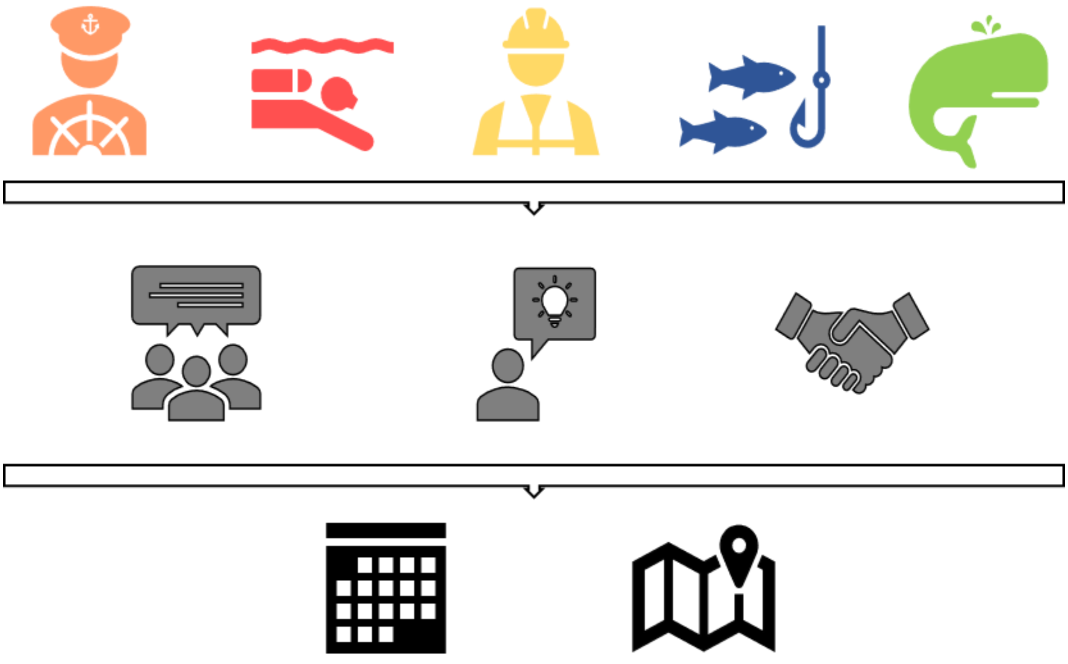

Figure 1.1| Marine spatial planning (MSP) process diagram. Entities responsible for developing MSP take into consideration all the existing and future human uses and activities for a specific marine management area (commonly, the entire maritime space of a nation). Through a public and participatory process, interested parties work together to reach an agreement on when and where such uses and activities can take place. For detailed phases and steps of MSP development see references [3, 5].

The European Union (EU) through the Marine Strategy Framework Directive (MSFD) has set itself the objective of achieving a good environmental status of its marine waters by 2020, while looking for the sustainable use of marine goods and services [21]. To that purpose, all Member States are expected to pursue Ecosystem-Based Management approaches (EBM) that are more integrated and more adaptive [15, 21-22]. EBM allows for a better understanding of the multiple existing human uses in the ocean and the way they affect (and are affected by) the environment [15-16]. This approach also allows for a more holistic approach, moving away from a sector-by-sector approach, towards considering sectors, species and habitats and all together [15-16]. Many authors recognize that MSP is an important instrument to support and implement EBM [5]. However, is often difficult to find the proper balance between socioeconomic development and conservation of marine ecosystems, as well as of the goods and services they provide [4, 7, 15, 22]. As a result, many times MSP "neglects" marine protection, and prioritize economic short/term goals [4, 7, 15, 22]. In the EU, the MSP Directive (Directive 2014/89/EU) establishes a framework for MSP aimed at first "promoting the sustainable growth of maritime economies" and "the sustainable use of marine resources", while "the preservation, protection and improvement of the environment" appears only latter on [23]. The main objective must, therefore, be to focus on both dimensions, recognizing the need of a healthy ocean to a thriving and sustainable ocean economy [16]. In Europe, the status of MSP implementation varies among countries, and an overview is provided in Table 1.1. Nevertheless, according to the MSP Directive, all coastal Member States are obliged to implement their national marine spatial plans, at the latest, by 31 March 2021, and review them at least every 10 years [23].

Table 1.1| Status of MSP development in each coastal Member State of the European Union. This table was adapted from data available in the European MSP Platform [24-25]. National marine spatial plans are defined as plans developed by national MSP authorities; sub-national marine spatial plans as those developed by sub-national MSP authorities. The United Kingdom (UK) is included in this table (and in the present study) because it was still a Member State at the beginning of this project.

Member State	Status of MSP development	
	National level	**Sub-national level**
Belgium	**Plan adopted**	-
Bulgaria	**Plan under preparation**	-
Croatia	**Plan under preparation**	**7 initiatives under preparation**
Cyprus	**Plan under preparation**	-
Denmark	**Plan under preparation**	-
Estonia	**Plan under preparation**	**2 plans adopted**
Finland	-	**1 plan adopted** + **4 initiatives under preparation**
France	-	**4 plans adopted**
Germany	**2 plans adopted**	**3 plans adopted**
Greece	**Plan under preparation**	-
Ireland	**Plan under preparation**	-
Italy	**Plan under preparation**	-
Latvia	**Plan adopted**	-
Lithuania	**Plan adopted**	-
Malta	**Plan under preparation**	-
Netherlands	**Plan adopted**	-
Poland	**5 plans under preparation**	-
Portugal	**Plan adopted**	**1 plan adopted** + **1 initiative under preparation**
Romania	**Plan under preparation**	**4 initiatives under preparation**
Slovenia	**Plan under preparation**	-
Spain	**Plan under preparation**	-
Sweden	**3 plans under preparation**	-
UK	**2 plans adopted (Scotland and Wales)** + **1 plan under preparation (Northern Ire-land)**	**2 plans adopted (England)** + **4 initiatives under preparation (England)**

1.2. Blue Growth

In many countries the economy is driven by marine and coastal areas, where a growing competition for goods and services has led to the development and expansion of various human activities [6, 18, 26-27]. More recently, this phenomenon has been designated as Blue Growth [6, 18, 26-27]. However, this expansion of economic activities such as aquaculture, renewable energy, coastal tourism and seabed mining, brings new threats to the marine environment and to the dependent human populations [27-28]. For this reason, it is essential to understand the impacts of the BE on both the environment and its users [27-28]. Coastal ecosystems have the particularity of producing 90% of all the food that comes from the ocean [29]. The fishing sector globally represents the source of income for 38.98 million people [30]. Furthermore, fish represents 17% of the animal protein consumed globally, almost half of which coming from aquaculture (46% in 2018) [29-30]. For example, aquaculture is a sector that, in addition to fishing, is of great importance to the Mediterranean economy and is strongly expanding in Asia, presently home of 89% of the global production [6, 29-31]. Coastal areas are also home to most of the tourism activities [26, 32-33]. Tourism, is one of the largest and most relevant sectors of the global economy, being partly represented by nautical and coastal tourism, which is extremely important for local and national economies of many developed and developing countries [26, 32-33].

In addition to these well establish sectors, the BE encompasses numerous other sectors that are interconnected with each other, as they sometimes share infrastructures (*e.g.* ports and electricity distribution networks) and/or depend on shared natural resources [6]. While some sectors have not yet reached their full potential, occupying only a reduced portion of the maritime space (*e.g.* seabed mining and biotechnology), others are increasingly expanding like it is the case of renewable energy in Europe where most countries in the North Sea have offshore wind fields [22, 28]. Europe has been a driver of Blue Growth, given that sea-dependent activities in the EU represent 5.4 million jobs and a gross value added (GVA) of 500 billion euros a year [6]. Blue Growth can also promote new livelihoods for coastal communities, such as tourism in communities that are very dependent on the fishing sector, allowing them to diversify their source of income and reduce pressure on marine resources [6, 34]. In this case, a healthy marine environment is essential, attracting more people to these areas, increasing nautical tourism and green tourism, such as whale-watching [6, 34]. It is equally relevant to note that these new activities will increase anthropogenic pressures on the ocean, in addition to traditional activities and sectors such as fishing and shipping [6, 28]. It is therefore important that when developing marine spatial plans decision-makers are able to recognize that Blue Growth needs to respect not only the different economic sectors, but also the health of the marine environment, seeking both socioeconomic and environment sustainability for the maritime space [6, 28].

1.3. The Challenge of Climate Change

There is currently a great notion that climate change has and will continue to have harmful effects on species, ecological processes, ecosystems, and human activities/infrastructures that depend on them [31, 35-36]. Changes in sea level, acidification, increasing sea surface temperature, increasing frequency and intensity of extreme events, changes in ocean currents and nutrient cycles will all affect marine and coastal ecosystems [22, 32, 34-35, 37-38]. This poses new challenges for communities that depend on the goods and services provided by such ecosystems, affecting the livelihoods of millions of people as well as economic sectors, in a space that is already under growing pressure from other anthropogenic stressors [22, 32, 34-35, 37-38].

Climate change will affect fisheries and dependent economies, as spatial and temporal variations will occur in fish populations with implications for human consumption [39-42]. Changes in the ecological quality of resources and habitats will also be visible, as well as, in the operationalization of the fishing activity, see Figure 1.2 [39-42]. In tourism, the effects may be positive or negative in relation to the number of visitors to a given destination [43-46]. However, a decline in the number of visitors due to sea level rise, extreme events, coastal erosion and precipitation, caused by climate change, will have an impact on local resources, security and on infrastructures essential to coastal and marine tourism, triggering potential crises in the sector [43-46]. Aquaculture will also have numerous difficulties in the face of the new climate context [44]. Changes in the availability of space for aquaculture may occur due to sea level rise, and due to the intensification of extreme events [44]. In addition, the nutrient input from rivers, diseases and harmful algae blooms (HABs), changing currents, acidification and increasing sea surface temperature can interfere in some aquaculture systems (*e.g.* water-based systems), due to the strong dependence on the surrounding environment for the development and maintenance of the cultivated organisms [44]. Sectors in which vulnerability to climate change tend to be lower, such as maritime transportation, will still face numerous difficulties with the increase in the intensity and frequency of extreme events, increase in average sea level, increase in temperature, and changes in wind regimes and circulation patterns [4, 5, 47]. These changes will cause the relocation of some ocean uses, that will lead to new conflicts and environmental impacts, forcing the marine spatial plans to become adaptive and flexible, looking for new opportunities and different adaptation approaches for the variety of existing sectors [4-6, 44, 48].

In short, climate change has been increasingly recognized as a social, environmental and economic problem [49-50]. Addressing this problem in the ocean has the inherent difficulty of the impacts of climate change being vast, uncertain and expected to occur in large areas with difficulties in accessibility [51-53]. However, the search for a better understanding of climate impacts and vulnerabilities will contribute to the development of more effective management and adaptation plans [53-54].

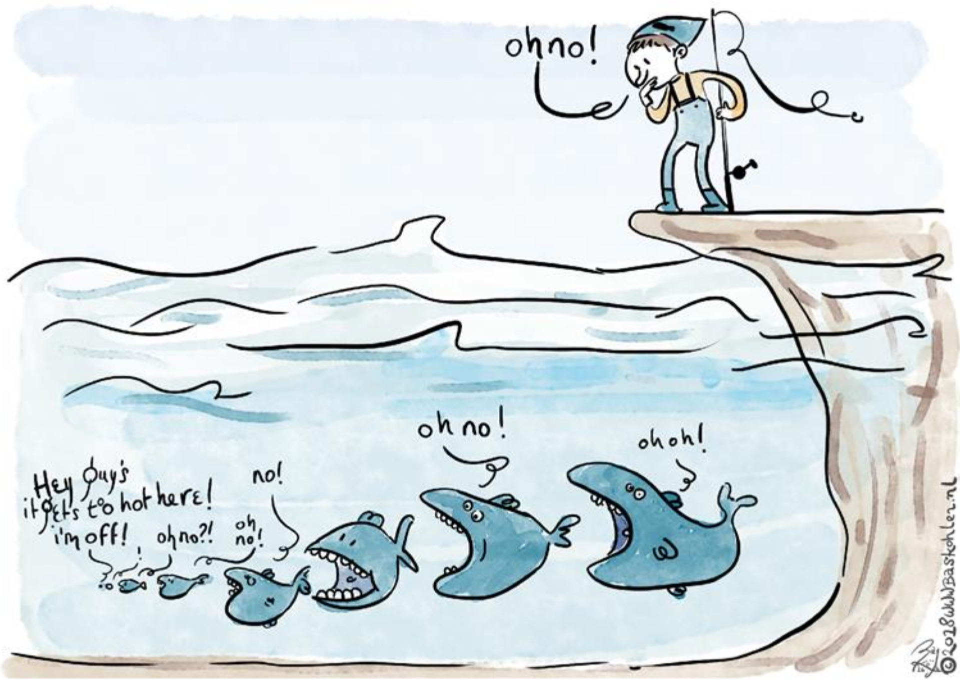

Figure 1.2| Shifting species in a changing climate. An example of how change on marine ecosystems, triggered by climate change, can influence ocean uses and activities - in this particular case distributional shifts of marine species affecting the fisheries sector. Cartoon created by visual artist Bas Köhler at the 4th International Symposium on the Effects of Climate Change on the World's Oceans [55].

1.4. The Importance of Climate-related Vulnerability Assessment Studies

The concept of vulnerability has been long applied in the context of natural hazards and risk analyses, environmental issues, health, and economics [35, 43, 56-63]. More recently, it has been increasingly used in the context of climate change [35, 43, 56-63]. However, it is still difficult to find a definition of vulnerability that is consistent and accepted by all, because of the variety of knowledge areas using this concept, as well of existing interpretations and definitions [35, 56-58, 60, 63]. Still, the most recognized and most referred definition pertains to vulnerability as a result of the interaction between exposure, sensitivity and adaptive capacity [53, 56]. This definition is used by the IPCC, which has been seeking to define and develop a framework capable of assessing the vulnerability of ecosystems, populations and economies in the context of climate change, integrating social, ecological and economic dimensions [35, 63]. This framework does not require extensive databases and can rely on information from experts in the area, to try to best relate vulnerability with other factors [35, 63]. Such variety of areas of specialization and concepts has led to the emergence of numerous methodologies to assess vulnerability, which, despite allowing for advances in the field, also raised uncertainties and the need for clarification regarding which approaches should be followed in vulnerability studies [54, 61-63].

VA studies can be used in a wide variety of ways [63]. They can be used, for example, to recognize the weaknesses of a system, alerting people to a specific threat or new opportunities arising from such treat, improving or developing effective adaptation plans, or allowing advances in scientific knowledge [38, 58, 63-65]. Depending on the context, VA studies may focus on the vulnerability of ecosystems, people or human activities (*e.g.* fishing, tourism or transport), on different locations (*e.g.* river, sea or coast), and on different natural and anthropogenic hazards (*e.g.* pollution or climate change) [63]. In addition, VA studies vary depending on the thematic area where they are being used [66]. Particularly in the context of climate change, and because climate impacts vary spatially, the analysis of spatial information is extremely relevant [66]. However, it is important to note that VA studies are temporally discrete, reducing the ability to capture the dynamics of analysed studies and adaptation plans over time [63-64]. This can take place because of the uncertainty in predicting long-term climate trends, difficulties in recognizing cause-effect relationships, existing knowledge on social-ecological systems and on cumulative impacts from different climate-related factors [63-64]. Nevertheless, VAs allow for a better understanding of how different marine goods and services, dependent economies and human communities can be affected by climate change effects, and their ability to respond and adapt [63].

To better characterize vulnerability, as well as assess the social and ecological complexities of analysed systems, numerous qualitative and quantitative methods can be used [57, 67]. One of the most popular methods pertains to the development of quantitative vulnerability models based on composite indexes and indicators [35]. Indeed, the IPCC has long used this approach to identify which countries are most in need of assistance to face climate change impacts [35]. These methodological approaches based on indicators and variables can also be integrated into maps in order to facilitate the presentation of results, which improves data communication to policy-makers, thus strengthening the link between science and policy [68]. However, when using indicators-based approaches there can be difficulties in identifying all the relevant stressors and/or capturing socioeconomic and biophysical uncertainty [67-68]. In addition, while it is already challenging to identify and obtain complete and adequate databases, available information will always be a simplification of the complex nature of vulnerability, a static representation of something that is incredibly dynamic and multidimensional [67-68]. Indeed, the factors that influence vulnerability range from social to political, economic or ecological, and vary with context from place to place [67-68].

VA studies developed in the context of MSP also face these spatial variability challenges [5, 7]. Indeed, ocean uses and activities have different social and economic importance from country to country, or region to region [5, 7]. This means that one particular ocean use can be prioritised in a particular MSP process (because of its social and/or economic relevance) even if it does not correspond to the ocean use globally more vulnerable [5, 7]. Still, VA studies allow for a better understanding of what ocean uses and activities will be more affected by climate change, and thus will need most attention within MSP and spatial management processes, the ultimate goal being the sustainable use of the ocean [27].

2. Methodology

The present work follows several methodological steps, detailed in the following sub-sections. First, a systematic review was conducted on existing scientific literature that addresses vulnerability assessments, risk, climate change and ocean uses (sub-section 2.1). Second, and building on the results from the literature review, a composite indicator was developed to analyse the combined vulnerability of main human uses of the ocean space to the impacts of climate change, using EU coastal Member States, and the United Kingdom (UK), as a case study (sub-section 2.2). Finally, obtained results were examined and discussed in the context of MSP, the BE, and the broader sustainable use of the ocean.

2.1. Literature review

The main goal of developing a literature review was to support a deeper understanding on the key concepts and processes related to the assessment of the vulnerability of ocean uses and ocean planning in the face of climate change. It allows, for example, for the identification of existing methodologies, their limitations, the different dimensions of vulnerability considered, or the different ocean uses and climate-related drivers of change that are integrated. Such review is especially important to inform and guide the second step of the present work, the development of a composite indicator (sub-section 2.2).

The methodological approach used to develop the systematic literature review is depicted in Figure 2.1. The International Scientific Indexing (ISI) Web of Knowledge website was first used to collect data [69]. Data was collected for all years (*i.e.* 1900-2019) and for the entire available database, on September 26, 2019. The search was carried in two different phases, using the keywords identified in Table 2.1.

While the first phase focused on a more general search, using broader terms that characterized the present study objective (namely “vulnerability assessment”, “climate change”, “ocean uses”), the second phase focused on a more in-depth search that allowed for the incorporation of additional relevant studies.

While searching the ISI Web of Knowledge website, 879 results were obtained for the selected keywords, 268 in the first phase and 611 in the second one [69]. Results were temporally organized into different themes (see Figure 3.1), based on their title and abstract. A preliminary analysis of contents (namely, titles, abstract and use of keywords in the main text) showed that a number of articles had substantial relevance to the present work. More specifically, these pertained to theoretical studies on vulnerability, risk, MSP, BE and climate change, as well as specific VA studies related to climate change impacts on ocean uses developed at different scales – from regions to countries, coastal communities or Small Island Developing States (SIDS). Each selected study was then analysed for contents and consistency. Articles in which the selected keywords appeared only in the title, abstract, keywords or references were excluded.

The subset of “more relevant” articles, in a total of 96 were submitted to a “full” analysis, 32 from the first phase and 64 from the second (Figure 2.1). Repeated articles identified in the two research phases were counted only once. A total of 11 additional studies that were identified from the references of initially analysed articles, and from other sources such as Google Scholar and Mendeley, were also fully analysed whenever they clearly showed potential to add relevant information to the present work [70-71]. Finally, four articles were further excluded because even though selected keywords were present in the main text, the study did not focus on any essential aspect that could contribute to the present work (Table S1, Supplementary Materials).

Table 2.1| Keywords used in the different research phases. Two research phases were elaborated, each one, with different keywords used.

1st Research phase	2nd Research phase
"vulnerability assessment" "*climate change*" "*ocean uses*"	"*vulnerability analysis*" *or* "*vulnerability approach*" *or* "*vulnerability assessment*" *or* "*risk analysis*" *or* "*risk methodology*" "*climate change*" *or* "*global change*" *or* "*acidification*" *or* "*deoxygenation*" *or* "*global warming*" *or* "*changing climate*" "*ocean*" *or* "*sea*" *or* "*marine*" *or* "*maritime*" *or* "*coast*" *or* "*coastal*"
The words were combined using the function "*and*"	The word sets were combined using the function "*and*"

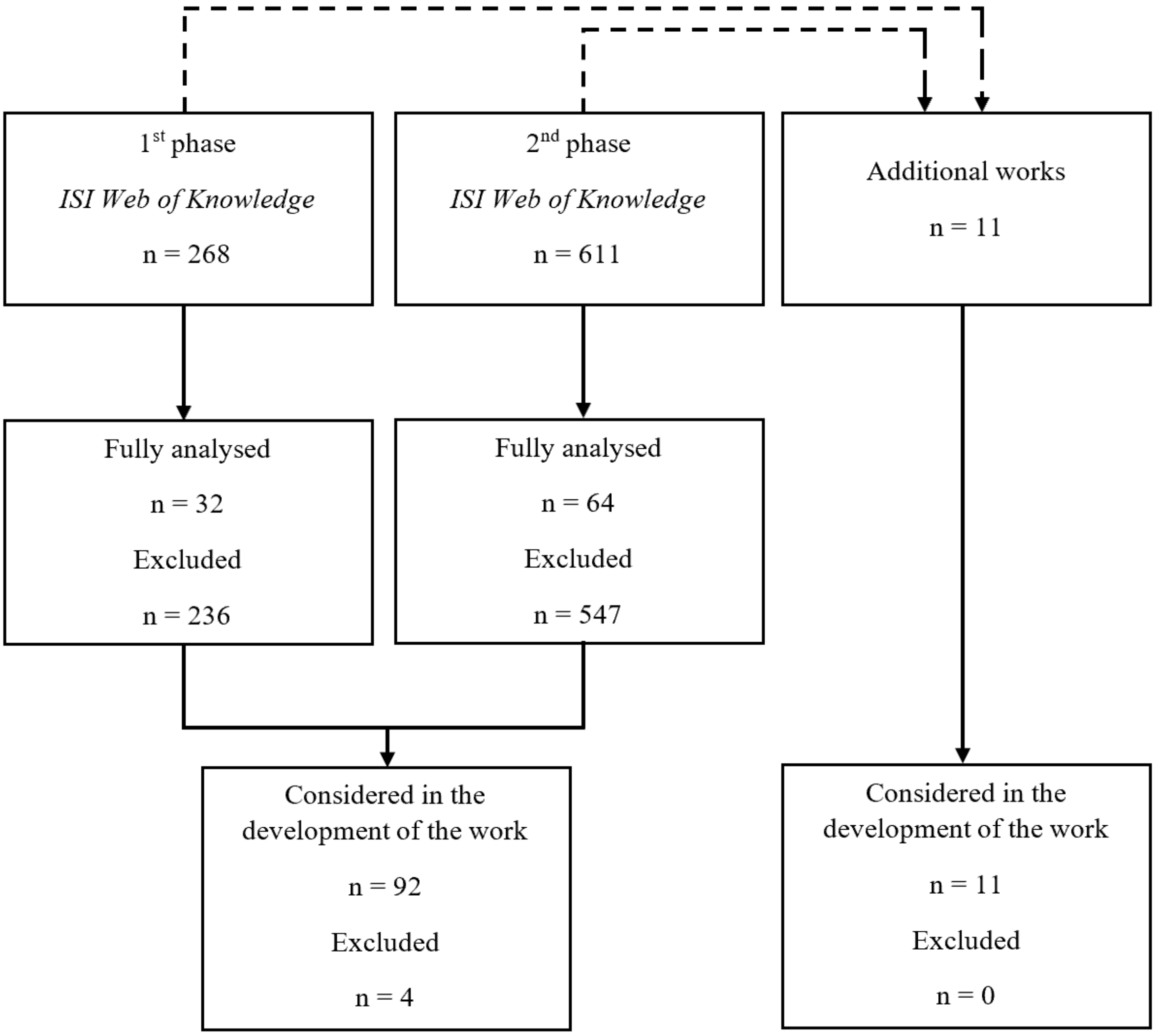

Figure 2.1| Methodological approach used to develop the literature review. n = number of articles.

The final list of studies considered in the present work was then differentiated into two sub-groups: theoretical articles (*i.e.* studies based on the ideas and abstract principles of a subject) and vulnerability assessment articles (see Tables S2 and S3, respectively in Supplementary Materials). Because of their relevance to support the development of a specific vulnerability index, VA studies were further analysed. Each article was examined according to: the spatial scope (Table S4, Supplementary Materials); the nature of the vulnerability assessment, including the addressed vulnerability dimensions and type, as well as the methodological approach (Table S5, Supplementary Materials); the focus on main ocean uses and climate-related drivers of change, and recognized importance to MSP and/or the BE (Table S6, Supplementary Materials).

Regarding the spatial comprehensiveness, four different classes were used: studies carried out at a global scale were considered 'global', studies carried out in more than one country as 'regional', studies focusing on a country as 'national', and those specific to a location as 'local' studies. As for the methodological approach, articles were analysed according to the dimension of vulnerability or risk they addressed (*i.e.* exposure, sensitivity, adaptive capacity, hazard potential), the type of vulnerability considered (*i.e.* 'ecological', 'social', and 'economic'), and the nature of such assessment (*i.e.* 'qualitative', 'quantitative', or both). Quantitative studies are those in which the vulnerability output is expressed by quantitative variables (*i.e.* number or percentages), while qualitative studies are those in which the vulnerability output is expressed qualitatively (*e.g.* low, medium, high). In what pertains to climate-related drivers of change, articles were searched for and analysed according to the main factors identified in Frazão-Santos *et al.* [5], namely: ocean warming, ocean acidification, deoxygenation, sea level rise, extreme events, changes in currents and winds, species distributional shifts, and diseases and HABs. The same source was used to select the main ocean uses to be considered, namely: fishing, aquaculture, marine conservation, marine renewable energy, seabed mining, shipping, and marine and coastal tourism [5].

For each analysed parameter, articles were coded as 0, 1, or 2 (see Tables S4 to S6, Supplementary Materials). For the spatial scope, type of vulnerability, methodological approach, and climate-related drivers of change, codes pertain simply to the presence (=1) and absence (=0) of the different parameters. In regard to addressed vulnerability dimensions, main ocean uses, relevance to MSP and to the BE, the code used pertains to absence (=0), brief reference (=1), and full mention (=2). Keywords or concepts were considered to be briefly mentioned (*i.e.* =1) when they appeared only once or twice in the text, without great context, or when they were implicit in the text.

2.2. Assessment of the vulnerability of MSP and the BE

2.2.1. Conceptual framework

In order to support the integration of climate change effects into MSP, a dedicated vulnerability index (or composite indicator) was developed and applied to European coastal countries [7]. As identified in the introductory section of this work, such index was developed according to guidelines from the 4th and 5th IPCC Assessment Reports on Climate Change [9-10], the OECD Handbook on Constructing Composite Indicators [11], and a preliminary approach on assessing MSP and BE vulnerability to climate change [5, 12-14]. These general guidelines were also complemented with specific results from the analysis of literature on vulnerability assessments (sub-section 2.1).

The 4th IPCC Assessment Report [9], from 2007, includes the vulnerability model most commonly used in marine management and conservation studies, and thus the one followed in the present work [72]. Such model considers vulnerability to be the result of exposure, sensitivity and adaptive capacity of a system to the effects of climate change [9, 53, 56, 63, 72]. According to such definition, 'exposure' is the presence of goods and services in a system (such as people, livelihoods or ecosystems) that may be adversely affected by climate change [9-10, 63, 72]. As well, 'sensitivity' is the degree to which a system is positively or negatively affected, directly or indirectly by climate drivers [9-10, 63, 72]. Finally, 'adaptive capacity' is the ability of a system to adjust to climate change effects, moderating damage, exploring new opportunities and dealing with its consequences [9-10, 63, 72].

In the present work, and according to the preliminary approach by Frazão-Santos *et al*. [12-13], the combined vulnerability of key human uses and activities that take place in the ocean is used (and assessed) as a *proxy* to the vulnerability of MSP and the BE to climate change. Here, nine key ocean uses and activities are considered, which are defined according to indications from the EU Blue Economy Reports for 2019 and 2020 [73-75] and from Frazão-Santos *et al.* [5]. These are fisheries, aquaculture, marine conservation, marine renewable energy, shipbuilding and repair, ports, maritime transport, marine and coastal tourism, and seabed mining [5, 73-75]. At the same time, the impacts from eight climate change factors are taken into account, namely: ocean warming; ocean acidification; deoxygenation; sea level rise; extreme events; changes in currents and winds; species distributional shifts, and diseases and HABs) [5].

In this context, exposure is perceived as the presence of ocean uses and activities that take place in each country maritime space. Exposure was measured for each main ocean use on each country. For ocean uses that correspond to economic activities, three socioeconomic variables were considered. These are the number of jobs (*i.e.* employment), the gross value added (*i.e.* GVA) and the productivity (*i.e.* GVA *per* employment) of a number of maritime activities associated to each particular ocean use (see section 2.2.3) [73-75]. These variables are also *proxies* for different types of vulnerability, namely social vulnerability (*i.e.* using employment as a *proxy*) and economic vulnerability (*i.e.* using GVA and GVA per employment – productivity as a *proxies*). As for marine conservation, a use of the ocean space that does not correspond to an economic activity, national exposure was measured using other types of variables, namely the coverage of marine protected area (MPA), and the two biodiversity sub-goals of the Ocean Health Index (OHI) (*i.e.* species and habitats) [76-77]. These are used as *proxies* for ecological vulnerability.

While the exposure dimension is calculated for each ocean use *per* country, the sensitivity of each ocean use is kept at the global level. Data to support the calculation of sensitivity, particularly in regard to the global, combined impact of the different climate-related drivers of change in each ocean use, was adopted from Frazão-Santos *et al*. [5]. These authors, however, did not consider the sensitivity of shipbuilding, ports, and maritime transport separately, but only the global sensitivity of shipping [5]. For the purpose of this project, and because socioeconomic data is available to each of these maritime activities from the EU Blue Economy Reports [73-75], the global sensitivity of each of these uses is calculated separately. Finally, for adaptive capacity, this work builds on the five domains proposed by Cinner *et al*. [78], namely: assets, learning, flexibility, social organization and agency. Accordingly, the variables used to calculate the adaptive capacity of each country are the gross national income (GNI) *per capita* purchasing power parity terms (≈ income), years of schooling (≈ education), life expectancy at birth (≈ health) and aggregated worldwide governance indicators (≈ governance) [78-80]. It should be noted that the flexibility domain was not integrated in the present work. Flexibility intends to the capacity to change livelihood strategies [78]. Considering the data sources available to this study, the most appropriate variable to estimate flexibility would be the GVA of non-maritime economic sectors. However, because GVA of maritime activities is already used in exposure calculation, this data would be overrepresented in the index. This means that adaptive capacity builds on general national data, not being centred on (nor reflecting) the maritime realm of each country.

The overall framework used to develop the vulnerability index is represented in Figure 2.2. and Table 2.2. The detailed description of each of the variables used in the index is available in Supplementary Materials (Section 7.2), together with reasons for their selection, where and how they are used, and their limitations and constrains.

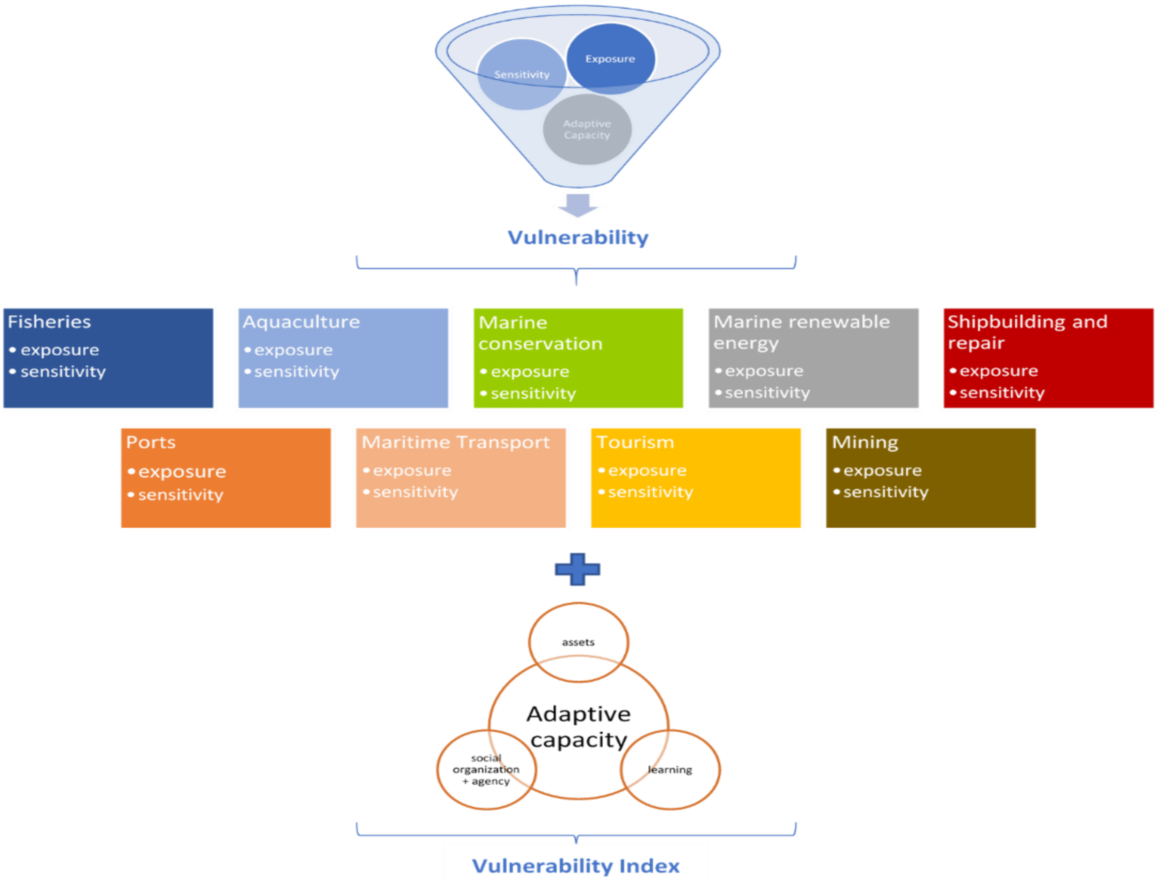

Figure 2.2| Index framework. Vulnerability of key ocean uses and activities to climate change is expressed by the interaction of three components: exposure; sensitivity and adaptive capacity. In that, for the development of the present index, the exposure was calculated for each ocean use in each country and sensitivity was calculated for each ocean use globally, while the adaptive capacity was obtained through data not centred on the maritime uses of each country.

Table 2.2| Variables used to calculate each of the three vulnerability components.

Ocean use	*Exposure (per country)*	*Sensitivity (global)*	*Adaptive Capacity (per country)*
Fisheries	Fisheries Employment Fisheries GVA Fisheries GVA *per* employment	Combined impacts on fisheries from climate stressors	Income ≈ Assets Education ≈ Learning Health + Governance ≈ Social Organization + Agency
Aquaculture	Aquaculture Employment Aquaculture GVA Aquaculture GVA *per* employment	Combined impacts on aquaculture from climate stressors	
Marine Conservation	MPA coverage Biodiversity sub-goals of OHI	Combined impacts on conservation from climate stressors	
Renewable Energy	Renewable Energy Employment Renewable Energy GVA Renewable Energy GVA *per* employment	Combined impacts on energy from climate stressors	
Shipbuilding and Repair	Shipbuilding Employment Shipbuilding GVA Shipbuilding GVA *per* employment	Combined impacts on shipbuilding from climate stressors	
Ports	Ports Employment Ports GVA Ports GVA *per* employment	Combined impacts on ports from climate stressors	
Maritime Transport	Maritime Transport Employment Maritime Transport GVA Maritime Transport GVA *per* employment	Combined impacts on maritime transport from climate stressors	
Tourism	Tourism Employment Tourism GVA Tourism GVA *per* employment	Combined impacts on tourism from climate stressors	
Mining	Mining Employment Mining GVA Mining GVA *per* employment	Combined impacts on mining from climate stressors	

2.2.2. Case study selection

The developed conceptual framework was applied to all coastal countries of the European Union, plus the UK (Table 2.3). This choice takes into account the availability of data and the relevance of both BE and MSP in Europe. Indeed, the EU developed countless initiatives with the objective of promoting the sustainable and intelligent growth of an economy increasingly centred on the ocean, which are reflected in numerous reports (*e.g.* Europe 2020 Strategy, Communication on Blue Growth, EU Blue Economy Reports) [6, 73-74, 81] and legal documents to be implemented by Member States, (*e.g.* the MSFD and the MSP Directive) [21, 23]. In addition, the BE played a key role in combating the European economic crisis of 2008 and 2009 [6, 73]. As an example of the great importance it has in the EU, in 2018 alone activities focused on the BE created nearly 5 million jobs, generating a GVA of 218 billion euro [74]. Moreover, as mentioned in the introduction, according to the MSP Directive all coastal Member States have to develop and implement national marine spatial plans by March 2021 [23]. MSP is thus in the "spotlight" in the EU context and understanding its vulnerability to climate change can constitute a step forward in ensuring its long-term adequacy and sustainability [7].

The UK was included in the present study for two reasons. First, it was still an EU Member State when the project started (September 2019). Second, the most recent data available for the BE in the EU still included the UK. For those reasons, the UK was analysed together with the other countries identified in Table 2.3. Analysing the data by country, and not at the EU level, allow us to study the inherent vulnerability in the different national contexts and locations, with the importance given to each ocean use and economic activity, different from country to country or from region to region [73-74, 82].

Table 2.3| Countries used in the current project to apply the vulnerability index.

Belgium	Bulgaria	Croatia	Cyprus	Denmark
Estonia	Finland	France	Germany	Greece
Ireland	Italy	Latvia	Lithuania	Malta
Netherlands	Poland	Portugal	Romania	Slovenia
Spain	Sweden	UK		

2.2.3. Exposure calculation

As mentioned in the conceptual framework description, for ocean uses that correspond to economic activities, three socioeconomic variables were used to calculate three types of exposure: (1) exposure based on the national number of jobs (*i.e.* employment) associated to each ocean use, from 2009 to 2018 (Es); (2) exposure based on the national GVA for each use, in million euro, from 2009 to 2018 (Ee); and (3) exposure based on the productivity of each ocean use (*i.e.* GVA per employment), in euro/jobs, from 2009 to 2018 (Ep). The year 2019 was not considered in this work, due to data availability. The detailed correspondence between each main ocean use and related maritime activities is presented in Table 2.4 [75]. GVA *per* employment was manually calculated, being the result of GVA, in euro, divided by the number of jobs. These variables were chosen because of their socioeconomic importance, their accessibility (being available at national level), and their comparability among countries (they are available from the same data source) [73-75].

The calculation for the three types of exposure was based on the following equations:

$$Es_{i,x} = \frac{1}{z}\left(\sum_{j=1}^{n} J_{j,2009} + \cdots + \sum_{j=1}^{n} J_{j,2018}\right)$$

(2.1)

where $Es_{i,x}$ is the exposure of ocean use i, in country x, based on the number of jobs (*i.e.* employment); J_j is the number of jobs of maritime activity j that corresponds to ocean use i (according to Table 2.4) for each year of the period from 2009-2018; and z is the number of years considered.

$$Ee_{i,x} = \frac{1}{z}\left(\sum_{j=1}^{n} G_{j,2009} + \cdots + \sum_{j=1}^{n} G_{j,2018}\right)$$

(2.2)

where $Ee_{i,x}$ is the exposure of ocean use i, in country x, based on GVA; G_j is the GVA of maritime activity j that corresponds to ocean use i (according to Table 2.4) for each year of the period from 2009-2018; and z is the number of years considered.

$$Ep_{i,x} = \frac{1}{z}\left(\sum_{j=1}^{n} E_{j,2009} + \cdots + \sum_{j=1}^{n} E_{j,2018}\right)$$

(2.3)

where $Ep_{i,x}$ is the exposure of ocean use i, in country x, based on productivity (*i.e.* GVA *per* employment); E_j is the GVA *per* employment of maritime activity j that corresponds to ocean use i (according to Table 2.4) for each year of the period from 2009-2018; and z is the number of years considered.

At the same time, for marine conservation two types of exposure were considered, according to two selected variables, namely : (1) national coverage of MPAs, in percentage; and (2) the national value of the biodiversity goal of the OHI (where values range from 0 to 100, and 100 is the maximum possible value for a country) (Figure 3.8) [73-74, 76-77]. Exposure based on MPA coverage (Ec) includes not only areas designated at national level, but also regional and international designated sites of protection, such as Sites of Community Importance from Habitats Directive, Special Protection Areas from Birds Directive, and Ramsar Sites [76].

Exposure based on the biodiversity goal of the OHI (Eo) reflects how successfully marine life is being maintained around the world. The OHI biodiversity goal is composed by the equal weight of two sub-goals: (1) species, which pertains to the conservation status of marine species; and (2) habitats, which evaluates the condition of key habitats that support high species numbers [77]. The two sub-goals are weighted equally when calculating the overall biodiversity goal score [77]. Here, it is important to note that for Portugal and Spain, the biodiversity score was calculated manually because of the existence of different biodiversity scores for their continental Exclusive Economic Zones (EEZs) and overseas territories (namely, the Azores and Madeira for Portugal, and Canary Islands for Spain). For that reason, the biodiversity scores of each area were weighted by the coverage of the corresponding EEZ subdivision in relation to the entire EEZ resulting in a combined biodiversity value for each country (OHI_i), according to the following equation:

$$OHI_i = \sum_{j=1}^{n} O_{j,i} E_{j,i}$$

(2.4)

where $O_{j,i}$ is the score of the OHI biodiversity goal of subdivision j from country i , and $E_{j,i}$ is the EEZ coverage of each subdivision j from country i pondered by the entire EEZ of such country ($\sum E_{j,i} = 1$). Baseline data is presented in Table 2.5.

Table 2.4| Sector, sub-sector and activities present in the EU Blue Economic Reports and complementary European Commission website platform, and related ocean use used in the development of this work. The activities used to calculate the corresponding ocean use are highlighted in *bold*. SSCF – small-scale coastal fleets, LSF – largescale industrial fleets, DWF – distant water fleets.

Sector	*Sub-sector*	*Activities*	*Ocean use*
Marine Living Resources	Primary production (Capture fisheries)	**Capture fisheries (SSCF)**	Fisheries
		Capture fisheries (LSF)	
		Capture fisheries (DWF)	
	Primary production (Aquaculture)	**Marine Aquaculture**	Aquaculture
		Shellfish Aquaculture	
		Freshwater Aquaculture	
	Processing and distribution	Manufacture of oils and fats	—
		Prepared meals and dishes	
		Processing and preserving of fish, crustaceans and molluscs	
		Retail sale of fish, crustaceans and molluscs in specialized stores	
		Wholesale of other food, including fish, crustaceans and molluscs	
		Other food products	
Marine Renewable Energy	Offshore wind energy	**Production of electricity**	Renewable Energy
		Transmission of electricity	
Ports activities	Cargo and warehousing	**Cargo handling**	Ports
		Warehousing and storage	
	Port and water projects	**Construction of water projects**	
		Service activities incidental to water transportation	
Shipbuilding and repair	Shipbuilding	**Building of pleasure and sporting boats**	Shipbuilding
		Building of ships and floating structures	
		Repair and maintenance of ships and boats	
	Equipment and machinery	**Manufacture of cordage, rope, twine and netting**	
		Manufacture of engines and turbines, except aircraft	
		Manufacture of instruments for measuring, testing and navigation	
		Manufacture of other fabricated metal products n.e.c.	
		Manufacture of sport goods	
		Manufacture of textiles other than apparel	
Maritime Transport	Passenger transport	**Sea and coastal passenger water transport**	Maritime Transport
		Inland passenger water transport	
	Freight transport	**Sea and coastal freight water transport**	
		Inland freight water transport	
	Services for transport	Renting and leasing of water transport equipment	
		Other transportation support activities	
Coastal tourism	Accommodation	**Accommodation**	Tourism
	Transport	**Transport**	
	Other expenditure	**Other expenditure**	
Marine non-living resources	Oil and gas	**Extraction of crude petroleum**	Mining
		Extraction of natural gas	
		Support activities for petroleum and natural gas extraction	
	Other minerals	**Operation of gravel and sand pits, mining of clays and kaolin**	
		Extraction of salt	
		Support activities for other mining and quarrying	

Table 2.5| Scores of the biodiversity goal of OHI for subdivision of Spain and Portugal [77], together with the extension of the corresponding Exclusive Economic Zone (EEZ) [83].

Subdivision	**EEZ extension (Km^2)**	**EEZ of each subdivision pondered by global EEZ ($E_{j,i}$)**	**Biodiversity goal ($O_{j,i}$)**
Portugal	1728718	-	-
Portugal – continental EEZ	315501	0.183	88
Portugal – Azores EEZ	960421	0.556	85
Portugal – Madeira EEZ	452796	0.262	88
Spain	1007673	-	-
Spain – continental EEZ	561763	0.557	76
Spain – Canary Islands EEZ	445910	0.443	75

2.2.4. Sensitivity calculation

To calculate sensitivity, data on the impact of the eight climate-related drivers of change in the different main ocean uses was used, based on Frazão-Santos *et al*. [5]. The latter study considers four classes of direct impact: high (= 3), medium (= 2), low (= 1) and none (= 0), as depicted in Table 2.6. However, as previously mentioned, the impact of climate-related factors was not calculated separately for shipbuilding, ports, and maritime transport [5]. For that reason, such calculations had to be developed within the scope of the present study, using the same methodology as in Frazão-Santos et al. [5] (see details in Supplementary Materials, Section 7.2.4).

In order to integrate the impact of climate-related drivers on ocean uses into sensitivity calculations, scores first need to be aggregated. Because not all drivers of change affect ocean uses in the same way, they were differently weighted according to their relevance to the generation of impacts (Table 2.7). Primary drivers (*i.e.* those directly resulting from greenhouse gases emissions) were granted a greater weight, when compared to secondary drivers (*i.e.* those derived from other drivers) – a 3:2 ratio [9-10]. Regarding the spatial incidence of the different drivers within each group (*i.e.* primary and secondary drivers), greater weight was given to drivers that occur continuously along the ocean (*i.e.* widespread) when compared to those that have a local manifestation – 2:1 ratio [9-10]. The two primary drivers were considered to be widespread. However, ocean acidification was granted less weight than ocean warming because responses to acidification are often specific to species and sub-species, and different among taxonomic groups [84-85]. Withing the subgroup of secondary drivers, all had the same weight. It could be expected that deoxygenation had a greater weight than other variables due to its deleterious impacts on marine ecosystems [9-10, 86]. However, because the occurrence of hypoxia zones is not globally dispersed, weights are equal [9-10, 86]. Sensitivity data is kept at the global level, due to the difficulty in obtaining baseline information (on the impacts of climate change on different uses) at the national level, particularly, from common data sources that allow for comparability among all analysed countries.

Therefore, the overall sensitivity of each ocean use (S_i) is calculated as:

$$S_i = \sum_{k=1}^{n} D_{k,i}\alpha_k \tag{2.5}$$

where $D_{k,i}$ is the direct impact degree of climate-related driver of change k on ocean use i and, α_k is the driver-specific weight ($\sum \alpha_k = 1$).

Table 2.6| Direct impacts of climate-related drivers of change on main ocean uses. Four classes of direct impact were considered: high (= 3), medium (= 2), low (= 1) and none (= 0). Adapted from Frazão-Santos *et al*. [5].

	Climate-related driver of change							
	Ocean warming	*Ocean acidification*	*Deoxygenation*	*Sea level rise*	*Extreme events*	*Changes in currents and winds*	*Distributional shifts*	*Diseases and HABs*
Marine conservation	3	2	2	2	1	2	3	1
Fisheries	3	2	2	2	3	2	3	2
Aquaculture	3	2	1	1	3	2	2	3
Tourism	2	1	1	2	3	2	2	1
Shipbuilding and repair	3	0	0	2	2	2	0	0
Ports	2	1	0	3	3	0	1	0
Maritime Transport	3	0	0	2	3	2	0	0
Marine renewable energy	2	0	0	2	3	3	0	0
Mining	0	0	0	0	3	0	0	0

Table 2.7| Specific weights of each climate-related driver of change according to considered characteristics (*e.g.* primary/secondary, widespread/localized). The driver specific weight (α) results from the multiplication of the previous individual weight (*e.g.* ocean warming α = 0.60 x 1 x 0.667 = 0.400). Cells with same colour sum 1.00.

Driver	**Primary/Secondary**	**Widespread/Localized**	**Sub-Group**	**α (Driver specific weight)**
Ocean warming	0.60	1.00	0.667	0.400
Ocean acidification			0.333	0.200
Distributional shifts	0.40	0.667	0.333	0.089
Sea level rise			0.333	0.089
Changes in currents and winds			0.333	0.089
Extreme events		0.333	0.333	0.044
Diseases and HABs			0.333	0.044
Deoxygenation			0.333	0.044

2.2.5. Adaptive capacity calculation

Taking into account the work of Cinner *et al*. [78], adaptive capacity was calculated by choosing representative variables for the domains proposed by the authors: (1) *assets*, the financial, technological and service resources people have access to; (2) *learning*, the capacity to obtain information on climate change, adaptation options and management of uncertainty; (3) *social organization*, the cooperation, collective action and knowledge sharing in society; (4) *flexibility*, the capacity to change livelihood strategies, and (5) *agency*, the power and freedom to mobilize the other four domains. The variables selected in the present study to represent each of these domains are detailed in Table 2.8. As mentioned in the conceptual framework section, the flexibility domain would be best described by the GVA of non-maritime economic sectors. However, it was not included in the present study to avoid an overrepresentation of particular variables (as GVA of maritime activities is already used in exposure calculation). As a result, selected variables are not marine-specific, instead representing more general socioeconomic aspects of each country capacity to adapt to climate change [87-89].

Data obtained for *income*, *health* and *education* were retrieved from the most recent Human Development Report [80]. For the *governance* variable, data was collected from the Worldwide Governance Indicators [79]. Education and governance are composite variables, because underlying data results from a combination of a set of sub-variables. Education results from the arithmetic average of the “expected years of schooling” and “mean years of schooling” for each country [80]. Governance is the arithmetic mean of six dimensions: “voice and accountability”; “political stability and absence of violence/terrorism”; “government effectiveness”; “regulatory quality”; “rule of law”; and “control of corruption” [79, 90].

The dimensions reflected by the governance variable, together with the quality of life translated by the health variable were considered to be an appropriate *proxy* of the capacity of society to collaborate and cooperate in a response to climate threats, to develop social cohesion, to strengthen people through participatory or collective processes and to share knowledge [78]. Thus, together they represent both the social organization and agency domains identified by Cinner et al. [78].

The adaptive capacity (AC_x) of country x is calculated by the unweighted average of all considered variables, as follows:

$$AC_x = \left(\frac{I + L + H + G}{4}\right)_x \tag{2.6}$$

where I_x is the income in country x, L_x is education, H_x is health and G_x is governance.

Table 2.8| Adaptive capacity representative variables for the domains proposed by Cinner et al. [78]. N/A – not applicable. PPP- purchasing power parity.

Adaptive capacity domains [78]	Variables used in the present study to represent each domain	Sub-variables
Assets	Income (GNI per capita constant 2011, PPP international dollars, 2018) [80]	N/A
Learning	Education (years of schooling, 2018) [80]	Expected years of schooling
		Mean years of schooling
Social organization & *Agency*	Health (*i.e.* life expectancy at birth, 2018) [80]	N/A
	Governance (*i.e.* aggregated worldwide governance indicators, 2018) [79]	Voice and accountability
		Political stability and absence of violence/terrorism
		Government effectiveness
		Regulatory quality
		Rule of law
		Control of corruption
Flexibility	N/A	N/A

2.2.6. Standardization of variables

All variables and respective indicators were normalized to a comparable scale of 0 to 1 before any aggregation [11]. For this, the *Min-Max* method was used [11, 91]. This method normalizes variables scores to an interval ranging from 0 to 1, by subtracting the minimum value from all other values and dividing the result by the range of values of the variables, according to the following equation:

$$\frac{(\mathrm{x} - \min)}{(\max - \min)} \tag{2.7}$$

However, instead of using the current minimum and maximum values present in the database for each variable, in the present work the "minimum possible value" and "maximum possible value" were used, that is the minimum and maximum values that each variable could obtain. For exposure variables, the minimum possible value was considered to be zero, corresponding to the absence of a particular ocean use in a given country, whereas the maximum value was the higher value of the dataset. Regarding sensitivity, as data is presented in intervals, the maximum and minimum values corresponded to the limits of such intervals, namely 0 (=minimum) and 3 (=maximum).

Finally, for adaptive capacity variables, normalization procedures varied depending on the indicator. Income, education and health were normalized according to the technical notes present in the Human Development Report [80]. According to these notes, income was normalized considering 100 and 75,000, respectively as the minimum and maximum possible values [80]. Education scores were normalized using 0 as the minimum and 18 as the maximum possible values for expected years of schooling, and 0 and 15 for mean years of schooling [80]. At the same time, health was normalized considering 20 as the minimum and 85 as the maximum possible values [80]. Finally, governance variables were normalized according to the methodological guidelines for the Worldwide Governance Indicators [90], which establish a minimum possible value of -2.5 and a maximum value of 2.5.

2.2.7. Vulnerability calculation

After calculating exposure, sensitivity, and adaptive capacity, and following the guidelines of the IPCC 4th Assessment Report [9], the three components were integrated into a vulnerability value for each ocean use. These components had the same treatment, making the value of vulnerability equally dependent on all of them. Given that countries with higher adaptive capacity are less vulnerable to climate change, similarly to what happens in other related studies the adaptive capacity variable had its values inverted prior to the inclusion in the index $(1 - x)$ [89, 91-92].

For ocean uses that correspond to economic activities, vulnerability was calculated based on the following equation:

$$V_{i,x} = \frac{1}{3}\left(E'_{i,x} + S'_{i} + (1 - AC'_{x})\right) \tag{2.8}$$

where $V_{i,x}$ is the vulnerability of ocean use i to climate change in country x; $E'_{i,x}$ is the normalised exposure of ocean use i, in country x; S'_{i} is the normalised global sensitivity of ocean use i; and AC'_{x} is the normalised adaptive capacity of country x. Because three types of exposure were considered for each ocean use (*i.e.* exposure based on employment, on GVA, and on productivity; see Section 2.2.3), three types of vulnerability were also calculated.

In regard to marine conservation, vulnerability was calculated as follows:

$$V_{mc,x} = \frac{1}{2}\left(E'_{c,x} + E'_{o,x}\right) + S'_{mc} + (1 - AC'_{x}) \tag{2.9}$$

where $V_{mc,x}$ is the vulnerability of marine conservation to climate change in country x; $E'_{c,x}$ is the normalised exposure of marine conservation based on the coverage of MPA, in country x; $E'_{o,x}$ is the normalised exposure of marine conservation based on the biodiversity goal of the OHI, in country x; S'_{mc} is the normalised global sensitivity of marine conservation; and AC'_{x} is the normalised adaptive capacity of country x.

Here, although two types of exposure were also considered for marine conservation use, it was decided to integrate them into a unique vulnerability value. This is justified by the fact that these two variables are complementary. As they represent the area that is protected and the ecological conditions existing there.

In order to produce a vulnerability value that reflects both the vulnerability of MSP and the vulnerability of the BE to climate change, the following equations were used:

$$V_{MSP,x} = \frac{\sum_{i=1}^{n} V_{i,x} + V_{mc,x}}{(n+1)} \tag{2.10}$$

$$V_{BE,x} = \frac{1}{n}\sum_{i=1}^{n} V_{i,x} \tag{2.11}$$

where $V_{MSP,x}$ is the vulnerability of MSP to climate change in country x; $V_{BE,x}$ is the vulnerability of the BE to climate change in country x; $V_{i,x}$ is the vulnerability of ocean use i that correspond to an economic activity, in country x; $V_{mc,x}$ is the vulnerability of marine conservation, in country x; and n is the number of ocean uses corresponding to economic activities considered.

While equation 2.10 aggregates the vulnerability of all main ocean uses considered in the present study, equation 2.11 excludes marine conservation from the calculations. The latter is because while marine conservation supports the development of several maritime activities (*e.g.* scuba-diving, whale watching, underwater photography) is does not correspond to an economic activity in itself, thus not being part of the equation 2.11.

Again, because three types of vulnerability were considered for ocean uses that correspond to economic activities (*i.e.* based on employment, on GVA, and on productivity), three types of $V_{MSP,x}$ and $V_{BE,x}$ were calculated. Final results were re-normalized and re-scaled to the interval [0-100] in order to facilitate data interpretation. These results were presented in the form of maps, using QGIS software, and EEZ and EU coastline shapefiles, for a better visualization of vulnerability values (Figures 3.10 to 3.16) [83, 93-94].

3. Results

3.1. Literature Review

The systematic review of scientific literature allowed for the identification of a number of topics that were more frequently addressed in the 879 initial references, as presented in Figure 3.1. From the preliminary analysis of such references, it was evident that studies on the impact of sea level rise and extreme events on coastal areas and coastal communities were the most frequent ones (n=319 in total, when considering both search phases), followed by studies on the impact of climate change on marine species and habitats (n=106). Conversely, studies on the impact of climate change on maritime transport and ports (n=11), on the impact of climate change on the tourism sector (n=8) and on marine renewable energies (n=4), were the least represented (Figure 3.1). As it would be expected in such preliminary stage of analysis, a high number of studies went beyond the topic addressed in the present work (n=254).

Following such initial analysis, 30 theoretical studies, plus 73 specific VA studies related to climate change were identified (see detailed lists, respectively in Tables S2 and S3, Supplementary Materials). In regard to identified VA studies, the first article dates from 2002. Since then, as especially from 2012 forward, numbers have started to increase (Figure 3.2). Although data for 2019 is not included in the graphic, because the literature search was conducted in late September 2019 (*i.e.* before the year was completed), nine new articles had already been published by then, overcoming the number of articles for 2018.

From a spatial scale perspective, the majority of VA studies were carried at the local level, focusing on specific areas within countries (39 studies, c. 53%; Figure 3.3). Local VA studies were most commonly found within the United States, Canada, Australia, and India (Table S4, Supplementary Materials). Regional studies are the second most frequent ones (15 studies, c. 21%; Figure 3.3), including examples from the Arctic region and the North Sea (Table S4). These are followed by global studies (11 studies, c. 15%), and finally by studies carried at the national level (8 studies, c. 11%). The latter include VA studies in Australia, United States, Maldives, Norway, Taiwan, Japan, Trinidad and Tobago, and Grenada (Table S4).

Regarding risk and vulnerability-related concepts addressed in the studies (*i.e.* vulnerability, exposure, sensitivity, adaptive capacity, risk, hazard potential), the most common ones were "vulnerability" itself (69 articles, c. 95%) followed by "risk/hazard potential" (67 articles, c. 92%; Table S5, Supplementary Materials). These are also the two dimensions that were most "referred in detail" in such articles (60 articles, c. 82%; and 56 articles, c. 77%; Figure 3.4). Other concepts, such as "exposure", "sensitivity", and "adaptive capacity", were also mentioned in the majority of studies, although in a more superficial way (*i.e.* concepts were many times implied in phrases and expressions). Indeed, each concept was "referred in detail" only in 42 (c. 58%), 38 (c. 52%), and 44 (c. 60%) articles respectively (Figure 3.4). It is also important to note, that all studies mention more than one vulnerability-related concept, and a significant number (26 studies, c. 36%) actually addresses all dimension in detail (such as the studies [42, 45]; see Table S5).

As for the type of vulnerability (*i.e.* economic, social, ecological, and a mix of them), considered in the analysed studies, social vulnerability stands out, being addressed in 55 studies. Indeed, while 20 studies addressed all types of vulnerability, 17 focused on socioeconomic aspects, 8 on social-ecological aspects, and 10 on social vulnerability alone (Table 3.1). It is interesting to note that both economic vulnerability and ecological vulnerability are mentioned in the same number of articles (n=42; Table 3.1 and Table S5, Supplementary Materials). However, while for economic vulnerability this is largely explained by a high number of socioeconomic studies (n=17), for ecological vulnerability there is a balanced number of both ecological studies (n=13) and social-ecological studies (n=8). Finally, only one article focused on both ecological and economic vulnerability [95].

At the same time, in terms of the nature of the assessment, studies that combined qualitative and quantitative approaches (*i.e.* those in which the results are expressed using both quantitative and qualitative variables) were by far the most frequent ones (44 studies, c. 60%).

Indeed, about only a third of the articles encompassed only quantitative frameworks (19 studies, c. 26%) or qualitative ones (10 studies, c. 14%; Table 3.1). Nevertheless, it is important to highlight that the analysed articles represent a large variety of frameworks and models, resulting from the different combination of the previously mentioned methodological aspects (*i.e.* spatial scale, vulnerability dimension, vulnerability type, nature of the assessment) (Table S4 and S5, Supplementary Materials).

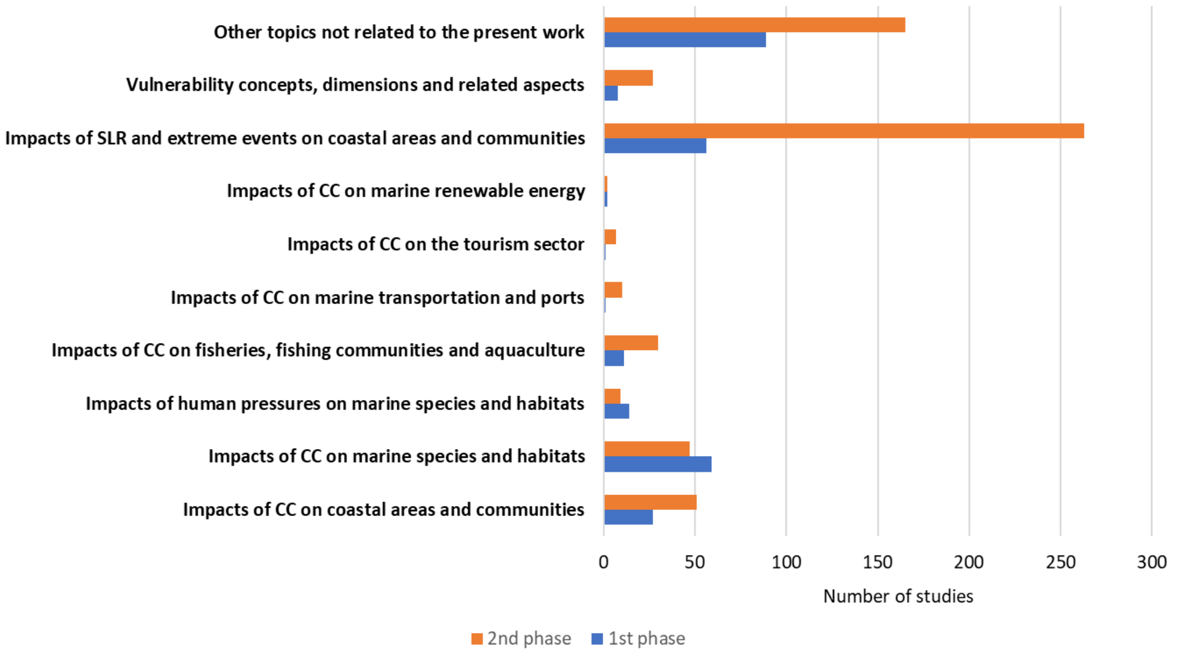

Figure 3.1| Most relevant topics addressed by the initially analysed 879 studies. CC – climate change, SLR – sea level rise.

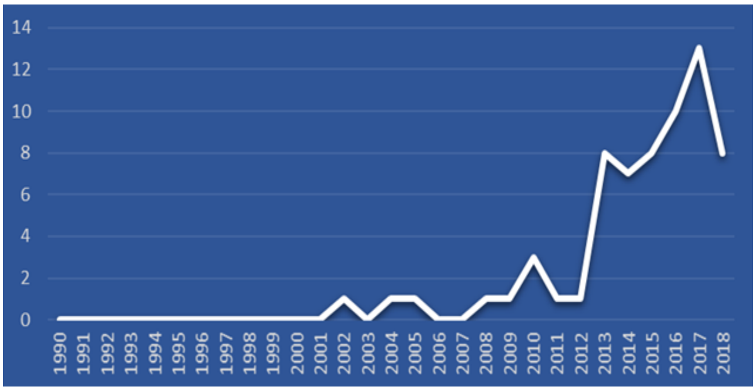

Figure 3.2| Publication trend for studies on vulnerability assessments, published between 1990 and 2018. Data collected from the ISI Web of Knowledge website.

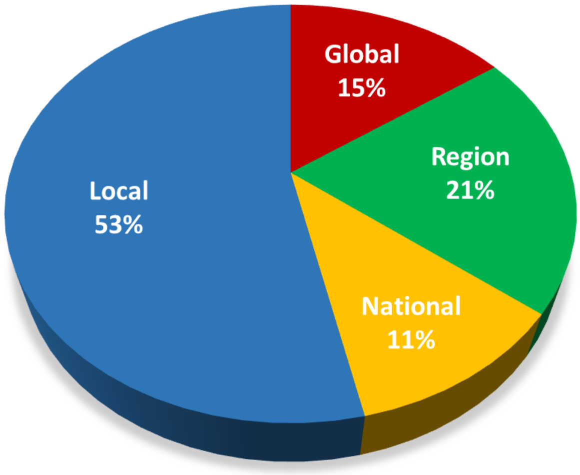

Figure 3.3| Distribution of the number of vulnerability assessment studies by the spatial scale of analysis (from local to global). Percentages are calculated based on a total number of 73 articles.

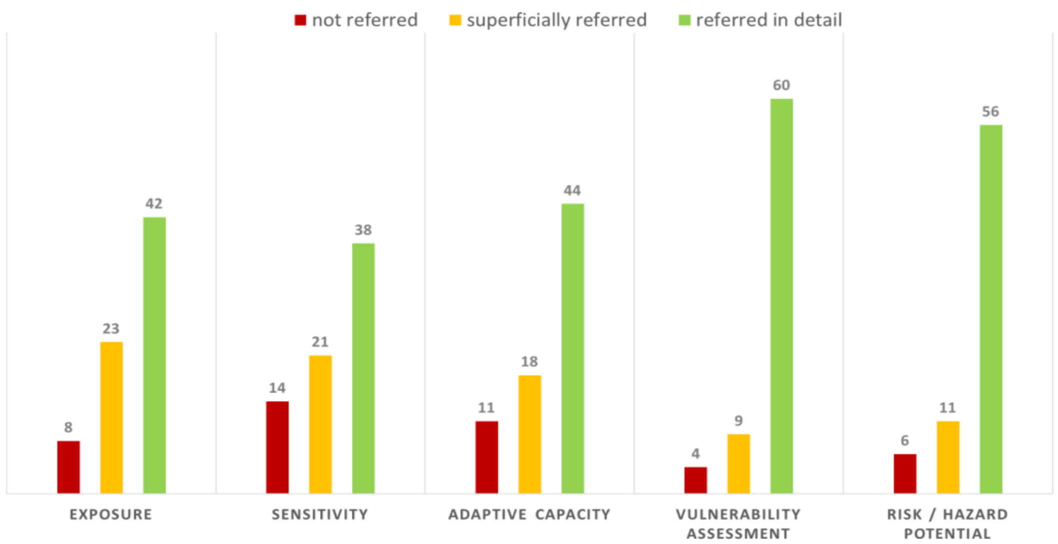

Figure 3.4| Incidence of references to each main vulnerability-related dimension in the analysed studies. Because articles can address multiple dimensions, the total number of references exceeds the number of articles considered (n=73).

Table 3.1| Type of vulnerability and nature of assessment considered in the analysed studies.

Type of vulnerability						
Ecological vulnerability	Social vulnerability	Economic vulnerability	Socioecological vulnerability	Socioeconomic vulnerability	Ecological and economic vulnerability	All types of vulnerability
13	10	4	8	17	1	20

Type of evaluation		
Quantitative studies	Qualitative studies	Quantitative and qualitative studies
19	10	44

Finally, results on specific references to ocean uses, MSP and the BE, as well as to particular climate-related drivers of change are depicted in Figures 3.5 and 3.6, respectively. Only one particular study mentioned all the ocean uses identified in Figure 3.5, plus MSP and the BE. This corresponds to a short article by Frazão Santos et al. [5], which specifically focuses on the impacts of climate change on MSP and the BE. In addition to this, only three other studies (c. 4%) strongly focus on MSP [15-16, 18], while 17 other studies (c. 23%) mention it superficially (Figure 3.5 and Table S6, Supplementary Materials).

As for the BE, the number of studies is higher: 21 studies "referred in detail" the BE (c. 29%), and 28 studies mention it superficially (c. 38%; Figure 3.5). Regarding particular ocean uses, fishing largely stands out. Besides being the most frequently mentioned use in general (56 articles, c. 77%), it is also the one that is most "referred in detail" (31 articles, c. 42%; Figure 3.5). On contrary, mining and marine renewable energy are the ocean uses least addressed in general (c. 12% and c. 16%, respectively).

Finally, when analysing the climate-related drivers that were considered in vulnerability assessment studies, extreme events, ocean warming, and sea level rise stood out. Indeed, the number of studies addressing each of these drivers is very similar (respectively, 50, 49 and 47; Figure 3.6), representing over 60% of the analysed references. By contrast, for all other climate-related drivers, the number of studies where they are mentioned is much more reduced, ranging between 11-40%. Once again, only one particular study mentioned all the considered climate drivers [5]. However, several other studies address the majority of the identified climate-related drivers of change (*e.g.* [44, 96] only fail to address deoxygenation, and [38] addresses all drivers except for ocean acidification).

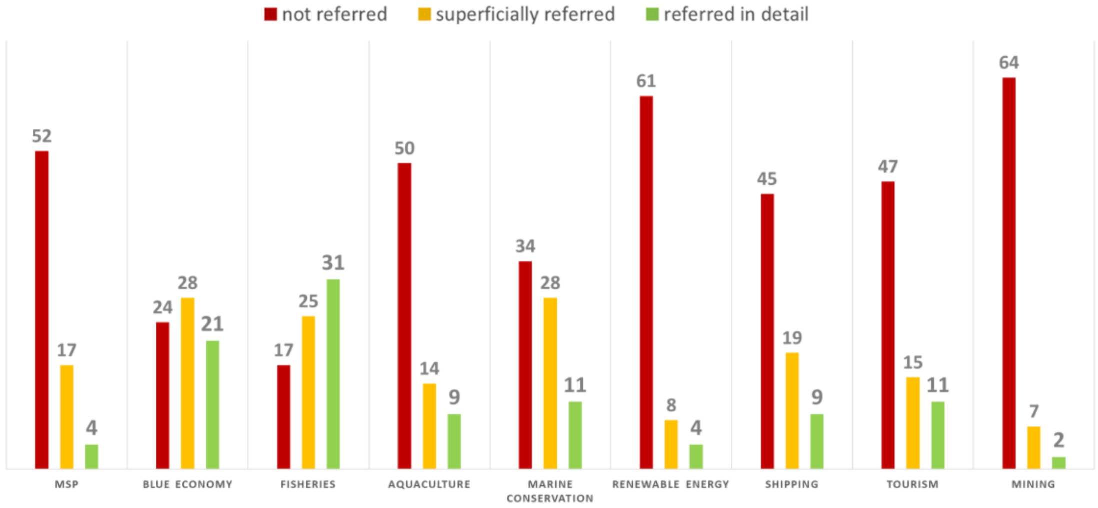

Figure 3.5| Main ocean uses addressed in the analysed studies, together with references to MSP and the BE.

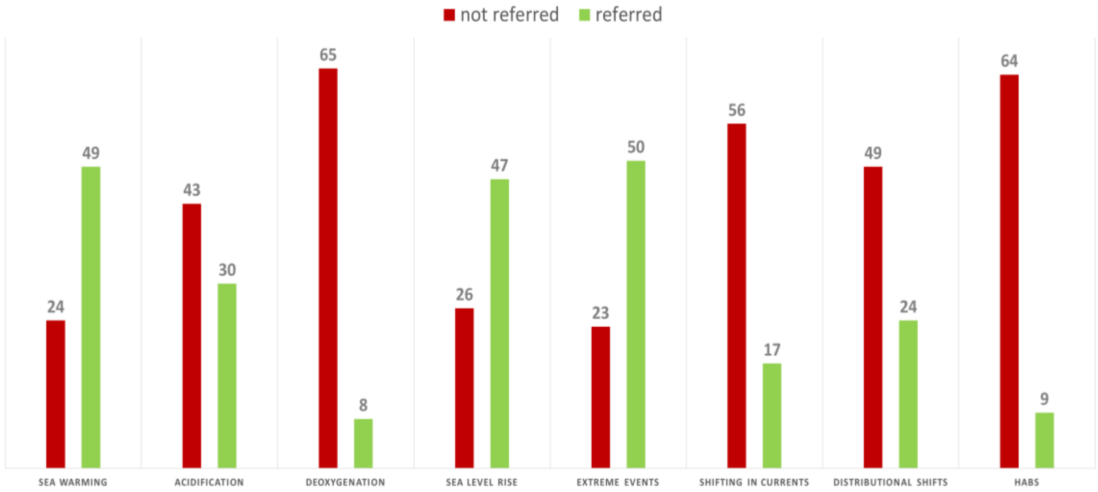

Figure 3.6| Main climate-related drivers of change addressed in the analysed studies.

3.2 Vulnerability of ocean uses, MSP and the BE

Figure 3.7 presents an overview of the non-normalized data pertaining to the exposure of ocean uses that correspond to economic activities, based on employment (Es), GVA (Ee), and productivity (Ep), *per* country (for detailed information see Table S9, Supplementary Materials).

In regards to exposure based on employment, tourism is by far the most exposed ocean use, with the highest number of jobs for all countries (especially Spain, Greece, Italy, and the UK, ranging from c. 260,000 to 600,000 jobs) except for Belgium and Romania where ports and shipbuilding encompass more jobs. The following more exposed ocean uses in terms of jobs – and this is valid across all countries – pertain to ports, shipbuilding and maritime transport. The same even distribution does not apply, however, to mining nor fishing. Indeed, while certain countries present a high number of jobs associated to mining (*i.e.* UK, Italy, Romania and Croatia, from c. 4,600 to 35,000 jobs), others do not present any jobs (*i.e.* Cyprus, Estonia, Finland, Latvia, Malta and Sweden). On contrary, fishing activities are present in all countries, although a much higher number of jobs corresponds to countries such as Spain, Italy, Greece, Portugal, France or the UK (from c. 12,000 to 34,500 jobs). Finally, emerging sectors such as renewable energy production and aquaculture are the least exposed based on employment. Renewable energy includes a reduced number of jobs in four countries (*i.e.* UK, Denmark, Netherlands and Belgium, always under 1,400 jobs) and is absent from all others. As for aquaculture, while being absent from Latvia, Lithuania, Belgium and Poland, and presenting substantially low numbers for Estonia, Slovenia and Romania (under 30 jobs), still has a significant relevance for nations such as Spain and France (with 20,520 and 15,627 jobs, respectively).

As for exposure based on GVA, tourism continues to be the most exposed ocean use for the majority of countries (with higher values for Spain, Italy and France, ranging from 8,200 to 17,800 million euros). However, here the difference to other exposed ocean uses is less preponderant (7 out of 23 nations). The latter incudes Belgium, Netherlands, Lithuania, Poland and Slovenia (highest GVA pertains to ports); Denmark and the UK (highest GVA pertains to mining); Germany (highest GVA pertains to maritime transport); and Romania (highest GVA pertains to shipbuilding). Fisheries and mining continue to present an irregular pattern among countries, presenting high GVA values for some nations (*e.g.* mining in the UK presents a GVA of 15,550 million euros), and low, or even null, values to others (*e.g.* fishing GVA in Cyprus, Romania and Slovenia is under 2 million euros). Renewable energy production and aquaculture are once again the least exposed ocean uses.

Finally, when looking at exposure based on productivity, patterns change significantly. Here, mining is the ocean use that presents by far the highest exposure values (namely, c. 3,000 to 7,500 million euros *per* job for Netherlands, Denmark, and Italy). Indeed, all other ocean uses present productivity values under 1,000 million euros *per* job. Although shipbuilding, maritime transport or ports still correspond to the second and third higher positions for most countries, renewable energy stands out in Belgium, Denmark and the UK. At the same time, tourism, fishing and aquaculture are the least productive sectors, thus showing lower exposure.

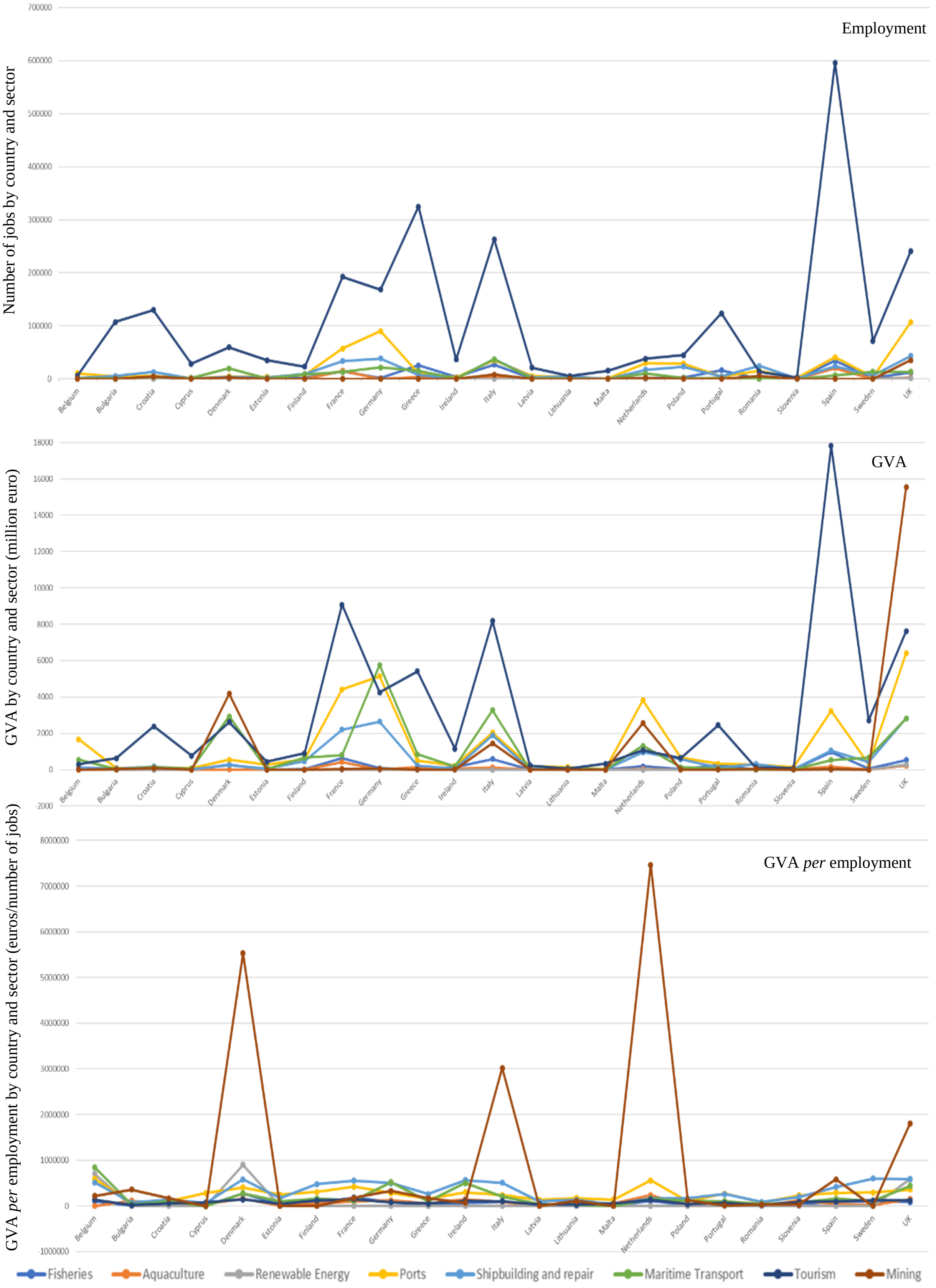

Figure 3.7| Exposure of main ocean uses that correspond to economic activities, by country (EU coastal Member States, plus the United Kingdom), based on employment, GVA, and productivity.

In regard to marine conservation, non-normalized data pertaining to exposure based on MPA coverage (Ec) and on the biodiversity goal of the OHI (Eo), *per* country, are presented in Figure 3.8. (for detailed information see Table S7, Supplementary Materials). As for exposure based on MPA coverage, France and Germany stand out as the most exposed, with values of 50.4 and 45.4%, respectively, followed by Belgium and the UK, with values ranging from 30% to 37%. By contrast, a number of countries present MPA coverages below 10%, therefore corresponding to the least exposed ones (*i.e.* Bulgaria, Croatia, Cyprus, Greece, Ireland, Malta and Slovenia). For exposure based on the biodiversity goal of the OHI, Romania, Bulgaria, Belgium, Estonia, Finland, Slovenia and Denmark are the most exposed, with values ranging from 91 to 96. The countries Spain, Poland, Lithuania and Netherlands, on the other hand, are the least exposed ones, with values bellow 80.

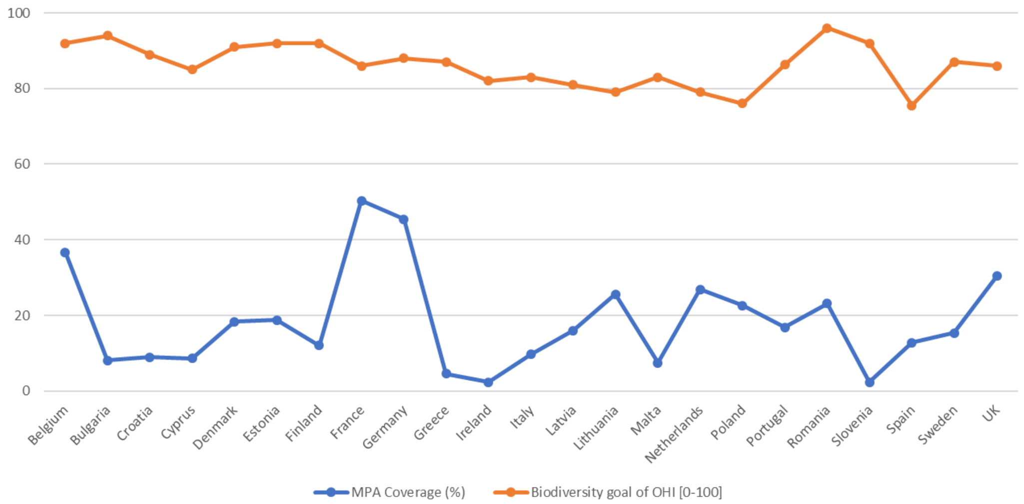

Figure 3.8| Exposure of marine conservation, by country (EU coastal Member States, plus the United Kingdom), based on marine protected area (MPA) coverage, and the biodiversity goal of the OHI.

Normalized values for exposure are presented in Tables 3.2 and 3.3. When considering the spatial distribution of these results, maximum values for exposure based on employment (social exposure) pertain to the UK (Es=1 for renewable energy, ports, shipbuilding, and mining), Spain (Es=1 for fisheries, aquaculture and tourism), and Italy (Es=1 for maritime transport).

As for exposure based on GVA (economic exposure), maximum values pertain once again to the UK (Ee=1 for exactly the same ocean uses) and Spain (Ee=1 for fisheries and tourism), and this time to Germany (Ee=1 for maritime transport) and France (Ee=1 for aquaculture; Table 3.2). In regards to exposure based on productivity (also a *proxy* for economic exposure), the observed pattern changes considerably with maximum values now pertaining to Belgium (Ep=1 for ports and maritime transport), Denmark (Ep=1 for fisheries and renewable energy sectors), Netherlands (Ep=1 for aquaculture and mining), France (Ep=1 for tourism), and Sweden (Ep=1 for shipbuilding and repair).

Finally, for exposure based on marine biodiversity (ecological vulnerability), maximum values pertain to France (Ec=1, when considering MPA coverage) and, Romania (Eo=1, when considering the biodiversity goal of OHI; Table 3.3).

Table 3.2| Normalized data on exposure to climate change based on employment, GVA, and productivity, for ocean uses that correspond to economic activities, by country.

Exposure	**Country**	Fisheries	Aquaculture	Renewable Energy	Ports	Shipbuilding and Repair	Maritime Transport	Tourism	Mining
	Belgium	0.011	0	0.147	0.100	0.040	0.028	0.011	0.001
	Bulgaria	0.045	0.006	0	0.048	0.125	0.018	0.180	0.003
	Croatia	0.164	0.055	0	0.049	0.298	0.111	0.218	0.133
	Cyprus	0.035	0.015	0	0.010	0.015	0.061	0.048	0
	Denmark	0.042	0.007	0.493	0.046	0.085	0.532	0.100	0.079
	Estonia	0.060	0.0001	0	0.037	0.063	0.024	0.059	0
	Finland	0.041	0.005	0	0.075	0.211	0.243	0.039	0
	France	0.405	0.762	0	0.535	0.777	0.350	0.323	0.011
	Germany	0.047	0.004	0	0.841	0.896	0.589	0.282	0.010
	Greece	0.737	0.171	0	0.099	0.180	0.426	0.544	0.002
	Ireland	0.101	0.087	0	0.024	0.017	0.019	0.061	0.001
Employment	Italy	0.788	0.205	0	0.329	0.859	1	0.441	0.234
	Latvia	0.025	0	0	0.053	0.061	0.021	0.036	0
	Lithuania	0.017	0	0	0.036	0.109	0.036	0.009	0.000005
	Malta	0.036	0.010	0	0.005	0.008	0.003	0.026	0
	Netherlands	0.060	0.013	0.228	0.281	0.407	0.275	0.064	0.056
	Poland	0.074	0	0	0.272	0.536	0.059	0.075	0.010
	Portugal	0.477	0.116	0	0.040	0.098	0.026	0.208	0.003
	Romania	0.011	0.0004	0	0.145	0.574	0.012	0.023	0.166
	Slovenia	0.003	0.001	0	0.021	0.017	0.005	0.005	0.003
	Spain	1	1	0	0.384	0.556	0.185	1	0.003
	Sweden	0.047	0.003	0	0.036	0.161	0.364	0.120	0
	UK	0.349	0.115	1	1	1	0.374	0.404	1
	Belgium	0.039	0	0.226	0.260	0.042	0.095	0.016	0.0004
	Bulgaria	0.003	0.014	0	0.013	0.023	0.003	0.035	0.001
	Croatia	0.028	0.046	0	0.019	0.061	0.024	0.134	0.005
	Cyprus	0.001	0.026	0	0.013	0.010	0.010	0.043	0
	Denmark	0.275	0.029	0.966	0.086	0.093	0.508	0.147	0.269
	Estonia	0.009	0.00003	0	0.042	0.022	0.004	0.024	0
	Finland	0.016	0.011	0	0.090	0.162	0.113	0.051	0
	France	0.643	1	0	0.689	0.782	0.139	0.510	0.002
	Germany	0.079	0.024	0	0.802	0.936	1	0.239	0.003
	Greece	0.006	0.303	0	0.079	0.080	0.146	0.304	0.0003
	Ireland	0.130	0.128	0	0.033	0.018	0.030	0.065	0.0002
GVA	Italy	0.608	0.282	0	0.317	0.672	0.568	0.460	0.093
	Latvia	0.010	0	0	0.030	0.011	0.002	0.012	0
	Lithuania	0.010	0	0	0.022	0.027	0.007	0.003	0.000001
	Malta	0.005	0.027	0	0.005	0.003	0	0.018	0
	Netherlands	0.187	0.101	0	0.596	0.340	0.227	0.059	0.165
	Poland	0.027	0	0	0.101	0.204	0.023	0.036	0.001
	Portugal	0.246	0.107	0	0.051	0.043	0.009	0.138	0.0001
	Romania	0.002	-0.0002	0	0.042	0.108	0.002	0.007	0.002
	Slovenia	0.002	0.005	0	0.020	0.009	0.002	0.004	0.0002
	Spain	1	0.393	0	0.504	0.374	0.093	1	0.001
	Sweden	0.070	0.002	0	0.049	0.148	0.116	0.152	0
	UK	0.544	0.532	1	1	1	0.490	0.428	1
	Belgium	0.397	0	0.781	1	0.862	1	0.932	0.029
	Bulgaria	0.030	0.483	0	0.114	0.129	0.043	0.137	0.048
	Croatia	0.036	0.116	0	0.173	0.226	0.119	0.369	0.023
	Cyprus	0.018	0.202	0	0.480	0.114	-0.007	0.486	0
	Denmark	1	0.678	1	0.684	0.970	0.325	0.962	0.741
	Estonia	0.135	0.048	0	0.417	0.294	0.126	0.314	0
	Finland	0.266	0.213	0	0.517	0.799	0.190	0.794	0
	France	0.683	0.416	0	0.706	0.927	0.146	1	0.024
	Germany	0.341	0.520	0	0.476	0.840	0.613	0.537	0.044
	Greece	0.009	0.214	0	0.264	0.431	0.126	0.343	0.023
GVA *per*	Ireland	0.255	0.636	0	0.508	0.948	0.592	0.775	0.010
employment	Italy	0.336	0.401	0	0.400	0.846	0.248	0.686	0.405
(productivity)	Latvia	0.092	0	0	0.220	0.163	0.047	0.241	0
	Lithuania	0.156	0	0	0.288	0.225	0.039	0.212	0.015
	Malta	0.056	0.225	0	0.235	0.045	0	0.361	0
	Netherlands	0.416	1	0	0.941	0.278	0.191	0.907	1
	Poland	0.092	0	0	0.170	0.277	0.128	0.281	0.017
	Portugal	0.262	0.318	0	0.461	0.434	0.121	0.438	0.002
	Romania	0.059	-0.008	0	0.123	0.146	0.056	0.173	0.004
	Slovenia	0.137	0.540	0	0.386	0.333	0.094	0.582	0.004
	Spain	0.381	0.187	0	0.489	0.695	0.184	0.653	0.078
	Sweden	0.358	0.069	0	0.491	1	0.132	0.796	0
	UK	0.314	0.645	0.646	0.601	0.981	0.517	0.803	0.241

Table 3.3| Normalized data on marine conservation exposure to climate change in the analysed countries.

Country	MPA coverage	Biodiversity OHI
Belgium	0.728	0.920
Bulgaria	0.161	0.940
Croatia	0.179	0.890
Cyprus	0.171	0.850
Denmark	0.364	0.910
Estonia	0.373	0.920
Finland	0.238	0.920
France	1	0.860
Germany	0.901	0.880
Greece	0.090	0.870
Ireland	0.046	0.820
Italy	0.193	0.830
Latvia	0.319	0.810
Lithuania	0.508	0.790
Malta	0.148	0.830
Netherlands	0.533	0.790
Poland	0.448	0.760
Portugal	0.334	0.863
Romania	0.459	0.960
Slovenia	0.046	0.920
Spain	0.253	0.756
Sweden	0.305	0.870
UK	0.604	0.860

Table 3.4 presents both the normalized and non-normalized data pertaining to the global sensitivity of the main ocean uses to climate change. Overall, fisheries is the ocean use that is globally more sensitive to climate change, being affected by all climate-related drivers of change with an impact degree from medium to high (Table 2.6). Indeed, from ocean warming to deoxygenation, changes in ocean currents and sea level rise, climate impacts will lead to shifts in the distribution, composition and productivity of fish stocks [97-100] at a global scale, with considerable regional variations [101]. Marine conservation, also has higher values of sensitivity (=0.80), being affected by all climate-related drivers of change with an impact degree from medium to high. In fact, all drivers of change can affect ocean conservation. For example, distributional shifts may lead priority habitats and species to move beyond the limits of current protected areas (either inside, across or outside national borders) [101-103]. As well, cumulative impacts of ocean warming and acidification, together with changes in circulation patterns, are expected to alter the spatial scale of marine ecological connectivity [102-103]. For aquaculture, sensitivity to climate change is high (=0.79), but not like the ocean uses referred before. However, aquaculture is another use that can be significantly affected by all climate drivers of change. Migration of optimal thermal conditions due to ocean warming can benefit cultivated species with wider optimal temperature range and higher thermal limits (*e.g.* increased metabolism and growth rates), while species with narrower optimal ranges and lower thermal limits are expected to suffer enhanced mortalities and a decline in productivity [104-105]. As well, aquaculture is limited to relatively “small” areas when compared to other ocean uses, and has unnaturally higher host densities, increased occurrence of infectious diseases (parasites, bacteria, viruses) can have significant deleterious impacts [104-105].

Followed by these ocean uses, tourism, maritime transport, shipbuilding and repair, ports and renewable energy are globally sensitive to climate change in a medium way (values are inferior to 0.60). For tourism, the extent to which marine tourism is depended on climate change impacts is highly variable, depending on both the activity (*e.g.* whale watching, diving, snorkelling, surfing, sailing and recreational fishing) and the destination [106]. In maritime transport, changes in the extent and thickness of sea-ice cover due to ocean warming may be a major problem [107-108]. As a consequence, new navigable routes will be opened in the poles and shipping patterns will be globally modified [107-108]. For shipbuilding the increase in adverse conditions, and consequently the increase in wind strength and wave height, caused by climate change, will increase the risk of ship accidents leading to ship repairs

[109]. In regard to ports, sea level rise will be one of the main impacts for ports, given their proximity to the coast, leading to loss of operability and consequent economic losses, and leading to redesign, strengthen or relocate port structures if necessary [110-112]. Finally, for renewable energy major impacts will come from changes in wind (speed and energy density) and wave patterns expected under future climate scenarios [113-114].

It is important to note, that mining is the sector less sensitive to climate change (=0.04), being only affected by extreme events. In fact, frequency of storms and hurricanes is expected to threaten mining infrastructures and to increase danger at sea (limiting operational procedures) [115].

Table 3.4| Normalized data and non-normalized data on the global sensitivity of ocean uses to climate change.

Ocean use	Non-normalized	Normalization
Marine conservation	2.400	0.80
Fisheries	2.533	0.84
Aquaculture	2.356	0.79
Tourism	1.756	0.59
Ports	1.489	0.50
Maritime Transport	1.689	0.56
Shipbuilding and repair	1.644	0.55
Renewable energy	1.378	0.46
Mining	0.133	0.04

Figure 3.9 presents an overview of the normalized contributions of each adaptive capacity variable (*i.e.* income, education, health and governance), *per* country (for non-normalized information see Table S10, Supplementary Materials). At the same time, Table 3.5 presents the normalized data pertaining to the general adaptive capacity of each country to climate change.

In regard to the values for each adaptive capacity variable considered, income and health do not present values lower than 0.8, being Ireland for income (=0.955), and Spain and Italy for health (=0.975), the countries with better values. For education, only Portugal, Romania, Italy and Croatia present values lower than 0.8, being Denmark the country with higher value (=0.951). Finally, for governance the countries Finland, Netherlands, Sweden and Denmark present values higher than 0.8, being Romania the country with lower value (=0.530).

Looking at the general adaptive capacity of each country to climate change, Sweden (=0.917), Finland (=0.915), Denmark (=0.914), Netherlands (=0.910), Ireland (=0.906) and Germany (=0.902) are the countries with high adaptive capacity to climate change impacts, while Romania (=0.745), Bulgaria (=0.748), Croatia (=0.776) and Greece (=0.794) are those who have more difficulty adapting to these new factors.

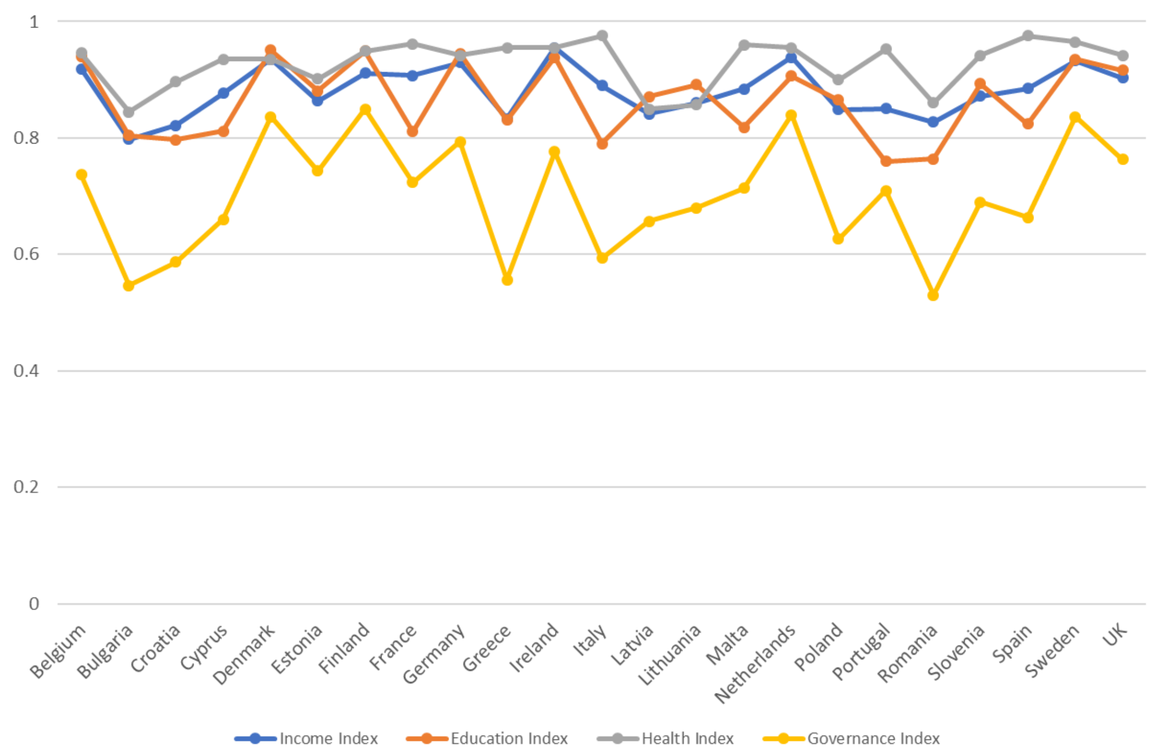

Figure 3.9| Normalized values for each adaptive capacity variable considered, by country (income, education, health and governance). Non-normalized data available in Table S10, Supplementary Materials.

Table 3.5| Normalized data on the adaptive capacity of the analysed countries to climate change.

Country	Adaptive Capacity
Belgium	0.886
Bulgaria	0.748
Croatia	0.776
Cyprus	0.821
Denmark	0.914
Estonia	0.847
Finland	0.915
France	0.851
Germany	0.902
Greece	0.794
Ireland	0.906
Italy	0.812
Latvia	0.805
Lithuania	0.822
Malta	0.844
Netherlands	0.910
Poland	0.810
Portugal	0.818
Romania	0.745
Slovenia	0.849
Spain	0.837
Sweden	0.917
UK	0.881

Normalized values for exposure, sensitivity and adaptive capacity were integrated into a vulnerability value for each ocean use, per country (Figures 3.10 to 3.14, Figure S1). Once again, for ocean uses that correspond to economic activities, three types of vulnerability were calculated (*i.e.* according to exposure based on employment, GVA, and productivity). Fisheries vulnerability (Figure 3.10) based on employment is higher in Spain and Italy (*i.e.* 0.669; 0.607, respectively), it is more vulnerable, based on GVA, in Spain (*i.e.* 0.669), and have greater vulnerability, based on productivity, in Denmark (*i.e.* 0.643). For aquaculture (Figure 3.10), vulnerability based on employment is higher for

Spain (*i.e.* 0.649); vulnerability based on GVA is more preponderant in France (*i.e.* 0.645); and vulnerability based on productivity is greater in the Netherlands (*i.e.* 0.625).

In the marine renewable energy sector (Figure 3.11), vulnerability based on employment is higher for the UK (*i.e.* 0.526); vulnerability based on GVA, is more preponderant in the UK and Denmark (*i.e.* 0.526; 0.504, respectively); and vulnerability based on productivity is higher in Denmark, Belgium and UK (*i.e.* 0.515; 0.452; 0.408, respectively). In ports (Figure 3.11), vulnerability based on employment, is higher in the UK and Germany (*i.e.* 0.538; 0.478, respectively), while vulnerability based on GVA is higher in the UK, Germany and France (*i.e.* 0.538; 0.465; 0.445, respectively); and vulnerability based on productivity, is higher in Belgium, Netherlands, France, Denmark and UK (*i.e.* 0.537; 0.509; 0.451; 0.422; 0.405, respectively).

The shipbuilding and repair sector (Figure 3.12), presents a greater vulnerability based on employment in the UK, Italy, Germany, France, Romania, Poland and Spain (*i.e.* 0.556; 0.532; 0.514; 0.491; 0.459; 0.425; 0.422, respectively); a greater vulnerability based on GVA in the UK, Germany, France and Italy (*i.e.* 0.556; 0.527; 0.493; 0.469, respectively); and a greater vulnerability based on productivity in the UK, Sweden, France, Denmark, Ireland, Italy, Belgium, Germany, Finland and Spain (*i.e.* 0.549; 0.544; 0.542; 0.535; 0.530; 0.527; 0.508; 0.495; 0.477; 0.469, respectively). For maritime transport (Figure 3.12) vulnerability based on employment and GVA is higher in Italy and Germany (*i.e.* 0.584; 0.440, respectively for Italy; 0.417; 0.554, respectively for Germany); and based on productivity is higher in Belgium, Germany and Ireland (*i.e.* 0.559; 0.424; 0.416, respectively).

The tourism sector (Figure 3.13) is more vulnerable based on employment in Spain, Greece and Italy (*i.e.* 0.583; 0.445; 0.405, respectively); is more vulnerable based on GVA in Spain, France and Italy (*i.e.* 0.583; 0.415; 0.411; , respectively); and more vulnerable in terms of productivity, in face of climate change, in France, Belgium, Denmark, Netherlands, UK, Finland, Sweden, Italy, Ireland, Spain, Slovenia, Cyprus, Germany and Portugal (*i.e.* 0.578; 0.544; 0.544; 0.527; 0.503; 0.488; 0.488; 0.486; 0.484; 0.467; 0.439; 0.417; 0.407; 0.402, respectively). Mining (Figure 3.13) is more vulnerable based on employment and GVA to climate change in the UK (*i.e.* 0.388); and vulnerability based on productivity is higher in the Netherlands, Denmark and Italy (*i.e.* 0.378; 0.290; 0.212 respectively).

Finally, for marine conservation (Figure 3.14) a vulnerability value was calculated *per* country, according to the combined exposure based on MPA coverage and biodiversity goal of the OHI. Here France stands out, presenting the highest ecological vulnerability value (*i.e.* 0.626).

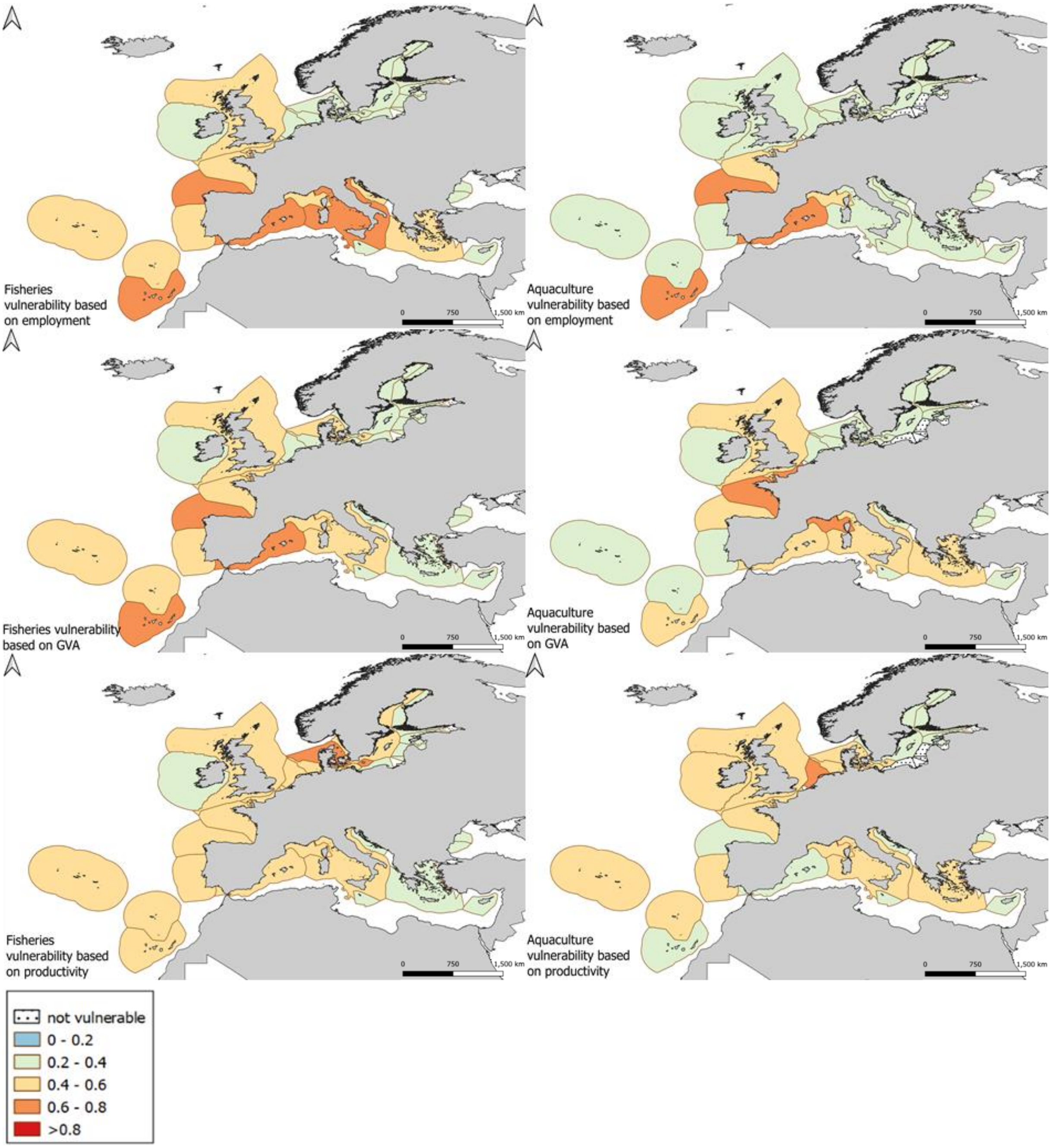

Figure 3.10| Fisheries and aquaculture vulnerability to climate change in the analysed countries. Country colours differ according to the values of vulnerability [0-1]. Three types of vulnerability are presented here: vulnerability based on employment (social vulnerability); based on GVA (economic vulnerability); and based on productivity (economic vulnerability).

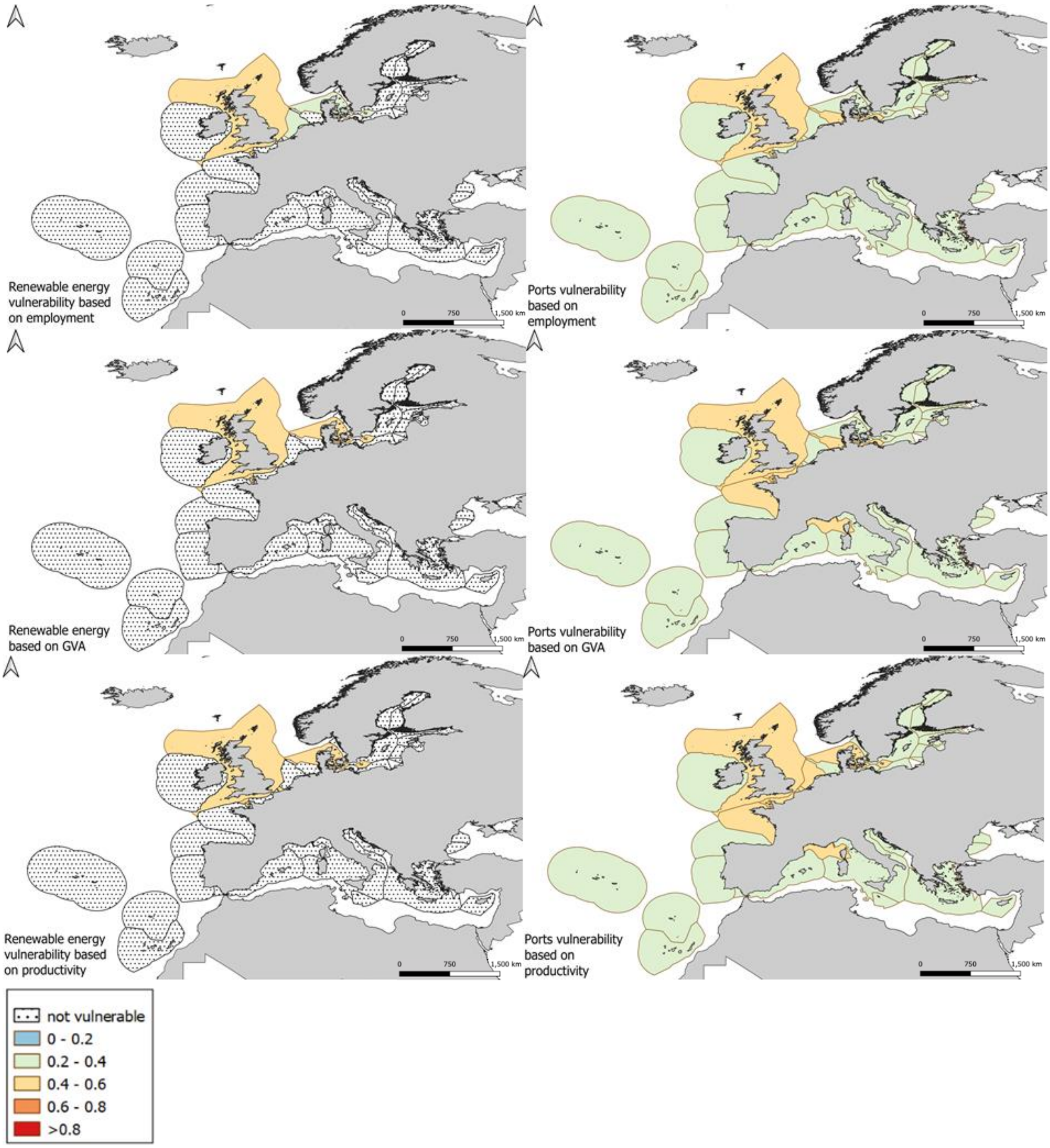

Figure 3.11| Renewable energy and ports vulnerability to climate change in the analysed countries. Country colours differ according to the values of vulnerability [0-1]. Three types of vulnerability are presented here: vulnerability based on employment (social vulnerability); based on GVA (economic vulnerability); and based on productivity (economic vulnerability).

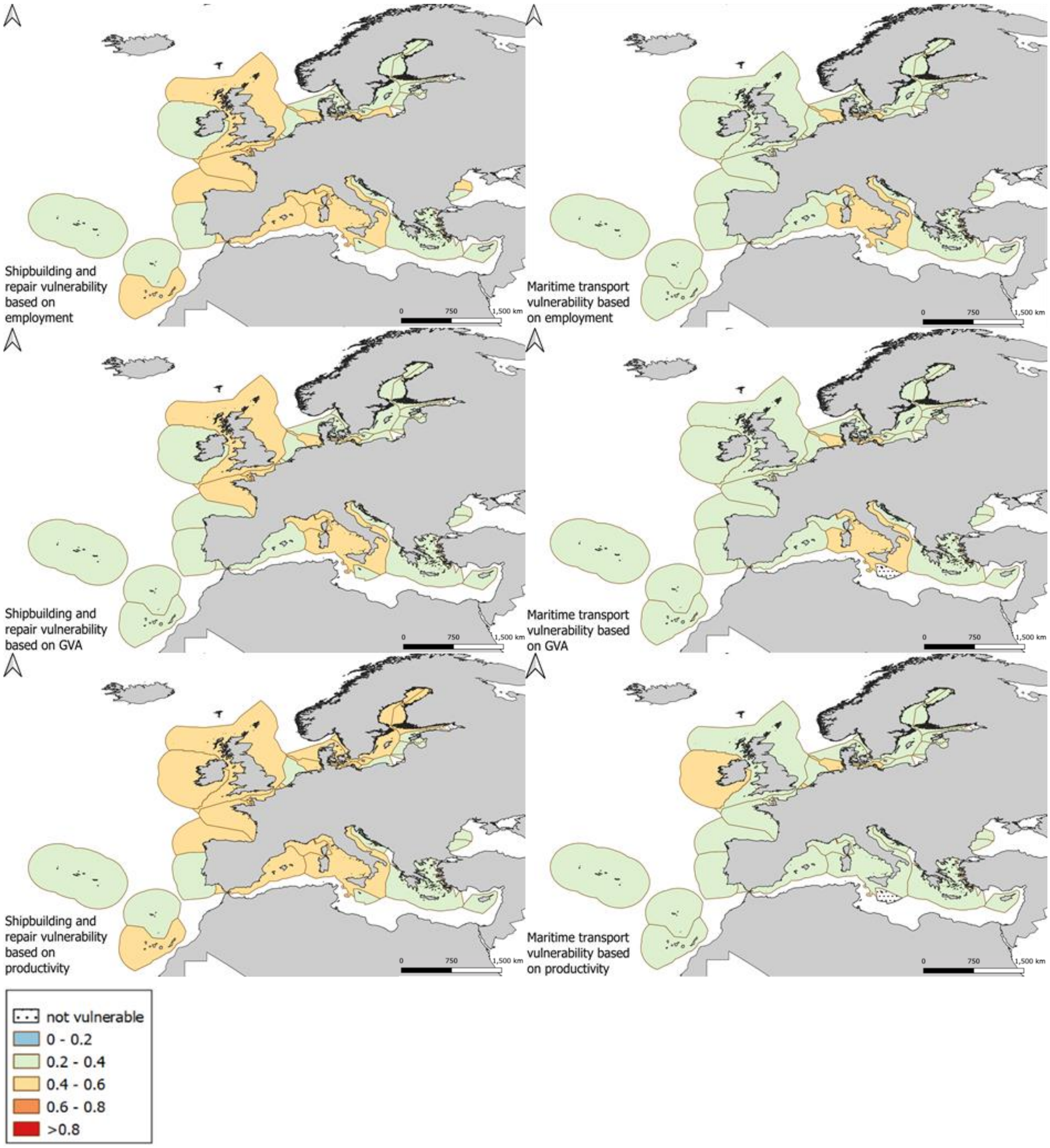

Figure 3.12| Shipbuilding and maritime transport vulnerability to climate change in the analysed countries. Country colours differ according to the values of vulnerability [0-1]. Three types of vulnerability are presented here: vulnerability based on employment (social vulnerability); based on GVA (economic vulnerability); and based on productivity (economic vulnerability).

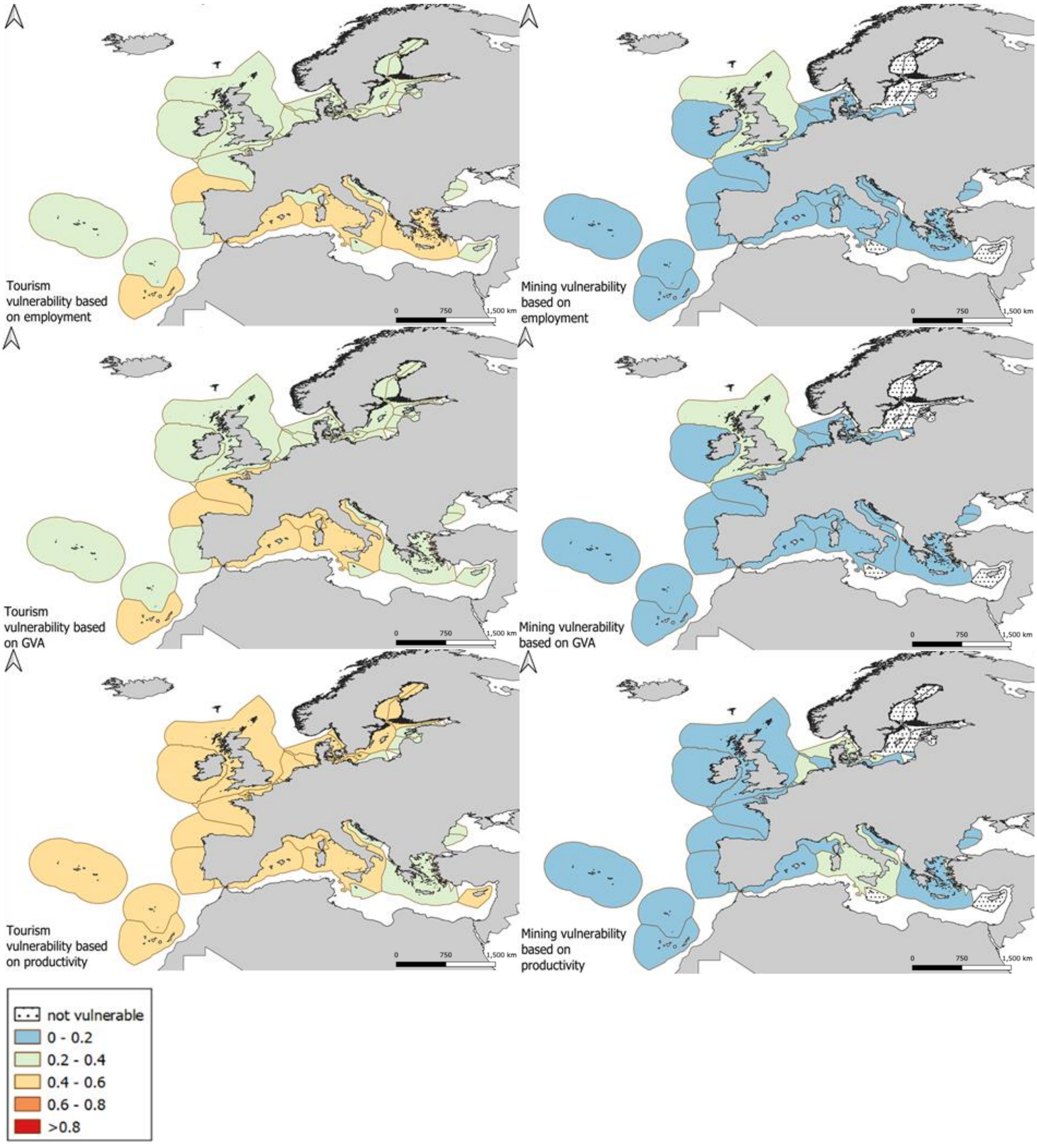

Figure 3.13| Tourism and mining vulnerability to climate change in the analysed countries. Country colours differ according to the values of vulnerability [0-1]. Three types of vulnerability are presented here: vulnerability based on employment (social vulnerability); based on GVA (economic vulnerability); and based on productivity (economic vulnerability).

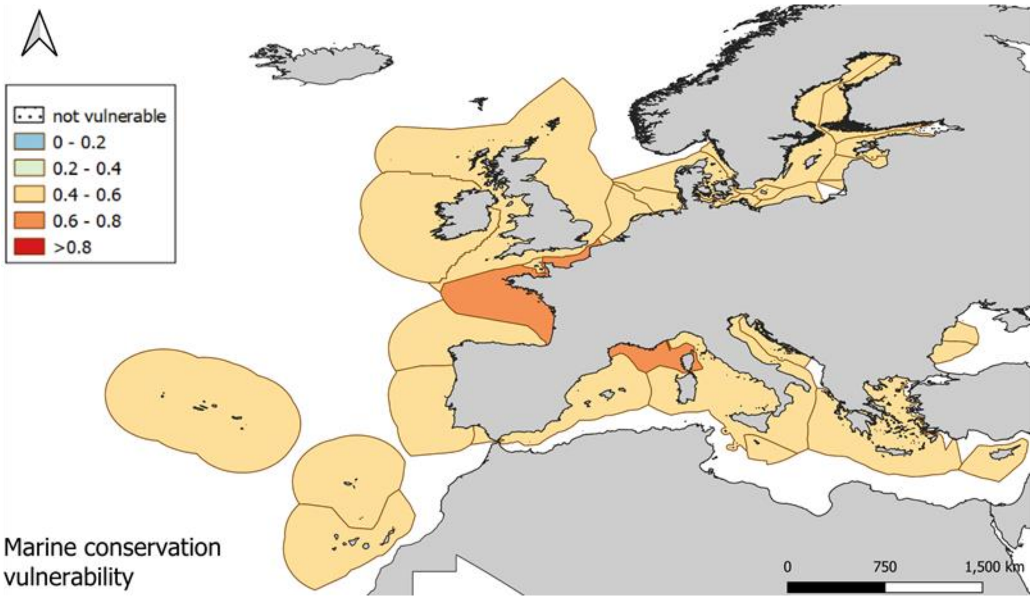

Figure 3.14| Marine conservation vulnerability to climate change in the analysed countries. Country colours differ according to the values of vulnerability [0-1]. Only one type of vulnerability is presented here, namely vulnerability based on a combination of MPA coverage and the biodiversity goal of the OHI (ecological vulnerability).

Figures 3.15 and 3.16 pertain to the final integration of all variables into a combined vulnerability value for both MSP and the BE, *per* country. In both cases, three types of results are presented (*i.e.* vulnerability based on employment, on GVA, and on productivity). In the case of MSP, however, each of these dimensions is combined with the vulnerability of marine conservation (*i.e.* vulnerability based on MPA coverage and biodiversity goal of OHI). Detailed results are also presented in Tables S11 and S12 (Supplementary Materials).

Countries where MSP is most vulnerable to climate change based on a combination of marine conservation (ecological vulnerability) and employment of all other ocean uses (social vulnerability) are the UK, Spain, Italy and France (*i.e.* 100; 87.15; 86.60; 81.81, respectively; Figure 3.15 and Table S11, Supplementary Materials). By contrast, Latvia, Lithuania, Ireland, Malta, Finland, Slovenia, Belgium, Sweden, Cyprus, Estonia, Poland are the countries that present the lowest values (*i.e.* 47.40; 49.17; 50.61; 51.70; 52.67; 52.70; 52.74; 53.58; 54.00; 54.07; 56.21, respectively; Table S11).

When considering a combination of marine conservation (ecological vulnerability) and GVA of all other ocean uses (economic vulnerability), the UK and France are the most vulnerable countries (*i.e.* 100; 81.71, respectively; Figure 3.15 and Table S11, Supplementary Materials). Here, Malta, Lithuania, Latvia, Poland, Finland, Ireland, Sweden, Slovenia, Estonia, Cyprus, Belgium, Croatia, Portugal, Bulgaria, Romania, Greece and the Netherlands are the countries where MSP is least vulnerable to climate change (*i.e.* 42.91; 43.64; 45.23; 48.02; 48.28; 48.39; 48.96; 49.51; 49.85; 50.23; 52.32; 56.59; 56.62; 56.68; 58.64; 59.69; 59.76, respectively; Table S11).

Finally, nations where MSP is most vulnerable based on a combination of marine conservation and the productivity of all other ocean uses (economic vulnerability) correspond to Denmark, the UK, Belgium, Netherlands and France (*i.e.* 100; 90.57; 85.95; 83.61; 82.95, respectively; Figure 3.15 and Table S11, Supplementary Materials). Where, Latvia, Malta, Lithuania, Poland, Estonia, Cyprus are the countries with lower vulnerability scores for MSP (*i.e.* 49.15; 49.69; 52.04; 52.56; 59.51; 59.56, respectively; Table S11).

When taking marine conservation (ecological vulnerability) out of the equation, the calculated vulnerability to climate change pertains only to ocean uses that correspond to economic activities, and therefore reflects the vulnerability of the BE.

Countries where the BE is most vulnerable to climate change based on employment of all economic ocean uses (social vulnerability) are the UK, Spain and Italy (*i.e.* 100; 86.87; 85.94, respectively; Figure 3.16 and Table S12, Supplementary Materials). By contrast, Latvia, Lithuania, Belgium, Ireland, Malta, Finland, Slovenia, Estonia, Sweden, Cyprus, Poland, Bulgaria and Portugal are the countries that present the lowest values (*i.e.* 40.02; 41.42; 44.49; 45.94; 46.08; 47.01; 47.34; 47.35; 48.01; 48.31; 49.88; 57.55; 58.07, respectively; Table S12).

When considering GVA of all economic ocean uses (economic vulnerability), the UK is the most vulnerable (*i.e.* 100; Figure 3.16 and Table S12, Supplementary Materials). Here, Latvia, Malta and Lithuania are the countries where the BE are the least vulnerable to climate change (*i.e.* 36.19; 36.37; 37.42, respectively, Table S12).

Finally, nations where the BE is most vulnerable based on the productivity of all economic ocean uses (economic vulnerability) correspond to Denmark, the UK, Belgium and Netherlands (*i.e.* 100; 88.18; 82.17; 81.16, respectively; Figure 3.16 and Table S12, Supplementary Materials). Where, Latvia, Malta, Lithuania, Poland, Estonia, Cyprus, Romania, Croatia, Bulgaria and Greece are the countries with lower vulnerability scores for the BE (*i.e.* 42.01; 43.64; 44.70; 45.59; 53.41; 54.44; 54.55; 57.16; 58.15; 59.09, respectively; Table S12).

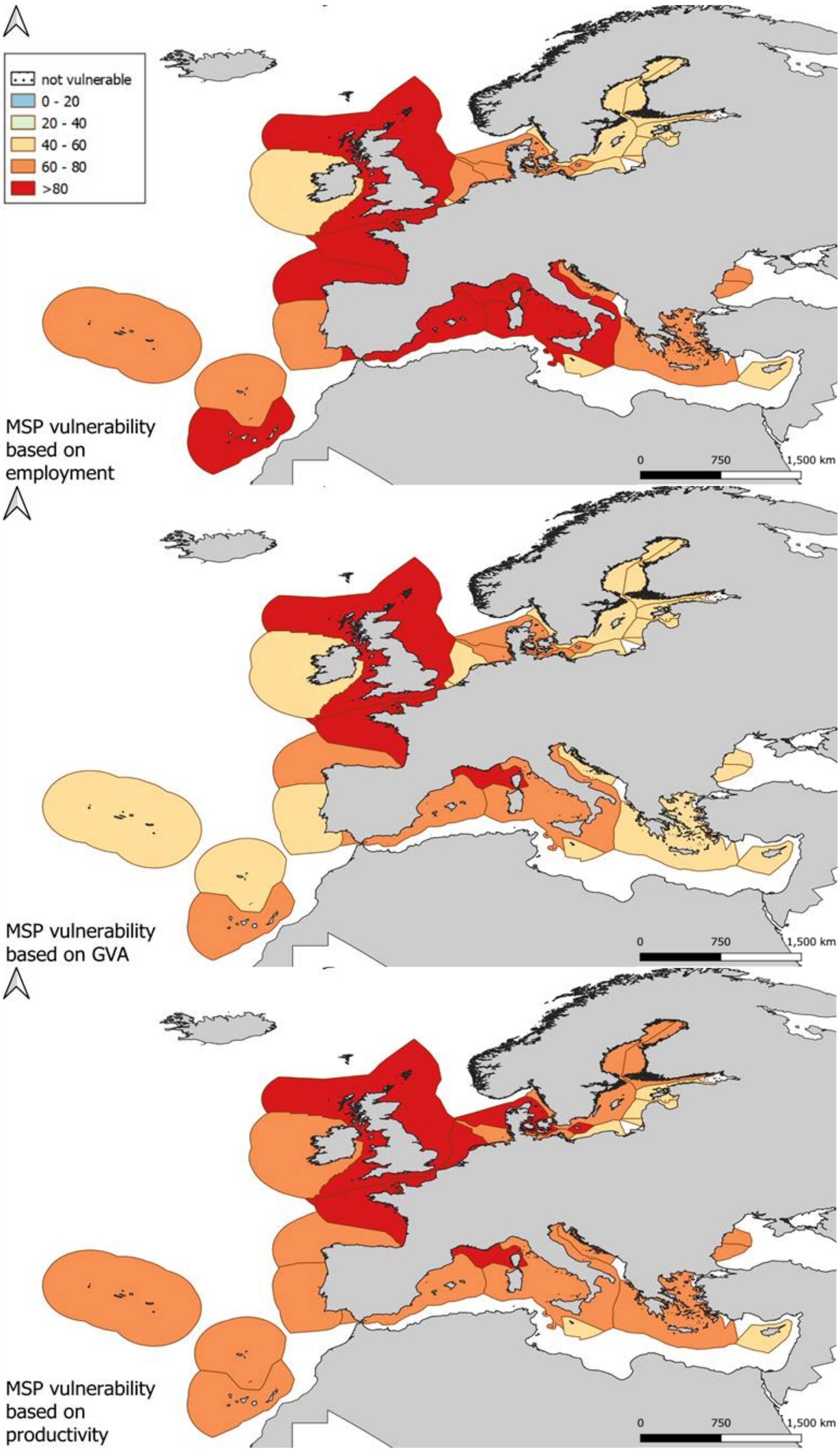

Figure 3.15| MSP vulnerability to climate change in the analysed countries. Country colours differ according to the values of vulnerability [0-100]. Four types of vulnerability are presented here: vulnerability based on employment (social vulnerability); based on GVA (economic vulnerability); based on productivity (economic vulnerability); and based on a combination of MPA coverage and the biodiversity goal of the OHI (ecological vulnerability).

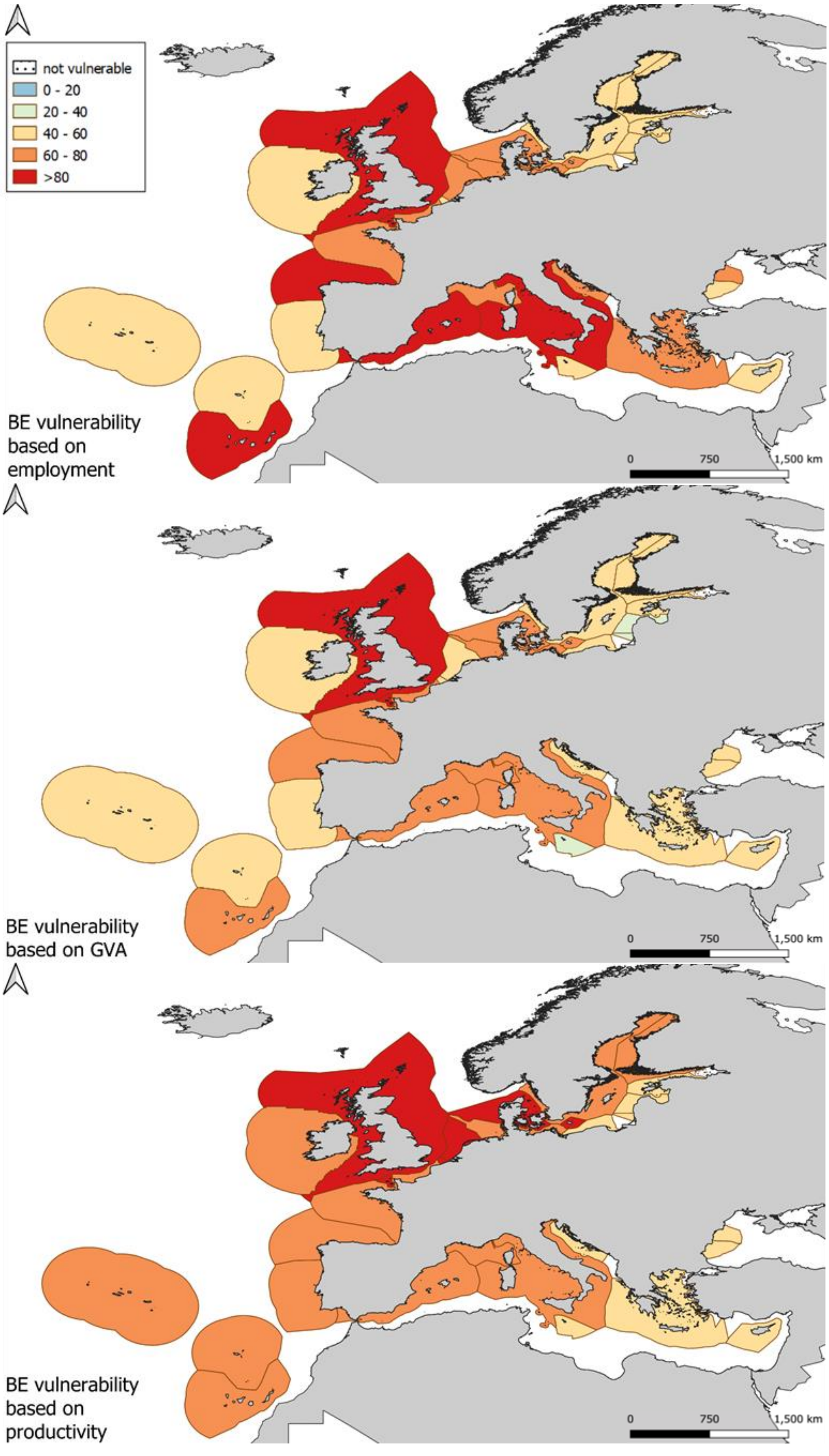

Figure 3.16| BE vulnerability to climate change in the analysed countries. Country colours differ according to the values of vulnerability [0-100]. Three types of vulnerability are presented here: vulnerability based on employment (social vulnerability); based on GVA (economic vulnerability); and based on productivity (economic vulnerability).

4. Discussion

The conducted literature review had the primary objective of providing guidelines for the development of the vulnerability assessment methodology, namely by identifying the existing climate-related VA studies that focused on human uses of the ocean, the marine environment, the BE or MSP. In a first phase of research, the review built on a small set of very specific concepts directly related to the objectives of the present work, which led to a reduced number of obtained results. By contrast, the second phase of the research was more comprehensive, unravelling a higher number of studies, but also including more studies that went beyond the topic of the present dissertation. In effect, while including key concepts related to VA, many of the articles identified in both phases did not relate at all to the scope of the present work, or to the sub-themes referred to in the methodology. The explanation may pertain to the fact that search words such as "vulnerability assessment" and "climate change" are widely used in scientific research, and in a variety of scientific areas [35, 56-58, 63]. It is also important to bear in mind that the choice of words and the definition of selection criteria to both include or exclude articles will significantly influence the obtained results. Indeed, there is an inherent subjectivity to review processes like this, where the absence of search words in titles, abstracts and keywords of search articles leads to their exclusion, even if the contents are relevant to the revise topic [54]. Thus, it is extremely important to be as specific and clear as possible, in order to reduce the subjectivity of this process.

Regarding the analysed VA articles, it was possible to identify an increase in publication numbers since 2008, with a more significant growth between 2012 and 2017. Such increase can be partially justified by the publication of the 4th IPCC Assessment Reports on Climate Change, published in 2007 and the 5th Assessment Report, published in 2013, which raised significant awareness on the need to conduct vulnerability assessments to support climate adaptation actions [32, 54]. Indeed, the identified trend presents similar contours to those mentioned in the work of Zhang *et al*. [54], which observed a growing trend in the publication of general climate-related VA studies over the last 20 years, describing an abrupt growth of articles for the period of 2001-2017 caused by the publication of the 3rd Assessment Report by the IPCC, in 2001. Although the present work addresses only VA studies focused on the ocean, it was also from 2002 that articles started to be published. It should be noted that expectations are that this growing trend continues to expand, in a future increasingly pressured by climate-related challenges [54].

As for the spatial scale, most of the identified VA studies were carried at the local level, followed by regional ones. This results from the recent increase of tools and methodologies to assess vulnerability to climate change in general or to specific climate-related drivers at both local and regional scales, in particular studies focussing on SIDS communities [51, 67]. Global studies are not as common as the previous ones because of a lack of globally agreed on vulnerability definitions and metrics as well as the difficulty in assessing adaptive capacity at a global scale [35]. Still, national studies are the least common, potential because of difficulties in integrating information from different sources and different metrics for the calculation of vulnerability, because of lack of funding, or because many relevant studies do not appear in common search engines and platforms, such as the ISI Web of Knowledge [116]. An example of the latter pertains to existing reports on vulnerability and adaptation to climate change for a number of EU countries, which however did not appear in the present study search [54, 116].

The review of VA studies also highlighted that all vulnerability and risk-related dimensions (*i.e.* exposure, sensitivity, adaptive capacity, hazard potential) ended up being mentioned in detail in more than half of the analysed articles. Still, the term vulnerability assessment itself was the most frequently referred in detail, which could be expected when searching for VA studies. However, the definitions for each of these dimensions varied significantly across the different articles. It is still challenging to find a consistent and accepted definition of vulnerability, due to the variety of fields that use the term, and existing interpretations and definitions [35, 54-58, 60, 63]. In addition, the variety of objectives and models used in different vulnerability studies end up influencing the definitions used by authors [117]. For example, if the objective is to assess the degree of climate change impact on a region's economy, or to assess the biophysical effects of climate changes in a region, or to compare vulnerabilities, with and without having preventive and adaptation measures, the definition of vulnerability and of related dimensions will vary significantly [117]. However, the most recognized definition in the scientific literature in the area of climate change becomes from IPCC, where vulnerability is considered the result of the interaction between exposure, sensitivity and adaptive capacity [53, 56]. Studies that simultaneously use quantitative and qualitative approaches, together with those that assess all types of vulnerability (*i.e.* ecological, economic and social) were also the most frequently used. The reason for the use of qualitative-quantitative studies can be related to a new trend on climate-related vulnerability studies [54, 68]. Here, there is an ongoing transition from quantitative studies focused on the assessment of ecosystems vulnerability using climate simulation models, to studies based on indicators and focused on assessing adaptive capacity, social resilience and vulnerability of the ecosystem as a whole (considering various stress factors to better understand how all these factors affect a given location) [54, 68]. This new trend also causes VA studies to increasingly focus on all types of vulnerability, allowing for a better understanding of how communities, sectors and dependent economies are capable of tackling climate change [63]. From the obtained results, was also evident that a significant number of different frameworks is being used in VA studies. This is again, linked, to the tremendous variety of concepts, areas of expertise and systems addressed by vulnerability studies [54, 63]. In effect, different methods exists to assess the vulnerability to climate change of a fishing community, a marine renewable energy area, or an MPA, making it hard to decide on the methodologies to use, each of them leading to different vulnerability outputs [54, 61-63, 118]. In the absence of guidelines for choosing the best VA approaches, it may be advantageous to seek the most accepted definitions of vulnerability and their dimensions [117]. Then, it may be important to follow the frameworks of the most accepted models by the scientific community for the calculation of vulnerability (*e.g.* models used by IPCC vulnerability reports on climate change), taking as a final objective, a better and greater international agreement on the steps to be followed in VA studies [67].

In the context of climate-related VA studies pertaining to ocean uses, MSP and the BE there is a great prominence for the words "fishing" and "blue economy", as well as for "ocean warming", "extreme events" and "sea level rise". Fishing is in fact one of the most prominent ocean uses, being one of the most traditional and most studied in the area of VA studies on climate change [39]. This is related to the growing assessment of the impacts of climate change on marine ecosystems, affecting fish stocks, fishing communities and dependent economies [39]. However, most articles focus on fishing communities in developing countries, while further studies are required for fishing communities in developed countries that will also be affected by climate change [40]. It was also found that only one of the analysed VA studies made an analysis of the impact of climate change on all ocean uses [5]. This can be justified by the fact that the different sectors are typically analysed individually, hence the little reference to management approaches such as MSP, which allow for the integration of different sectors [73-74]. At the same time, marine conservation is not considered as an ocean use in many references, such as in the EU Blue Economy Reports from 2019 and 2020, which might have influenced the obtained results for VA studies [73-74]. In addition, the fact that seabed mining and marine renewable energy are emerging sectors, partially explains the small number of studies referring to them in the present analysis [6, 73-74]. Finally, the most mentioned climate-related drivers are widely mentioned in the climate change context, being referred in detail not only in VA studies focused on the ocean uses, but also in other contexts such as urban vulnerability to climate change [54].

Literature review processes like this, provide a general picture of this complex topic and may contribute to future vulnerability assessments. However, there are some constraints that we need to be aware of. First, we must keep in mind that a content analysis like the one developed in this study present an inherent subjectivity, due to the multiple interpretations that each author may have when analysing an article [54]. Second, our search was largely based on the ISI Web of Knowledge platform, and only a limited number of studies were identified from other platforms. For this reason, documents such as monographs and reports may not appear in these databases, and those that do appear may not correspond to the most commonly used terminology [54]. Still, literature reviews can be important in helping the scientific community to understand the complexity of a given topic and areas in need of attention, allowing for further developments in research [54].

For the vulnerability of ocean uses, MSP and the BE it is possible to say that the socioeconomic importance of each ocean use, varies according to the analysed country. Even so, tourism seems to be the most relevant ocean use for the analysed countries, contributing in large scale to the employability of countries, as well as to their GVA. In fact, coastal tourism is one of the largest and most relevant sectors globally, with great importance for employment, social development and national economies of many countries, including the analysed countries [26, 32-33, 74]. It should also be noted that sectors such as ports, maritime transport and shipbuilding, although important employers, present a greater contribution to countries in economic and productivity terms. This is justified by the importance of the EU in the global shipbuilding industry, with around 300 shipyards, by the importance of maritime transport in the global economy and mainly in the European economy, representing 75 to 90% of the EU external trade, and by the importance of ports in the European economic development, as important benchmarks in the global trade network [74]. Regarding fisheries, we found to be a sector of great social importance in Mediterranean countries, such as Spain, Italy, France, Portugal and Greece [31, 74]. As a traditional and more labour-intensive sector, fisheries contribute more significantly to the European economy in terms of employability than in GVA [31, 74]. Moreover, due to the relevance that it presents in the Mediterranean economy, it is normal that fishing plays an important social role in the countries described above [31, 74]. On the other hand, emerging sectors such as renewable energy and aquaculture, are not present in all analysed countries [74]. As such, they do not have the same strength as other ocean uses [74]. Even so, it is important to highlight the high productivity of renewable energy in Belgium, Denmark and UK, explained by the increasing investment in offshore wind energy by the EU, mainly in the shallow waters of the North Sea, where these countries are located [74]. Looking at mining, we can see that values vary greatly depending on the country. This sector is actually absent, in certain Member States. However, mining use turns out to be one of the most productive and the one that contributes the most to the national economy in Denmark, Netherlands, UK and Italy. This can be explained by the great contribution of oil extraction for energy consumption, despite the decline of this activity together with gas extraction [74]. In addition, most of the oil and gas extraction in Europe is done in the North Sea [74].

By analysing the socioeconomic importance of these sectors for the analysed countries, we are contributing to better understanding of the level of socioeconomic exposure of each country to climate change, and to an informed perception of countries vulnerabilities to climate change [5, 7]. Such an analysis also allows for further clarification on, depending on each ocean use vulnerability in a specific country, priority sectors for subsequent mitigation and adaptation measures in the marine spatial plans [5, 7]. An example of this, is the case of fisheries, where their vulnerability to climate change is more significant in Mediterranean countries, apart from Denmark where vulnerability based on productivity is also high. Moreover, the incidence of climate change drivers such as ocean warming and acidification, on these countries together with overfishing, may cause significant reductions in commercial fish catches leading to food security problems [31-32]. If we look at mining, the vulnerability to climate change is much lower than fisheries, due to the low sensitivity of this sector to climate change, even for the UK, one of the countries with higher socioeconomic importance. In marine conservation, despite using different variables for exposure, it is also possible to determine which countries will face greater difficulties in protecting their ocean under new climate context. The same example can be treated for the other sectors, where the results contribute to a better understanding of where the ocean uses are most vulnerable, thus informing policy and decision-making on adaptation and mitigation measures to cope with climate change.

When we look at the final vulnerability scores, it is important to know that for MSP vulnerability, UK, France and countries from the Mediterranean are the most vulnerable in terms of employment and GVA. Meanwhile, in terms of productivity Denmark, UK, Belgium, France and the Netherlands are the most vulnerable ones. This can be explained by the fact that the most socially and economically vulnerable countries are those that present significant vulnerability in many ocean uses, mainly uses that are very sensitive to climate change. The same countries are also the most vulnerable in terms of BE vulnerability, although vulnerability values are lower, due to the non-inclusion of marine conservation use, a sector highly sensitive to climate change. It should also be noted that Latvia, Lithuania and Malta although they have lower adaptive capacity, and for that should have greater vulnerability scores, they have the lowest vulnerability scores. This is justified by the fact that these countries have low socioeconomic exposure compared to other countries, as they are small countries with small sector power compared to others. However, these countries should also be aware of what ocean uses are more vulnerable in their countries, in order to take adaptation measures in time [17]. In addition, for vulnerability based on productivity, Denmark, Belgium and the Netherlands replace the Mediterranean countries in the raking of the most vulnerable, for having greater representation of productive sectors and for presenting higher productivity in sectors not so productive in other countries, thus, influencing the outcome. Still, it is important to remember that many of these countries, being developed countries and EU Member States, end up having a great adaptive capacity, which influences the values of vulnerability and which can contribute to a better response to the challenges posed by climate change [119]. So, it is important to remember that all factors influence the obtained MSP and BE vulnerability scores as well as the methodological choices made in the development of this index, and although vulnerability scores may be higher or smaller, every country should see what sectors are more vulnerable to climate change, and which of them, due to their national importance, will urgently need to adapt to promote resilient MSP processes, contributing to long-term sustainable management [7, 118].

These results also share light in what problems can come from this vulnerability scores and what implications will MSP and BE have in the face of climate change. The MSP is a process that allows, through the temporal and spatial management of the various ocean uses, the development of the sectors and the national economy, where for example EU sea-dependent activities represent 5.4 million jobs and a gross added value of 500 billion euros a year [5-6]. However, changes caused by climate change will lead to a relocation of specific ocean uses and the emergence of new conflicts and new environmental impacts [4-6, 44, 48]. Thus, it is extremely relevant the ability of marine spatial plans to integrate climate change into their process, making them more flexible and adaptive [4-6, 44, 48]. It is important to mention, that there are few marine spatial plans, of those already published at the European level, that recognize the problems climate change may bring to the plans and their sustainable functioning in the long term [7, 120]. Even fewer, consider in their objectives the need to plan and develop mitigation and adaptation measures to climate change (only Netherlands, United Kingdom and Sweden do so) [7, 120]. This lack of recognition and consideration of the problems that may arise for MSP, and consequently for a sustainable BE, in a world where environmental pressures on marine biodiversity continue to increase, shows that most plans continue to emphasize a short-term and reactive perspective, rather than planning for the future [7, 120]. Thus, there is an urgent need to seek to include the climate change issue in MSP processes [7]. Approaches such as dynamic ocean management, anticipatory zoning and just-in-time planning can help achieve this, as well as making plans more adaptive and flexible [7]. Also, more collaboration across social and ecologic sciences, as well as collaboration across sectors and combining risk and vulnerability analysis with scenario approaches could help to prepare countries to adapt to climate change and to improve social-ecological resilience and marine conservation, while continuing to grow their BEs [22, 39]. We should also know that no single MSP initiative will be able to anticipate all future impacts of climate change, given the uncertainties implied in these processes [7]. However, each country must evaluate which are the dynamic solutions, revision and monitoring processes that suit them better and why, to ensure a more effective planning [7].

With this work, it was possible to ascertain that vulnerability assessments can determine what ocean uses are more socioeconomically important, as well as what ocean uses, MSP and BE of the analysed countries are most vulnerable to climate change. So, VAs are scientific exercises that can inform decisions-making concerning ocean services management and conservation and can help to achieve a sustainable ocean management [17, 63]. However, the analyses obtained in these studies will bring important social-ecological linkages, but also new methodological limitations that will need to be accounted for [7]. Detailed information about the limitations and constrains of this work are presented in section 7.2.9. (Supplementary Materials). Still, our study serves as a way to raise public and policy-makers awareness, and to add more information about VA studies to the scientific community, being the ultimate goal to alert people for the importance of these studies to a sustainable management of the sea under new climate context.

5. Final Considerations

This work had always in mind two different objectives. First, focus was on making a literature review about VA studies regarding the marine environment, where we tried to understand the form and intensity of how the dimensions of vulnerability, ocean uses, and climate-related drivers of change were present in VA studies, making possible to know the state of the art of these studies. We should remember that revision processes like these, play an important role in the general comprehension of this complex theme and can contribute to inform future vulnerability studies regarding the marine environment. It is also important to bear in mind, that these revision processes will always have an inherent subjectivity attached and some limitations, regarding authors interpretation or availability of studies [54]. However, literature reviews like the one developed in this study, can help the scientific community to identify the thematic areas most in need of attention contributing to their development [54]. Second, attention was taken to develop an MSP and BE vulnerability index to climate change. Through this, it was possible to calculate three types of vulnerability to climate change based on the employment, GVA and productivity, in the analysed countries, and to determine what implications these vulnerabilities will have on marine spatial plans and on the BE. So far, few studies have applied a comprehensive approach to estimate and discuss the effects of climate change on MSP and BE, as well as integrating them within the process [5]. For this reason, our study tried to recognize the challenge that climate change will bring to MSP and to the BE, as an essential step towards sustainable ocean use [5].

Marine and coastal environment provides numerous important services for humans and serves as a source of income for many populations that depend on the sea [15]. MSP arose with the aim of promoting better management and governance of the ocean, trying to reduce conflicts and arranging compatibility between uses [5]. However, climate change will continue to affect marine and coastal ecosystems imposing new difficulties and challenges for communities that depend on the goods and services provided and affecting their livelihood [22, 32, 34-35, 37-38]. Thus, VAs will allow for a better understanding of what activities will be most impacted by climate change and most needed to manage, and what harmful effects will be needed to reduce [7, 27]. Although being scientific exercises, these studies can provide important information to support decision-making concerning ocean services management and conservation, and can help to achieve a sustainable ocean management, allowing for a better understanding of how the sectors, and dependent economies and communities can be affected by climate change [17, 63-64].

VA studies are set to develop robust and credible measures, but the difficulty in finding a definition of vulnerability consistent and accepted by all, the existence of countless methods that are used for calculating vulnerability, the difficulty on identifying all the factors of stress and/or capturing socioeconomic and biophysical uncertainty, and the difficulty in obtaining complete and adequate databases will always affect vulnerability outcomes, as they will always be a simplification of the complexity of vulnerability [35, 56-58, 60, 63, 67-68]. However, despite this diversity of contexts and definitions, and the existing limitations for calculating vulnerability, these studies can provide relevant information for support decision planning [57]. VAs can identify potential problems that must be planned for and addressed by appropriate environmental and conservation policies [72]. Being that said, our VA study can support EU coastal Member States policies, by informing on the most socioeconomically vulnerable uses, as well as on the marine spatial plans and BEs most vulnerable to climate change, giving sights of the importance of integrate and recognize the challenge of climate change in future ocean management plans [7].

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7. Supplementary Materials

7.1. Literature review

7.1.1. Supporting tables

Table S1| List of studies that while including searched keywords in the main text, where excluded from the present work. Each article has information about the year, title, author(s), and a small resume with the reason of exclusion.

Year	Author(s)	Title	Resume and reason of exclusion
2005	Preston	Stochastic Simulation for Climate Change Risk Assessment and Management	Develops a framework for determining the risk and impact of climate change, considering the uncertainty of the phenomena. (Exclusion because ocean uses are not presented in the article).
2011	Mortsch	Multiple Dimensions of Vulnerability and Its Influence on Adaptation Planning and Decision Making	Review vulnerability concepts and ideas, vulnerability analysis, and adaptation plans. It considers the phenomenon of climate change and uses a case study. (Exclusion because the case study is an urban case study, although it uses some marine examples).
2018	Huynh *et al.*	Multi-scale assessment of social vulnerability to climate change: An empirical study in coastal Vietnam	Evaluates the social vulnerability of a coastal community in Vietnam using surveys and direct observations. (Exclusion, although the social assessment of the coastal city is good the expected focus to ocean uses is lacking, because through surveys the livelihood of the district was found to be just agriculture).
2018	Brown	Assessing climate change risks to the natural environment to facilitate cross-sectoral adaptation policy	Reflects on the theme of risk assessment in the face of climate phenomena. It seeks to address important concepts such as EBA for good policy adaptation in different sectors. (Exclusion because the sectors focused, lack ocean uses).

Table S2| Theoretical studies from the obtained search results. 30 articles where compiled in an excel table like the presented below after being separated from VA and excluded studies. Each article has information about the year, title, author(s), and a small resume.

Year	Author(s)	Title	Resume
2006	Patwardhan	Assessing vulnerability to climate change: The link between objectives and assessment	It reviews concepts and studies on coastal vulnerability analysis, seeking to link objectives with assessment methodologies.
2006	Adger	Vulnerability	Review of concepts, studies and methodologies about vulnerability.
2008	Ragen *et al.*	Conservation of Artic mammals faced with climate change	It seeks to understand the effectiveness of conservation measures for marine mammals in the Arctic, considering anthropogenic pressures and climate change.
2011	Perry	Potential impacts of climate change on marine wild capture fisheries: an update	It reviews the literature, focusing on the impacts of climate change on the marine ecosystem and fisheries.
2012	European Commission	Blue Growth: Opportunities for marine and maritime sustainable growth	European Commission report on the importance of the blue economy for Europe, where it focuses on the most important areas for investing.
2012	Bostrom *et al.*	Causal thinking and support for climate change policies: International survey findings	Conducts a set of questionnaires to assess the most famous choices among respondents on climate change response policy.
2013	Hollowed *et al.*	Projected impacts of climate change on marine fish and fisheries	Conducts a literary review on the impacts of climate change on fisheries, marine fish and coastal communities.
2013	Davidson *et al.*	Toward Operationalizing Resilience Concepts in Australian Marine Sectors Coping with Climate Change	It seeks to develop a framework with the resilience indicator. For this, four case studies and sectors with climate change impacts already experienced were used, providing an integrated approach to resilience assessment.
2014	Orbach	A brief essay on the nature of (and in) environmental policy	It focuses on the discussion of an environmental policy focusing on human values and their behaviours. The work also explores the perspective of "total ecology".
2015	Nicotra *et al.*	Assessing the components of adaptive capacity to improve conservation and management efforts under global change	It portrays the theory behind the concept adaptive capacity in relation to species and populations. They seek to facilitate discussion among key stakeholders for better management and conservation decision-making.
2015	Ramesh *et al.*	Land–Ocean Interactions in the Coastal Zone: Past, present & future	Explore human interaction with the sea in the coastal zone, seeking to contribute to the implementation of sustainable and resilient management measures.
2015	Blenckner *et al.*	Past and future challenges in managing European seas	It seeks to reflect on European case studies of coastal socioecological systems in order to help give ideas and inform for better future management programs.
2015	Mcleod *et al.*	Community-Based Climate Vulnerability and Adaptation Tools: A Review of Tools and Their Applications	Reflects on existing tools for assessing vulnerability of coastal communities and adaptation measures.
2015	Maxwell *et al.*	Integrating human responses to climate change into conservation vulnerability assessments and adaptation planning	It focuses on the importance of integrating the human response to climate change, together with the vulnerability analysis of the species and the prepared adaptation plans.

Table S2| (Continuation)

2015	Brugère and De Young	Assessing climate change vulnerability in fisheries and aquaculture	It gives an overview of existing vulnerability assessment methodologies and provides important tools for assessing the vulnerability of fisheries and aquaculture facing climate change.
2015	Ahmed Khan and Vincent Amelie	Assessing climate change readiness in Seychelles: implications for ecosystem-based adaptation mainstreaming and marine spatial planning	Uses the Seychelles case study to illustrate the importance of assessing the effects of climate change on EBA management and maritime spatial planning in the region.
2016	Gallina *et al.*	A review of multi-risk methodologies for natural hazards: Consequences and challenges for a climate change impact assessment	It reviews existing risk assessment methodologies, seeking to provide ideals for the development of a climate change-focused risk assessment.
2016	Bennett *et al.*	Communities and change in the Anthropocene: understanding social-ecological vulnerability and planning adaptations to multiple interacting exposures	Review concepts and ideas to develop a framework for integrating multiple exposures into vulnerability analysis.
2016	Weatherdon *et al.*	Observed and projected impacts of climate change on marine fisheries, aquaculture, coastal tourism, and human health: An update	Review of concepts, ideas and new information on the impact of climate change on the ocean and its dependent sectors.
2017	Grafton R. Q. and Little L. R.	Risks, Resilience, and Natural Resource Management: Lessons from selected findings	Elucidate and elaborate new knowledge through a review of results and methods on resilience and risk analysis.
2017	Monnereau *et al.*	The impact of methodological choices on the outcome of national-level climate change vulnerability - assessments: An example from the global fisheries sector	It studies different methodologies for assessing the vulnerability of the fishing industry to climate change in least developed countries (LDCs), small island developing states (SIDS) and other coastal countries.
2017	Blanchard *et al.*	Linked sustainability challenges and trade-offs among fisheries, aquaculture and agriculture	It analyses several factors, such as climate change, that may affect the countries' fishing, aquaculture and agriculture sectors.
2018	Frazão-Santos *et al.*	Major challenges in developing marine spatial planning	It seeks to see the key challenges that need to be addressed, with the aim of MSP promoting a sustainable ocean use.
2018	Cinner *et al.*	Building adaptive capacity to climate change in tropical coastal communities	Develops a new approach to improve and make the adaptive capacity of coastal communities more effective.
2018	Cramer *et al.*	Climate change and interconnected risks to sustainable development in the Mediterranean	Synthesizes existing knowledge on risk analysis and other concepts with the aim of contributing to sustainable development in the Mediterranean area.
2018	Zhang *et al.*	Knowledge Domain and Emerging Trends in Vulnerability Assessment in the Context of Climate Change: A Bibliometric Analysis (1991-2017)	Makes a biographical analysis on the concept of vulnerability assessment in the face of climate change, trying to find out the origin, growth and new trends
2019	Rilov *et al.*	Adaptive marine conservation planning in the face of climate change: What can we learn from physiological, ecological and genetic studies?	Focuses on non-recognition of physiology, ecology and evolution studies for MSP planning in a world increasingly affected by climate phenomena.
2019	Ferro-Azcona *et al.*	Adaptive capacity and social-ecological resilience of coastal areas: A systematic review	It explores the role that marine protected areas can play in the adaptive capacity and socioecological resilience of coastal communities.
2019	Shaffril *et al.*	Mirror-mirror on the wall, what climate change adaptation strategies are practiced by the Asian's fishermen of all?	Analysis of available literature on the social perspective of Asian fishing communities and their adaptation to climate change phenomena.
2019	Comte *et al.*	Conceptual advances on global scale assessments of vulnerability: Informing investments for coastal populations at risk of climate change	It analyses various vulnerability assessments to understand similarities and differences in outcomes and how they construct vulnerability indicators.

Table S3| Vulnerability assessment (VA) studies from the obtained search results. 73 articles where compiled in an excel table like the presented below after being separated from theoretical and excluded studies. Each article has information about the year, title, author(s), and a small resume.

Year	Author(s)	Title	Resume
2002	O´Hara	Endemism, rarity and vulnerability of marine species along a temperate coastline	Evaluates the vulnerability of marine species in relation to sea temperature rise.
2004	Robert J. Nicholls and Jason A. Lowe	Benefits of mitigation of climate change for coastal areas	Emphasizes the importance of mitigation measures and good adaptive capacity for coastal communities due to the intensification of climate change-related phenomena, namely the sea level rise. Due a risk assessment of wetland to sea level rise.
2005	Tsimplis *et al.*	Towards a vulnerability assessment of the UK and northern European coasts: the role of regional climate variability	Assesses coastal vulnerability in relation to mean sea level rise and wind regime.
2008	Lars Bernard and Nicole Ostländer	Assessing climate change vulnerability in the arctic using geographic information services in spatial data infrastructures	It uses the Spatial Data Infrastructures system to facilitate climate change vulnerability assessment.
2009	Alvaro Moreno and Susanne Becken	A climate change vulnerability assessment methodology for coastal tourism	It develops a methodology to assesses the vulnerability of the tourism sector in coastal communities to climate change. Uses a case study.
2010	Johanna E. Johnson and David J. Welch	Marine Fisheries Management in a Changing Climate: A Review of Vulnerability and Future Options	It seeks to undertake a vulnerability analysis of the fisheries sector to climate change and to attempt to identify areas of focus for sector management. Explore concepts such as adaptive capacity, seeking to give future options.

Table S3| (Continuation)

2010	Grafton	Adaptation to climate change in marine capture fisheries	It tries to develop new methodologies for a better plan for adapting the fisheries sector to climate change.
2010	West and Hovelsrud	Cross-scale Adaptation Challenges in the Coastal Fisheries: Findings from Lebesby, Northern Norway	It assesses the challenges and adaptability of the Lebesby coastal community in the face of climate change.
2011	Zhang *et al.*	An IFRAME approach for assessing impacts of climate change on fisheries	Develops a new framework for assessing and monitoring fisheries management in the climate change scenario.
2012	Hughes *et al.*	A framework to assess national level vulnerability from the perspective of food security: The case of coral reef fisheries	It develops an index to calculate the vulnerability of countries to the decline in coral reef fisheries caused by multiple stressors.
2013	Kamranzad *et al.*	Assessment of CGCM 3.1 wind field in the Persian Gulf	Evaluates the effects of climate change on wind regime in a potential renewable energy use zone.
2013	Mamauag *et al.*	A framework for vulnerability assessment of coastal fisheries ecosystems to climate change-Tool for understanding resilience of fisheries (VA–TURF)	It uses a framework to understand the vulnerability of fisheries to climate change, particularly in the tropics.
2013	Hameed *et al.*	The value of a multi-faceted climate change vulnerability assessment to managing protected lands: Lessons from a case study in Point Reyes National Seashore	It analyses the vulnerability of the biological community to climate change phenomena.
2013	Nursey-Bray *et al.*	Vulnerabilities and adaptation of ports to climate change	It conducts a vulnerability analysis of Australian ports and reflects on their adaptability, to climate change.
2013	Ford *et al.*	The Dynamic Multiscale Nature of Climate Change Vulnerability: An Inuit Harvesting Example	It assesses the vulnerability of Inuit populations to climate change and studies their adaptive capacity.
2013	Sandra Fatoric and Ricard Morén-Alegret	Integrating local knowledge and perception for assessing vulnerability to climate change in economically dynamic coastal areas: The case of natural protected area Aiguamolls de l'Empordà, Spain	It seeks to integrate local experience with climate change vulnerability analysis to assess coastal zones. Use a case study as an example.
2013	Gadamus	Linkages between human health and ocean health: a participatory climate change vulnerability assessment for marine mammal harvesters	It assesses through interviews the vulnerability of the coastal community to the decline in the presence of marine mammals due to climate change.
2013	Yáñez-Arancibia *et al.*	Understanding the Coastal Ecosystem-Based Management Approach in the Gulf of Mexico	It seeks to elucidate how ecosystem-based management works in the Gulf of Mexico and to show the importance of risk analysis for this approach.
2014	van Putten *et al.*	Fishing for the impacts of climate change in the marine sector: a case study	It investigates the impacts of climate change on fisheries, aquaculture and tourism. They use a community as a case study and conduct surveys of the population present there.
2014	Bennett *et al.*	The capacity to adapt? Communities in a changing climate, environment, and economy on the northern Andaman coast of Thailand	Strive to understand Thailand's offshore capacity to cope with scarce marine resources, habitat degradation, new economic opportunities and increased impact of climate change.
2014	Gaichas *et al.*	A risk-based approach to evaluating northeast US fish community vulnerability to climate change	Assesses the vulnerability of six fish communities to climate change. They assessed the likelihood of climate change impacts as well the community sensitivity and exposure.
2014	Gorokhovich *et al.*	Integrating Coastal Vulnerability and Community-Based Subsistence Resource Mapping in Northwest Alaska	It seeks to determine coastal vulnerability in Alaska communities through the CVI model and anthropological, physical and survey data to determine the area most in need of planning and environmental protection measures.
2014	Mendoza *et al.*	Assessing Vulnerability to Climate Change Impacts in Cambodia, the Philippines and Vietnam: An Analysis at the Commune and Household Level	It analyses the socioeconomic vulnerability of communities in three specific regions to climate change phenomena.
2014	Morzaria-Luna *et al.*	Social indicators of vulnerability for fishing communities in the Northern Gulf of California, Mexico: Implications for climate change	It assesses the vulnerability of the coastal communities in the region to numerous anthropogenic pressures and climate change.
2014	Shyam *et al.*	Vulnerability assessment of coastal fisher households in Kerala: A climate change perspective	It assesses the vulnerability of coastal communities in the region through the use of the PARS methodology.
2015	Anil Kumar Roy and Shweta Sharma	Perceptions and Adaptations of the Coastal Community to the Challenges of Climate Change: A Case of Jamnagar City Region, Gujarat, India	Assess the vulnerability of the coastal community, namely agriculture and fisheries, taking into account the phenomenon of climate change.
2015	Aishath Shakeela and Susanne Becken	Understanding tourism leaders' perceptions of risks from climate change: an assessment of policy-making processes in the Maldives using the social amplification of risk framework (SARF)	It studies the knowledge, perception and adaptive capacity of tourism sector stakeholders in the light of the phenomenon of climate change. For this there was the conduction of surveys and use of the framework SARF.
2015	Amber Himes-Cornell and Stephen Kasperski	Assessing climate change vulnerability in Alaska's fishing communities	Assess vulnerability of 315 Alaska communities to climate change.
2015	Okey *et al.*	Mapping ecological vulnerability to recent climate change in Canada's Pacific marine ecosystems	Develops an ecological vulnerability assessment of the Canadian Marine Area in the Pacific. Produce maps for better planning and adaptive capacity for the region.
2015	Stortini *et al.*	Assessing marine species vulnerability to projected warming on the Scotian Shelf, Canada	It seeks to identify which species are most vulnerable to water warming in order to contribute to sound resource management. Evaluated 33 species of fish and marine invertebrates, based on two scenarios of water warming (medium and severe).

Table S3| (Continuation)

2015	Murray *et al.*	Cumulative effects of planned industrial development and climate change on marine ecosystems	Analyses the cumulative effects of two different scenarios (climate change and industrial development) on Canada's marine ecosystem, finding which sites are most at risk.
2015	Ekstrom *et al.*	Vulnerability and adaptation of US shellfisheries to ocean acidification	It evaluates the vulnerability analysis of coastal communities, focusing on shellfish.
2015	Kalim U. Shah and Hari Bansha Dulal	Household capacity to adapt to climate change and implications for food security in Trinidad and Tobago	Assesses the adaptive capacity of communities in Trinidad and Tobago in relation to the climate change factor.
2016	Frazão-Santos *et al.*	Ocean Planning in a changing climate	It seeks to reinforce the idea that MSP needs to be more flexible and adaptive, incorporating the change factor into the process.
2016	Johanna E. Johnson and David J. Welch	Climate change implications for Torres Strait fisheries: assessing vulnerability to inform adaptation	Determines vulnerability of key local fish species using IPCC model.
2016	Colburn *et al.*	Indicators of climate change and social vulnerability in fishing dependent communities along the Eastern and Gulf Coasts of the United States	It refers to the importance of indicators for calculating the impact of climate change and calculating the fishing community's dependence on endangered species. They are trying to help policy makers to develop ecologically and economically sustainable management of coastal communities.
2016	Nelson *et al.*	Climate challenges, vulnerabilities, and food security	Quantify and assess food scarcity and changing societal behaviour following climate change challenges, relating them to the inherent vulnerability existing prior to those challenges.
2016	van der Veeken *et al*.	Tourism destinations' vulnerability to climate change: Nature-based tourism in Vava'u, the Kingdom of Tonga	It assesses the vulnerability of nature tourism in Vava'u to climate change using the Destination Sustainability Framework of Calgaro.
2016	Hereher *et al.*	Vulnerability assessment of the Saudi Arabian Red Sea coast to climate change	It assesses coastal vulnerability of the Red Sea coast of Saudi Arabia through the CVI index.
2016	Daniel J. Kennedy and Jean O. Toilliez	Risk-Based Approach for More Resilient and Sustainable Marine Structures	It develops a model to assess the risk posed by climate change on marine structures.
2016	Ramachandran *et al.*	Vulnerability and adaptation assessment a way forward for sustainable sectoral development in the purview of climate variability and change: insights from the coast of Tamil Nadu, India	It seeks to assess the vulnerability of some coastal sectors in the Tamil Nadu region
2016	Weis *et al.*	Assessing vulnerability: an integrated approach for mapping adaptive capacity, sensitivity, and exposure	It uses the GIS method to spatially represent the socioeconomic vulnerability of the island of Grenada.
2016	Bennett *et al.*	Community-based scenario planning: a process for vulnerability analysis and adaptation planning to social–ecological change in coastal communities	It refers to work done in two coastal communities in Thailand, where the modified community-based scenario planning process for vulnerability analysis was used.
2017	Wyatt *et al.*	Habitat risk assessment for regional ocean planning in the U.S. Northeast and MidAtlantic	It seeks to conduct a habitat risk assessment based on an exposure-consequence framework. The objective of this project is to improve knowledge of human uses and how they affect the marine ecosystem and its resources.
2017	Luise Heinrich and Torsten Krause	Fishing in Acid Waters: A Vulnerability Assessment of the Norwegian Fishing Industry in the Face of Increasing Ocean Acidification	Assess the socioeconomic risk of the fisheries sector against ocean acidification off the Norwegian coast.
2017	Chiu *et al.*	A framework for assessing risk to coastal ecosystems in Taiwan due to climate change	Develops a framework for assessing ecosystem risk by determining the vulnerability and exposure of the environment to climate change phenomena.
2017	West *et al.*	Climate-Smart Design for Ecosystem Management: A Test Application for Coral Reefs	Develops a climate change adaptation process, including vulnerability assessments, for coral reefs. Uses a case study in West Maui's, Hawaii.
2017	Schmutter *et al.*	Ocean acidification: assessing the vulnerability of socioeconomic systems in Small Island Developing States	Assesses the exposure of the socioeconomic system in Small Island Developing States to ocean acidification.
2017	Mutombo K. and Ölçer A.	Towards port infrastructure adaptation: a global port climate risk analysis	It develops a risk and exposure framework of ports to climate change, in order to improve adaptability.
2017	Lam *et al.*	Cyclone risk mapping for critical coastal infrastructure: Cases of East Asian seaports	It develops a climate risk assessment methodology for ports, specifically for cyclones.
2017	Fawcett *et al.*	Operationalizing longitudinal approaches to climate change vulnerability assessment	It uses the longitudinal approach in assessing the vulnerability of communities to climate change.
2017	Nguyen *et al.*	Assessment of social vulnerability to climate change at the local scale: development and application of a Social Vulnerability Index	Develops new ideas for the methodology of social vulnerability assessment of coastal communities, using a case study.
2017	Molinos *et al.*	Improving the interpretability of climate landscape metrics: An ecological risk analysis of Japan's Marine Protected Areas	It attempts to assess the marine locations that will be most affected by climate change in Japan and analyses them based on the network of existing MPAs.
2017	Yuan *et al.*	Risk management of extreme events under climate change	Develops a framework to manage the risk of extreme events under climate change.
2017	Toubes *et al.*	Vulnerability of Coastal Beach Tourism to Flooding: A Case Study of Galicia, Spain	It develops a methodology for assessing the vulnerability of the tourism sector to climate change, specifically sea level rise and extreme events.

Table S3| (Continuation)

2017	van den Burg *et al.*	Business case for mussel aquaculture in offshore wind farms in the North Sea	Assesses the reliability of a mussel aquaculture in a wind farm.
2018	Wabnitz *et al.*	Climate change impacts on marine biodiversity, fisheries and society in the Arabian Gulf	It assesses the potential impacts, as well as the vulnerability of marine biodiversity and the fishing sector, to climate change. Subsequently, an assessment was made of the vulnerability of economies to the impacts of climate change on fisheries.
2018	Gaichas *et al.*	Implementing Ecosystem Approaches to Fishery Management: Risk Assessment in the US Mid-Atlantic	Description of the US ecosystem risk assessment. The evaluation made it possible to highlight the main species and management problems most at risk, given the many factors present.
2018	Yang *et al.*	Risk and cost evaluation of port adaptation measures to climate change impacts	Develops a risk-cost assessment to be applied in assessing climate change adaptation of ports.
2018	Weißhuhn *et al.*	Ecosystem Vulnerability Review: Proposal of an Interdisciplinary Ecosystem Assessment Approach	It reviews the literature through the Web of Science website on studies and components that address ecosystem vulnerability and proposes a framework for ecosystem assessment.
2018	Karen L. Astles and Roland Cormier	Implementing Sustainably Managed Fisheries Using Ecological Risk Assessment and Bowtie Analysis	Uses a new analysis model (Bowtie) to complement risk assessment for better sustainable fisheries management.
2018	Avelino *et al.*	Survey Tool for Rapid Assessment of Socio-Economic Vulnerability of Fishing Communities in Vietnam to Climate Change	Assesses the vulnerability of the coastal community in Vietnam, focusing on the fisheries sector (main source of income for many developing countries).
2018	Sowman *et al.*	Socio-ecological vulnerability assessment in coastal communities in the BCLME region	It makes a quick assessment of the vulnerability of eight fishing communities in the Benguela region. It thus seeks to understand which are the most susceptible and how responsive they are to climate change.
2018	Oulahen *et al.*	Contextualizing institutional factors in an indicator-based analysis of hazard vulnerability for coastal communities	Development of an index that can identify differences and similarities of capital types that influence vulnerability. In addition, they attempt to demonstrate the importance of institutional capital indicators in analysing which local political factors can affect the vulnerability of coastal communities.
2019	Asmus *et al.*	The risk to lose ecosystem services due to climate change: A South American case	Assess the risk of ecosystem services used by stakeholders in the face of climate change.
2019	Rogers *et al.*	Shifting habitats expose fishing communities to risk under climate change	Develops a socioecological assessment of fishing communities' exposure to climate change risk.
2019	Mehvar *et al.*	Climate change-driven losses in ecosystem services of coastal wetlands: A case study in the West coast of Bangladesh	Assess the impacts of climate change, especially the rise in mean sea water levels, on the value of ecosystem services.
2019	Venegas *et al.*	Climate-induced vulnerability of fisheries in the Coral Triangle: Skipjack Tuna thermal spawning habitats	Investigates the impacts of rising sea temperatures on tuna spawning and its implications for fishing in the region.
2019	Kontogianni *et al.*	Development of a composite climate change vulnerability index for small craft harbours	It develops an index of vulnerability to climate change for small ports, following the IPCC vulnerability analysis methodology.
2019	Lillebø *et al.*	Measuring Vulnerability of Marine and Coastal Habitats' Potential to Deliver Ecosystem Services: Complex Atlantic Region as Case Study	It applies a model to assess the vulnerability of benthic habitats and to create an index of vulnerability with their potential for ecosystem service production against two different scenarios.
2019	Paul Buchana and Patrick E. McSharry	Windstorm risk assessment for offshore wind farms in the North Sea	Assess through damage analysis and catastrophic models the vulnerability of wind turbines to increasing wind strength and storm intensification due to climate change.
2019	Duncan McIntosh and Austin Becker	Expert evaluation of open-data indicators of seaport vulnerability to climate and extreme weather impacts for U.S. North Atlantic ports	Tries to find the indicators needed to assess port vulnerability using the IBVA method.
2019	Hodgson *et al.*	Integrated risk assessment for the blue economy	Develop a new risk assessment framework considering Blue Growth.

Table S4| Spatial scope of the selected VA studies from the obtained search results. Each article has information about the year, author(s) and spatial scale (*i.e.* Global, Regional, National or Local). 0 = absence, 1 = presence.

Year	Author(s)	Spatial Scale				Notes
		Global	Regional	National	Local	
2002	O´Hara	0	0	0	1	State of Victoria, Australia
2004	Robert J. Nicholls and Jason A. Lowe	1	0	0	0	Global
2005	Tsimplis *et al.*	0	1	0	0	UK and northern European coast
2008	Lars Bernard and Nicole Ostländer	0	1	0	0	Barents Region, Artic
2009	Alvaro Moreno and Susanne Becken	0	0	0	1	Mamanuca Islands, Fiji
2010	Johanna E. Johnson and David J. Welch	1	0	0	0	Global
2010	Grafton	1	0	0	0	Global
2010	West and Hovelsrud	0	0	0	1	Lebesby, Northern Norway
2011	Zhang *et al.*	1	0	0	0	Global
2012	Hughes *et al.*	1	0	0	0	Global
2013	Kamranzad *et al.*	0	1	0	0	Persian Gulf
2013	Mamauag *et al.*	0	0	0	1	Mindoro, Philippines
2013	Hameed *et al.*	0	0	0	1	Point Reyes National Seashore, United States of America (USA)
2013	Nursey-Bray *et al.*	0	0	1	0	Australia
2013	Ford *et al.*	0	0	0	1	Iqaluit, Nunavut, Canada
2013	Sandra Fatoric and Ricard Morén-Alegret	0	0	0	1	Aiguamolls de l'Empordà, Spain
2013	Gadamus	0	0	0	1	Alaska's Bering Strait Region
2013	Yáñez-Arancibia *et al.*	0	1	0	0	Gulf of Mexico
2014	Van Putten *et al.*	0	0	0	1	Australian Southeast, Tasmania
2014	Bennett *et al.*	0	0	0	1	Northern Andaman Coast, Thailand
2014	Gaichas *et al.*	0	0	0	1	USA Northeast Coast
2014	Gorokhovich *et al.*	0	0	0	1	Northwest Alaska, USA
2014	Mendoza *et al.*	0	1	0	0	Kampong Speu, Cambodia; Laguna province, Philippines and Thua Thien Hue, Vietnam
2014	Morzaria-Luna *et al.*	0	0	0	1	Northern Gulf of California, Mexico
2014	Shyam *et al.*	0	0	0	1	Alappuzha, Kerala, India
2015	Anil Kumar Roy and Shweta Sharma	0	0	0	1	Jamnagar City Region, Gujarat, India
2015	Aishath Shakeela and Susanne Becken	0	0	1	0	Maldives
2015	Amber Himes-Cornell and Stephen Kasperski	0	0	0	1	Alaska, USA
2015	Okey *et al.*	0	0	0	1	Canada's Pacific marine ecosystem
2015	Stortini *et al.*	0	0	0	1	Scotian Shelf, Canada
2015	Murray *et al.*	0	0	0	1	British Columbia, Canada
2015	Ekstrom *et al.*	0	0	1	0	USA
2015	Kalim U. Shah and Hari Bansha Dulal	0	0	1	0	Trinidad and Tobago
2016	Frazão-Santos *et al.*	1	0	0	0	Global
2016	Johanna E. Johnson and David J. Welch	0	0	0	1	Torres Strait, Australia
2016	Colburn *et al.*	0	0	0	1	Eastern and Golf Coasts of the USA
2016	Nelson *et al.*	0	1	0	0	North Atlantic Islands and Southwest deserts of the USA
2016	Van der Veeken *et al*.	0	0	0	1	Vava'u, the Kingdom of Tonga
2016	Hereher *et al.*	0	1	0	0	Saudi Arabian Red Sea coast

Table S4| (Continuation)

2016	Daniel J. Kennedy and Jean O. Toilliez	1	0	0	0	Global
2016	Ramachandran *et al.*	0	0	0	1	Coast of Tamil Nadu, India
2016	Weis *et al.*	0	0	1	0	Grenada
2016	Bennett *et al.*	0	0	0	1	Baan Tapae Yoi and Baan Talae Nok, Thailand
2017	Wyatt *et al.*	0	0	0	1	USA Northeast and Mid-Atlantic Coast
2017	Luise Heinrich and Torsten Krause	0	0	1	0	Norway
2017	Chiu *et al.*	0	0	1	0	Taiwan
2017	West *et al.*	0	0	0	1	West Maui's, Hawaii, USA
2017	Schmutter *et al.*	1	0	0	0	Global
2017	Mutombo K. and Ölçer A.	1	0	0	0	Global
2017	Lam *et al.*	0	1	0	0	East Asia
2017	Fawcett *et al.*	0	1	0	0	Artic
2017	Nguyen *et al.*	0	0	0	1	Quy Nhon city, Vietnam
2017	Molinos *et al.*	0	0	1	0	Japan
2017	Yuan *et al.*	1	0	0	0	Global
2017	Toubes *et al.*	0	0	0	1	Galicia, Spain
2017	Van den Burg *et al.*	0	1	0	0	North Sea
2018	Wabnitz *et al.*	0	1	0	0	Arabian Gulf
2018	Gaichas *et al.*	0	0	0	1	USA Mid-Atlantic Coast
2018	Yang *et al.*	0	1	0	0	China and Taiwan
2018	Weißhuhn *et al.*	1	0	0	0	Global
2018	Karen L. Astles and Roland Cormier	0	0	0	1	New South Wales, Australia
2018	Avelino *et al.*	0	0	0	1	Phu Trinh Ward and Duc Long Ward, Vietnam
2018	Sowman *et al.*	0	1	0	0	BCLME Region
2018	Oulahen *et al.*	0	0	0	1	British Columbia, Canada
2019	Asmus *et al.*	0	0	0	1	Patos Estuary, Brazil
2019	Rogers *et al.*	0	0	0	1	New England and USA Mid-Atlantic Coast
2019	Mehvar *et al.*	0	0	0	1	West Coast of Bangladesh
2019	Venegas *et al.*	0	1	0	0	Coral Triangle
2019	Kontogianni *et al.*	0	0	0	1	Lesvos, Greece
2019	Lillebø *et al.*	0	0	0	1	Western-Atlantic coast of Portugal
2019	Paul Buchana and Patrick E. McSharry	0	1	0	0	North Sea
2019	Duncan McIntosha and Austin Becker	0	0	0	1	North East USA
2019	Hodgson *et al.*	0	0	0	1	West coast USA

Table S5| Type of methodology used and incidence on the dimensions of vulnerability from selected VA studies. Each article has information about the year, author(s), incidence on the dimensions of vulnerability (*i.e.* exposure, sensitivity, adaptive capacity and risk), on the word VA, and type of methodology (*i.e.* type of vulnerability and nature of the assessment). Coding 0, 1 and 0, 1, 2 are explained in the methodology.

Year	Author(s)	Dimensions of vulnerability					Type of vulnerability			Type of assessment	
		Exposure	Sensitivity	Adaptive Capacity	VA	Risk	Ecological	Social	Economic	Quantitative	Qualitative
2002	O´Hara	0	0	0	2	1	1	0	0	1	1
2004	Robert J. Nicholls and Jason A. Lowe	1	2	2	1	2	1	1	1	1	0
2005	Tsimplis *et al.*	1	2	0	2	1	1	1	0	1	1
2008	Lars Bernard and Nicole Ostländer	2	2	2	2	1	0	1	0	1	1
2009	Alvaro Moreno and Susanne Becken	2	2	2	2	2	1	1	1	1	1
2010	Johanna E. Johnson and David J. Welch	2	2	2	2	2	1	1	1	1	1
2010	Grafton	2	2	2	2	2	0	1	1	1	1
2010	West and Hovelsrud	1	1	2	2	0	1	1	1	0	1
2011	Zhang *et al.*	0	1	0	0	2	1	1	1	1	1
2012	Hughes *et al.*	2	2	2	2	2	1	1	0	1	0
2013	Kamranzad *et al.*	0	0	0	0	0	1	0	0	1	0
2013	Mamauag *et al.*	2	2	2	2	1	1	1	1	1	1
2013	Hameed *et al.*	1	1	1	2	1	1	0	0	1	1
2013	Nursey-Bray *et al.*	2	2	2	2	2	1	1	1	0	1
2013	Ford *et al.*	2	2	2	2	2	1	1	0	1	1
2013	Sandra Fatoric and Ricard Morén-Alegret	2	1	2	2	2	1	1	1	1	1
2013	Gadamus	2	2	2	2	2	0	1	0	0	1
2013	Yáñez-Arancibia *et al.*	1	0	1	2	2	1	1	0	1	1
2014	Van Putten *et al.*	1	0	2	1	1	1	1	1	0	1
2014	Bennett *et al.*	0	0	2	1	2	1	1	1	1	1
2014	Gaichas *et al.*	2	2	2	2	2	1	0	0	1	0
2014	Gorokhovich *et al.*	1	1	0	2	2	1	1	0	1	1
2014	Mendoza *et al.*	2	2	2	2	2	0	1	1	1	1
2014	Morzaria-Luna *et al.*	2	2	2	2	0	0	1	1	1	1
2014	Shyam *et al.*	0	1	1	2	2	1	1	1	1	1
2015	Anil Kumar Roy and Shweta Sharma	2	2	2	2	2	0	1	1	1	1
2015	Aishath Shakeela and Susanne Becken	1	0	2	1	2	0	1	0	0	1
2015	Amber Himes-Cornell and Stephen Kasperski	2	2	2	2	2	0	1	1	1	1
2015	Okey *et al.*	2	2	2	2	2	1	0	0	1	0
2015	Stortini *et al.*	2	2	2	2	2	1	0	0	1	0
2015	Murray *et al.*	0	0	0	1	1	1	0	0	1	1
2015	Ekstrom *et al.*	2	2	2	2	2	0	1	0	1	1
2015	Kalim U. Shah and Hari Bansha Dulal	2	2	2	2	2	0	1	0	1	1
2016	Frazão-Santos *et al.*	1	0	1	2	0	0	1	1	0	1
2016	Johanna E. Johnson and David J. Welch	2	2	2	2	2	1	1	1	1	0
2016	Colburn *et al.*	1	0	2	2	2	0	1	0	1	0
2016	Nelson *et al.*	1	2	1	2	2	0	1	0	1	0
2016	Van der Veeken *et al.*	2	2	2	2	2	1	1	1	0	1

Table S5| (Continuation)

2016	Hereher *et al.*	1	1	1	2	1	1	1	1	1	1
2016	Daniel J. Kennedy and Jean O. Toilliez	1	1	1	2	2	0	1	1	1	1
2016	Ramachandran *et al.*	2	2	2	2	2	0	1	0	1	1
2016	Weis *et al.*	2	2	2	2	2	0	1	1	1	1
2016	Bennett *et al.*	2	2	2	2	2	1	1	0	0	1
2017	Wyatt *et al.*	2	1	1	2	2	1	0	0	1	0
2017	Luise Heinrich and Torsten Krause	2	2	2	2	2	0	1	1	1	1
2017	Chiu *et al.*	2	2	2	2	2	1	1	1	1	1
2017	West *et al.*	1	1	1	2	2	1	0	0	0	1
2017	Schmutter *et al.*	2	1	1	1	2	0	1	1	0	1
2017	Mutombo K. and Ölçer A.	2	1	1	2	2	0	1	1	1	1
2017	Lam *et al.*	2	0	0	2	2	0	0	1	1	0
2017	Fawcett *et al.*	2	2	2	2	2	0	1	0	1	1
2017	Nguyen *et al.*	2	2	2	2	2	0	1	0	1	1
2017	Molinos *et al.*	1	2	1	1	2	1	0	0	1	0
2017	Yuan *et al.*	2	2	2	2	2	0	1	1	1	1
2017	Toubes *et al.*	2	1	2	2	2	0	1	1	1	1
2017	Van den Burg *et al.*	1	1	0	0	2	0	0	1	1	1
2018	Wabnitz *et al.*	2	2	2	2	1	1	1	1	1	0
2018	Gaichas *et al.*	2	2	0	2	2	1	1	1	1	1
2018	Yang *et al.*	1	1	2	2	2	0	0	1	1	1
2018	Weißhuhn *et al.*	2	2	2	2	2	1	0	0	1	0
2018	Karen L. Astles and Roland Cormier	1	0	1	1	2	1	0	0	1	1
2018	Avelino *et al.*	2	2	2	2	1	0	1	1	1	1
2018	Sowman *et al.*	1	1	1	2	1	1	1	0	1	1
2018	Oulahen *et al.*	1	1	2	2	2	0	1	1	1	1
2019	Asmus *et al.*	1	0	1	2	2	1	1	1	1	1
2019	Rogers *et al.*	2	1	2	2	2	1	1	0	1	0
2019	Mehvar *et al.*	0	2	1	2	0	1	0	1	1	0
2019	Venegas *et al.*	0	1	0	1	0	1	0	0	1	0
2019	Kontogianni *et al.*	1	1	1	2	2	0	1	1	1	1
2019	Lillebø *et al.*	2	1	2	2	2	1	1	1	1	0
2019	Paul Buchana and Patrick E. McSharry	2	0	0	2	2	0	0	1	1	0
2019	Duncan McIntosha and Austin Becker	2	2	2	2	2	0	1	1	1	1
2019	Hodgson *et al.*	1	0	1	0	2	1	1	1	1	1

Table S6| Focus on ocean uses, climate-related drivers of change, and in the words MSP and BE, from selected VA studies. Each article has information about the year, author(s), focus on the ocean uses (*i.e.* fisheries, aquaculture, marine conservation, renewable energy, shipping, tourism and mining), climate-related drivers of change (*i.e.* ocean warming, acidification, deoxygenation, sea level rise, extreme events, shifting in currents, species distributional shifts and HABs) and in MSP and BE. Coding 0, 1 and 0, 1, 2 are explained in the methodology.

Year	Author(s)	MSP	Blue Economy	Ocean Uses							Climate-related driver of change							
				Fisheries	Aquaculture	Conservation	Energy	Shipping	Tourism	Mining	Ocean warming	Acidification	Deoxygenation	Sea level rise	Extreme events	Shifting in currents	Species distributional shifts	HABs
2002	O´Hara	0	0	1	1	2	0	0	0	0	1	0	0	1	0	1	1	0
2004	Robert J. Nicholls and Jason A. Lowe	0	1	0	1	0	1	1	1	0	1	0	0	1	1	0	0	0
2005	Tsimplis *et al.*	0	0	1	0	0	0	1	0	0	0	0	0	1	1	0	0	0
2008	Lars Bernard and Nicole Ostländer	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	Alvaro Moreno and Susanne Becken	0	1	0	0	1	0	0	2	0	1	0	0	1	1	0	0	0
2010	Johanna E. Johnson and David J. Welch	0	2	2	0	0	0	0	0	0	1	1	0	1	1	1	1	1
2010	Grafton	0	0	2	0	1	0	0	0	0	1	1	0	1	1	1	1	0
2010	West and Hovelsrud	0	1	2	1	1	1	1	1	1	1	0	0	0	1	1	0	0
2011	Zhang *et al.*	0	0	2	1	1	0	0	0	0	1	0	0	0	0	0	1	0
2012	Hughes *et al.*	1	1	2	1	1	0	1	1	0	1	1	0	0	0	0	0	0
2013	Kamranzad *et al.*	0	0	0	0	0	2	1	0	0	0	0	0	0	1	1	0	0
2013	Mamauag *et al.*	0	2	2	0	0	0	0	0	0	1	0	0	1	1	0	1	0
2013	Hameed *et al.*	1	0	0	0	2	0	0	0	0	1	1	0	1	1	0	1	0
2013	Nursey-Bray *et al.*	1	2	0	0	1	0	2	0	0	1	1	0	1	1	1	0	0
2013	Ford *et al.*	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0
2013	Sandra Fatoric and Ricard Morén-Alegret	0	0	1	0	1	0	0	2	0	1	0	0	1	1	0	0	0
2013	Gadamus	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0
2013	Yáñez-Arancibia *et al.*	2	1	1	0	2	0	1	1	1	1	0	1	1	1	0	1	1
2014	Van Putten *et al.*	0	2	2	2	0	0	0	2	0	1	1	0	1	1	1	1	1
2014	Bennett *et al.*	0	2	2	2	2	0	0	2	0	1	1	0	1	1	0	0	0
2014	Gaichas *et al.*	0	1	2	0	1	0	0	0	0	1	1	1	1	0	1	1	0
2014	Gorokhovich *et al.*	0	0	2	0	1	0	0	0	0	0	0	0	1	0	0	0	0
2014	Mendoza *et al.*	0	1	1	2	0	0	0	0	0	0	0	0	1	1	0	0	0
2014	Morzaria-Luna *et al.*	1	1	2	0	1	0	0	1	0	1	1	0	1	1	1	1	0
2014	Shyam *et al.*	0	1	2	1	0	0	0	0	0	1	0	0	1	1	0	1	0
2015	Anil Kumar Roy and Shweta Sharma	0	0	2	0	0	0	0	0	0	0	0	0	1	1	0	0	0
2015	Aishath Shakeela and Susanne Becken	0	2	0	0	0	1	0	2	0	1	0	0	1	1	0	0	0
2015	Amber Himes-Cornell and Stephen Kasperski	1	2	2	0	0	1	1	0	1	1	1	0	1	1	0	1	0
2015	Okey *et al.*	1	0	1	0	1	0	0	0	0	1	1	0	0	0	0	0	0
2015	Stortini *et al.*	0	2	1	0	1	0	0	0	0	1	0	0	0	0	0	1	0
2015	Murray *et al.*	1	1	1	1	1	0	1	0	1	1	1	0	0	0	0	0	0
2015	Ekstrom *et al.*	0	1	2	2	0	0	1	0	0	0	1	1	0	0	0	0	1
2015	Kalim U. Shah and Hari Bansha Dulal	0	0	1	0	0	1	0	1	0	1	0	0	1	1	0	0	0

Table S6| (Continuation)

2016	Frazão-Santos *et al.*	2	1	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1
2016	Johanna E. Johnson and David J. Welch	0	1	2	0	1	0	0	0	0	1	1	0	1	1	1	1	0
2016	Colburn *et al.*	0	2	2	0	0	0	0	0	0	1	1	0	1	1	0	1	0
2016	Nelson *et al.*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
2016	Van der Veeken *et al.*	0	1	1	0	1	0	0	2	0	1	0	0	1	1	0	0	0
2016	Hereher *et al.*	0	1	1	0	1	0	0	1	0	1	1	0	1	0	0	0	0
2016	Daniel J. Kennedy and Jean O. Toilliez	0	0	0	0	0	0	2	0	0	0	0	0	1	1	0	0	0
2016	Ramachandran *et al.*	0	0	2	0	1	0	0	0	0	1	0	0	0	1	0	0	0
2016	Weis *et al.*	0	1	1	0	0	0	1	1	0	0	0	0	1	1	0	0	0
2016	Bennett *et al.*	1	1	1	1	1	0	1	1	0	1	1	0	1	1	1	0	0
2017	Wyatt *et al.*	2	2	2	2	1	0	2	2	2	1	0	0	0	0	0	0	0
2017	Luise Heinrich and Torsten Krause	0	2	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0
2017	Chiu *et al.*	0	1	1	0	1	0	0	0	0	1	1	0	1	0	0	0	0
2017	West *et al.*	1	1	1	0	2	0	0	0	0	1	1	0	0	1	1	0	1
2017	Schmutter *et al.*	1	2	2	2	1	0	1	2	0	1	1	1	0	1	0	1	1
2017	Mutombo K. and Ölçer A.	0	0	0	0	0	0	2	0	0	1	0	0	1	1	0	0	0
2017	Lam *et al.*	0	1	0	0	0	1	2	0	0	0	0	0	1	1	0	0	0
2017	Fawcett *et al.*	0	0	1	0	0	0	0	0	1	1	0	0	0	1	0	0	0
2017	Nguyen *et al.*	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0
2017	Molinos *et al.*	1	0	0	0	2	0	0	0	0	1	0	0	0	0	1	1	0
2017	Yuan *et al.*	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
2017	Toubes *et al.*	1	1	1	1	1	0	1	2	0	0	1	0	1	1	0	0	0
2017	Van den Burg *et al.*	0	2	0	2	0	2	0	1	1	0	1	0	0	0	0	0	1
2018	Wabnitz *et al.*	1	2	2	0	2	0	0	0	0	1	1	1	1	1	0	1	0
2018	Gaichas *et al.*	1	2	2	0	1	0	0	0	0	1	1	0	1	0	1	1	0
2018	Yang *et al.*	0	1	0	0	0	0	2	0	0	0	0	0	1	1	0	0	0
2018	Weißhuhn *et al.*	0	0	1	0	1	0	0	0	0	1	0	0	1	0	0	0	0
2018	Karen L. Astles and Roland Cormier	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	1	0
2018	Avelino *et al.*	0	2	2	0	0	0	0	0	0	1	1	0	1	1	0	0	0
2018	Sowman *et al.*	1	1	2	1	0	0	0	1	0	1	0	1	1	1	1	1	1
2018	Oulahen *et al.*	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
2019	Asmus *et al.*	0	1	1	1	0	0	1	1	0	1	1	0	1	1	0	0	0
2019	Rogers *et al.*	1	1	2	0	0	0	1	0	0	1	0	0	0	0	0	1	0
2019	Mehvar *et al.*	0	2	2	2	2	0	0	2	0	1	1	1	1	1	0	0	0
2019	Venegas *et al.*	0	2	2	0	1	0	0	0	0	1	1	0	1	1	0	1	0
2019	Kontogianni *et al.*	0	2	1	0	0	0	2	1	0	0	0	0	1	1	0	0	0
2019	Lillebø *et al.*	2	2	1	1	2	1	1	1	0	0	0	0	0	0	0	0	0
2019	Paul Buchana and Patrick E. McSharry	0	1	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0
2019	Duncan McIntosha and Austin Becker	0	1	0	0	1	0	2	0	0	1	0	0	1	1	1	0	0
2019	Hodgson *et al.*	0	2	2	1	2	1	1	1	1	0	0	0	0	0	0	0	0

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7.2. Description, calculation and limitations of vulnerability variables

7.2.1 Exposure variables:

Marine Protected Area Coverage

Where used: Exposure dimension – Marine Conservation

Description: This variable represents the national marine area that is legally protected. This includes not only areas designated at the national level, but also regional and international designated sites of protection, such as Site of Community Importance from Habitats Directive; Special Protection Area from Birds Directive; and Ramsar Sites (UNEP-WCMC, 2020). It aims to serve as an indicator for marine conservation exposure, serving as a proxy for the national effort to preserve the marine environment. For this, the MPA coverage, in percentage, was considered, see Table S7. Data was obtained from the protected planet website, managed by the United Nations Environment World Conservation Monitoring Centre with support from the International Union for Conservation of Nature and its World Commission on Protected Areas (UNEP-WCMC, 2020). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Biodiversity Goal of the Ocean Health Index

Where used: Exposure dimension – Marine Conservation

Description: This variable is an estimation of how successfully marine life is being maintained around the world, and it is composed by the equal weight of two sub-groups: marine species conservation status and key habitats condition (OHI, 2020). It aims to serve as an indicator for marine conservation exposure, serving as a proxy for the national effort to preserve the marine environment. For this, the Biodiversity OHI, with values ranging from 0 to 100, was considered, see Table S7. Data were obtained from the Ocean Health Index website (OHI, 2020). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater importance of this variable for the national context, leading to greater exposure to climate change impacts.

Fisheries Employment

Where used: Exposure dimension – Fisheries

Description: This variable represents the number of jobs in the fishing sector at the national level. It aims to serve as an indicator of exposure, serving as a proxy for the social importance of the sector at the national level. It was considered the number of jobs in the sector, from 2009 to 2018. Fisheries employment includes information on three activities (*i.e.* capture fisheries on small-scale coastal fleets, capture fisheries on largescale industrial fleets and capture fisheries on distant water fleets, see Table 2.4). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater social importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Fisheries Gross Value Added

Where used: Exposure dimension – Fisheries

Description: This variable corresponds to the gross value added of the fishing sector at the national level. It aims to serve as an indicator of exposure, serving as proxy for the economic importance of the sector at the national level. It was considered the GVA *per* sector, in million euro, from 2009 to 2018. Fisheries GVA includes information on three activities (*i.e.* capture fisheries on small-scale coastal fleets, capture fisheries on largescale industrial fleets and capture fisheries on distant water fleets). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater economic importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Fisheries GVA *per* employee - productivity
Where used: Exposure dimension – Fisheries
Description: This variable corresponds to the labour productivity of the fishery sector at the national level. It aims to serve as an indicator of exposure, serving as a proxy for the socioeconomic importance of the sector at the national level. It was considered the GVA *per* sector, in euro, from 2009 to 2018 and the number of jobs in the sector, from 2009 to 2018. Fisheries GVA *per* employee includes information on three activities (*i.e.* capture fisheries on small-scale coastal fleets, capture fisheries on largescale industrial fleets and capture fisheries on distant water fleets). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater socioeconomic importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Aquaculture Employment
Where used: Exposure dimension – Aquaculture
Description: This variable represents the number of jobs in the aquaculture sector at the national level. It aims to serve as an indicator of exposure, serving as a proxy for the social importance of the sector at the national the level. It was considered the number of jobs in the sector, from 2009 to 2018. Aquaculture employment includes information on two activities (*i.e.* marine aquaculture and shellfish aquaculture, see Table 2.4). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater social importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Aquaculture Gross Value Added
Where used: Exposure dimension – Aquaculture
Description: This variable corresponds to the gross value added of the aquaculture sector at the national level. It aims to serve as an indicator of exposure, serving as proxy for the economic importance of the sector at the national level. It was considered the GVA *per* sector, in million euro, from 2009 to 2018. Aquaculture GVA includes information on two activities (*i.e.* marine aquaculture and shellfish aquaculture). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater economic importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Aquaculture GVA *per* employee - productivity

Where used: Exposure dimension – Aquaculture

Description: This variable corresponds to the labour productivity of the aquaculture sector at the national level. It aims to serve as an indicator of exposure, serving as a proxy for the socioeconomic importance of the sector at the national level. It was considered the GVA *per* sector, in euro, from 2009 to 2018 and the number of jobs in the sector, from 2009 to 2018. Aquaculture GVA *per* employee includes information on two activities (*i.e.* marine aquaculture and shellfish aquaculture). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater socioeconomic importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Renewable Energy Employment

Where used: Exposure dimension – Renewable Energy

Description: This variable represents the number of jobs in the marine renewable energy sector at the national level. It aims to serve as an indicator of exposure, serving as a proxy for the social importance of the sector at the national level. It was considered the number of jobs in the sector, from 2009 to 2018. Renewable Energy employment includes information on two activities (*i.e.* production and transmission of electricity from offshore wind energy, see Table 2.4). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater social importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Renewable Energy Gross Value Added

Where used: Exposure dimension – Renewable Energy

Description: This variable corresponds to the gross value added of the marine renewable energy sector at the national level. It aims to serve as an indicator of exposure, serving as proxy for the economic importance of the sector at the national level. It was considered the GVA *per* sector, in million euro, from 2009 to 2018. Renewable Energy GVA includes information on two activities (*i.e.* production and transmission of electricity from offshore wind energy). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater economic importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Renewable Energy GVA *per* employee - productivity

Where used: Exposure dimension – Renewable Energy

Description: This variable corresponds to the labour productivity of the marine renewable energy sector at the national level. It aims to serve as an indicator of exposure, serving as a proxy for the socioeconomic importance of the sector at the national level. It was considered the GVA *per* sector, in euro, from 2009 to 2018 and the number of jobs in the sector, from 2009 to 2018. Renewable Energy GVA *per* employee includes information on two activities (*i.e.* production and transmission of electricity from offshore wind energy). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater socioeconomic importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Ports Employment
Where used: Exposure dimension – Ports
Description: This variable represents the number of jobs in the ports sector at the national level. It aims to serve as an indicator of exposure, serving as a proxy for the social importance of the sector at the national level. It was considered the number of jobs in the sector, from 2009 to 2018. Ports employment includes information on four activities (*i.e.* cargo handling, warehousing and storage, construction of water projects, service accidental to water transportation, see Table 2.4). Data were obtained from the European Commission's database on The EU Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater social importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Ports Gross Value Added
Where used: Exposure dimension – Ports
Description: This variable corresponds to the gross value added of the ports sector at the national level. It aims to serve as an indicator of exposure, serving as proxy for the economic importance of the sector at the national level. For exposure, it was considered the GVA *per* sector, in million euro, in 2018. Ports GVA includes information on four activities (*i.e.* cargo handling, warehousing and storage, construction of water projects, service accidental to water transportation). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater economic importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Ports GVA *per* employee - productivity
Where used: Exposure dimension – Ports
Description: This variable corresponds to the labour productivity of the ports sector at the national level. It aims to serve as an indicator of exposure, serving as a proxy for the socioeconomic importance of the sector at the national level. It was considered the GVA *per* sector, in euro, from 2009 to 2018 and the number of jobs in the sector, from 2009 to 2018. Ports GVA *per* employee includes information on four activities (*i.e.* cargo handling, warehousing and storage, construction of water projects, service accidental to water transportation). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater socioeconomic importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Shipbuilding and repair Employment
Where used: Exposure dimension – Shipbuilding
Description: This variable represents the number of jobs in the shipbuilding and repair sector at the national level. It aims to serve as an indicator of exposure, serving as a proxy for the social importance of the sector at the national level. It was considered the number of jobs in the sector, from 2009 to 2018. Shipbuilding employment includes information on nine activities (*i.e.* building of ships and floating structures; building of pleasure and sporting boats; repair and maintenance of ships and boats; manufacture of textiles other than apparel; manufacture of cordage, rope twine and netting; manufacture

of instruments for measuring, testing and navigation; manufacture of engines and turbines, except aircraft; manufacture of other fabricated metal products n.e.c.; manufacture of sport goods, see Table 2.4). Data were obtained from the European Commission's database on The EU Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater social importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Shipbuilding and repair Gross Value Added
Where used: Exposure dimension – Shipbuilding
Description: This variable corresponds to the gross value added of the shipbuilding and repair sector at the national level. It aims to serve as an indicator of exposure, serving as proxy for the economic importance of the sector at the national level. For exposure intensity, it was considered the GVA *per* sector, in million euro, in 2018. Shipbuilding GVA includes information on nine activities (*i.e.* building of ships and floating structures; building of pleasure and sporting boats; repair and maintenance of ships and boats; manufacture of textiles other than apparel; manufacture of cordage, rope twine and netting; manufacture of instruments for measuring, testing and navigation; manufacture of engines and turbines, except aircraft; manufacture of other fabricated metal products n.e.c.; manufacture of sport goods). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater economic importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Shipbuilding and repair GVA *per* employee - productivity
Where used: Exposure dimension – Shipbuilding
Description: This variable corresponds to the labour productivity of the shipbuilding and repair sector at the national level. It aims to serve as an indicator of exposure, serving as a proxy for the socioeconomic importance of the sector at the national level. It was considered the GVA *per* sector, in euro, from 2009 to 2018 and the number of jobs in the sector, from 2009 to 2018. Shipbuilding GVA *per* employee includes information on nine activities (*i.e.* building of ships and floating structures; building of pleasure and sporting boats; repair and maintenance of ships and boats; manufacture of textiles other than apparel; manufacture of cordage, rope twine and netting; manufacture of instruments for measuring, testing and navigation; manufacture of engines and turbines, except aircraft; manufacture of other fabricated metal products n.e.c.; manufacture of sport goods). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater socioeconomic importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Maritime Transport Employment
Where used: Exposure dimension – Maritime Transport
Description: This variable represents the number of jobs in the maritime transport sector at the national level. It aims to serve as an indicator of exposure, serving as a proxy for the social importance of the sector at the national level. It was considered the number of jobs in the sector, from 2009 to 2018. Maritime Transport employment includes information on two activities (*i.e.* sea and coastal passenger water transport, and sea and coastal freight water transport, see Table 2.4). Data were obtained from the

European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater social importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Maritime Transport Gross Value Added
Where used: Exposure dimension – Maritime Transport
Description: This variable corresponds to the gross value added of the maritime transport sector at the national level. It aims to serve as an indicator of exposure, serving as proxy for the economic importance of the sector at the national level. It was considered the GVA *per* sector, in million euro, from 2009 to 2018. Maritime Transport GVA includes information on two activities (*i.e.* sea and coastal passenger water transport, and sea and coastal freight water transport). Data was obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater economic importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Maritime Transport GVA *per* employee - productivity
Where used: Exposure dimension – Maritime Transport
Description: This variable corresponds to the labour productivity of the maritime transport sector at the national level. It aims to serve as an indicator of exposure, serving as a proxy for the socioeconomic importance of the sector at the national the level. It was considered the GVA *per* sector, in euro, from 2009 to 2018 and the number of jobs in the sector, from 2009 to 2018. Maritime Transport GVA *per* employee includes information on two activities (*i.e.* sea and coastal passenger water transport, and sea and coastal freight water transport). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater socioeconomic importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Tourism Employment
Where used: Exposure dimension – Tourism
Description: This variable represents the number of jobs in the tourism sector at the national level. It aims to serve as an indicator of exposure, serving as a proxy for the social importance of the sector at the national level. It was considered the number of jobs in the sector, from 2009 to 2018. Tourism employment includes information on three activities (*i.e.* accommodation, transport, other expenditures, see Table 2.4). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater social importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Tourism Gross Value Added
Where used: Exposure dimension – Tourism
Description: This variable corresponds to the gross value added of the tourism sector at the national level. It aims to serve as an indicator of exposure, serving as proxy for the economic importance of the sector at the national level. It was considered the GVA *per* sector, in million euro, from 2009 to 2018. Tourism GVA includes information on three activities (*i.e.* accommodation, transport, other

expenditures). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater economic importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Tourism GVA *per* employee - productivity

Where used: Exposure dimension – Tourism

Description: This variable corresponds to the labour productivity of the tourism sector at the national level. It aims to serve as an indicator of exposure, serving as a proxy for the socioeconomic importance of the sector at the national level. It was considered the GVA *per* sector, in euro, from 2009 to 2018 and the number of jobs in the sector, from 2009 to 2018. Tourism GVA *per* employee includes information on three activities (*i.e.* accommodation, transport, other expenditures). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater socioeconomic importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Mining Employment

Where used: Exposure dimension – Mining

Description: This variable represents the number of jobs in the mining sector at the national level. It aims to serve as an indicator of exposure, serving as a proxy for the social importance of the sector at the national level. It was considered the number of jobs in the sector, from 2009 to 2018. Mining employment includes information on six activities (*i.e.* extraction of crude petroleum; extraction of natural gas; support activities for petroleum and natural gas activities; extraction of salt; operation of gravel and sand pits, mining of clays and kaolin; and support activities for other mining and quarrying, see Table 2.4). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater social importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Mining Gross Value Added

Where used: Exposure dimension – Mining

Description: This variable corresponds to the gross value added of the mining sector at the national level. It aims to serve as an indicator of exposure, serving as proxy for the economic importance of the sector at the national level. It was considered the GVA *per* sector, in million euro, from 2009 to 2018. Mining GVA includes information on six activities (*i.e.* extraction of crude petroleum; extraction of natural gas; support activities for petroleum and natural gas activities; extraction of salt; operation of gravel and sand pits, mining of clays and kaolin; and support activities for other mining and quarrying). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater economic importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Mining GVA *per* employee - productivity

Where used: Exposure dimension – Mining

Description: This variable corresponds to the labour productivity of the mining sector at the national level. It aims to serve as an indicator of exposure, serving as a proxy for the socioeconomic importance of the sector at the national level. It was considered the GVA *per* sector, in euro, from 2009 to 2018 and the number of jobs in the sector, from 2009 to 2018. Mining GVA *per* employee includes information on six activities (*i.e.* extraction of crude petroleum; extraction of natural gas; support activities for petroleum and natural gas activities; extraction of salt; operation of gravel and sand pits, mining of clays and kaolin; and support activities for other mining and quarrying). Data were obtained from the European Commission's database on The Eu Blue Economic Report from 2019 and 2020 (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater socioeconomic importance of this variable for the national context, leading to a greater exposure to climate change impacts.

Table S7| MPA coverage and scores of the biodiversity goal of the Ocean Health Index for EU coastal Member States, and the United Kingdom. Baseline data from UNEP-WCMC, 2020 and OHI, 2020.

Country	MPA coverage (%)	Biodiversity goal [0-100]
Belgium	36.65	92
Bulgaria	8.11	94
Croatia	8.99	89
Cyprus	8.62	85
Denmark	18.32	91
Estonia	18.78	92
Finland	11.99	92
France	50.36	86
Germany	45.39	88
Greece	4.52	87
Ireland	2.33	82
Italy	9.74	83
Latvia	16.04	81
Lithuania	25.59	79
Malta	7.44	83
Netherlands	26.86	79
Poland	22.57	76
Portugal	16.82	86
Romania	23.10	96
Slovenia	2.31	92
Spain	12.76	76
Sweden	15.38	87
UK	30.42	86

7.2.2. Sensitivity variables:

Impacts of climate change on marine conservation
Where used: Sensitivity dimension – Marine conservation
Description: This variable corresponds to the impact degree of the main climate drivers on marine conservation at a global level. It aims to serve as an indicator for sensitivity, serving as a proxy for the positive or negative outcomes that can be imposed to marine conservation, by climate change. Data were adapted from Frazão-Santos *et al*., 2016, where three scales of impact were considered: high (score 3), medium (score 2), and low (score 0). The aggregation with the weighting factors follows the steps detailed in the methodology, see also table 3 and 4 and, equation 5. The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater sensitivity of the ocean use to climate change impacts.

Impacts of climate change on fisheries
Where used: Sensitivity dimension – Fisheries
Description: This variable corresponds to the impact degree of the main climate drivers on fisheries at a global level. It aims to serve as an indicator for sensitivity, serving as a proxy for the positive or negative outcomes that can be imposed to fisheries, by climate change. Data were adapted from Frazão-Santos *et al*., 2016, where three scales of impact were considered: high (score 3), medium (score 2), and low (score 0). The aggregation with the weighting factors follows the steps detailed in the methodology, see also table 3 and 4 and, equation 5. The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater sensitivity of the ocean use to climate change impacts.

Impacts of climate change on aquaculture
Where used: Sensitivity dimension – Aquaculture
Description: This variable corresponds to the impact degree of the main climate drivers on aquaculture at a global level. It aims to serve as an indicator for sensitivity, serving as a proxy for the positive or negative outcomes that can be imposed to aquaculture, by climate change. Data were adapted from Frazão-Santos *et al*., 2016, where three scales of impact were considered: high (score 3), medium (score 2), and low (score 0). The aggregation with the weighting factors follows the steps detailed in the methodology, see also table 3 and 4 and, equation 5. The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater sensitivity of the ocean use to climate change impacts.

Impacts of climate change on marine renewable energy
Where used: Sensitivity dimension – Renewable energy
Description: This variable corresponds to the impact degree of the main climate drivers on renewable energy at a global level. It aims to serve as an indicator for sensitivity, serving as a proxy for the positive or negative outcomes that can be imposed to renewable energy, by climate change. Data were adapted from Frazão-Santos *et al*., 2016, where three scales of impact were considered: high (score 3), medium (score 2), and low (score 0). The aggregation with the weighting factors follows the steps detailed in the methodology, see also table 3 and 4 and, equation 5. The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater sensitivity of the ocean use to climate change impacts.

Impacts of climate change on ports
Where used: Sensitivity dimension – Ports
Description: This variable corresponds to the impact degree of the main climate drivers on ports at a global level. It aims to serve as an indicator for sensitivity, serving as a proxy for the positive or negative outcomes that can be imposed to ports, by climate change. Data were calculated manually, in the scope

of this project, following the methodological steps from Frazão-Santos *et al*., 2016, where three scales of impact were considered: high (score 3), medium (score 2), and low (score 0). The aggregation with the weighting factors follows the steps detailed in the methodology, see also table 3 and 4 and, equation 5. The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater sensitivity of the ocean use to climate change impacts.

Impacts of climate change on shipbuilding and repair

Where used: Sensitivity dimension – Shipbuilding and repair

Description: This variable corresponds to the impact degree of the main climate drivers on shipbuilding and repair at a global level. It aims to serve as an indicator for sensitivity, serving as a proxy for the positive or negative outcomes that can be imposed to shipbuilding and repair, by climate change. Data were calculated manually, in the scope of this project, following the methodological steps from Frazão-Santos *et al*., 2016, where three scales of impact were considered: high (score 3), medium (score 2), and low (score 0). The aggregation with the weighting factors follows the steps detailed in the methodology, see also table 3 and 4 and, equation 5. The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater sensitivity of the ocean use to climate change impacts.

Impacts of climate change on maritime transport

Where used: Sensitivity dimension – Maritime transport

Description: This variable corresponds to the impact degree of the main climate drivers on maritime transport at a global level. It aims to serve as an indicator for sensitivity, serving as a proxy for the positive or negative outcomes that can be imposed to maritime transport, by climate change. Data were calculated manually, in the scope of this project, following the methodological steps from Frazão-Santos *et al*., 2016, where three scales of impact were considered: high (score 3), medium (score 2), and low (score 0). The aggregation with the weighting factors follows the steps detailed in the methodology, see also table 3 and 4 and, equation 5. The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater sensitivity of the ocean use to climate change impacts.

Impacts of climate change on tourism

Where used: Sensitivity dimension – Tourism

Description: This variable corresponds to the impact degree of the main climate drivers on tourism at a global level. It aims to serve as an indicator for sensitivity, serving as a proxy for the positive or negative outcomes that can be imposed to tourism, by climate change. Data were adapted from Frazão-Santos *et al*., 2016, where three scales of impact were considered: high (score 3), medium (score 2), and low (score 0). The aggregation with the weighting factors follows the steps detailed in the methodology, see also table 3 and 4 and, equation 5. The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater sensitivity of the ocean use to climate change impacts.

Impacts of climate change on mining

Where used: Sensitivity dimension – Mining

Description: This variable corresponds to the impact degree of the main climate drivers on mining at a global level. It aims to serve as an indicator for sensitivity, serving as a proxy for the positive or negative outcomes that can be imposed to mining, by climate change. Data were adapted from Frazão-Santos *et al*., 2016, where three scales of impact were considered: high (score 3), medium (score 2), and low (score 0). The aggregation with the weighting factors follows the steps detailed in the methodology, see also table 3 and 4 and, equation 5. The results were normalized to a scale of 0 to 1, where values closer to 1 correspond to a greater sensitivity of the ocean use to climate change impacts.

7.2.3. Adaptive capacity variables:

Income
Where used: Adaptive capacity dimension – Assets
Description: This variable corresponds to the resources people have access to, at the national level (Cinner *et al*., 2018). It aims to serve as an indicator for adaptive capacity, serving as a proxy of assets domain, adopted from Cinner *et al*., 2018. It was considered the GNI *per* capita, in constant 2011 PPP international dollars, in 2018. Data was obtained from the Human Development Report 2019 (UNDP, 2019). The results were normalized to a scale of 0 to 1, following specifics methodological steps, where values closer to 1 correspond to a greater adaptive capacity of the country to climate change, see methodology.

Education
Where used: Adaptive capacity dimension – Learning
Description: This variable corresponds to the capacity to obtain information on climate change and related concepts, at the national level (Cinner *et al*., 2018). It aims to serve as an indicator for adaptive capacity, serving as a proxy of learning domain, adopted from Cinner *et al*., 2018. It was considered the expected and mean years of schooling, in 2018. Data was obtained from the Human Development Report 2019 (UNDP, 2019). The results were normalized to a scale of 0 to 1, following specifics methodological steps, where values closer to 1 correspond to a greater adaptive capacity of the country to climate change, see methodology.

Health
Where used: Adaptive capacity dimension – Social organization
Description: This variable corresponds to the capacity of a society to share knowledge and show cooperation, at the national level (Cinner *et al*., 2018). It aims to serve as an indicator for adaptive capacity, serving as a proxy of social organization domain, adopted from Cinner *et al*., 2018. It was considered the life expectancy at birth, in 2018. Data was obtained from the Human Development Report 2019 (UNDP, 2019). The results were normalized to a scale of 0 to 1, following specifics methodological steps, where values closer to 1 correspond to a greater adaptive capacity of the country to climate change, see methodology.

Governance
Where used: Adaptive capacity dimension – Agency
Description: This variable corresponds to the power and freedom to mobilize the other domains, at the national level (Cinner *et al*., 2018). It aims to serve as an indicator for adaptive capacity, serving as a proxy of agency domain, adopted from Cinner *et al*., 2018. It was considered the voice and accountability, political stability and absence of violence/terrorism, government effectiveness, regulatory quality, rule of law and, control of corruption, in 2018. Data was obtained from the Worldwide Governance Indicators (World Bank, 2018). The results were normalized to a scale of 0 to 1, following specifics methodological steps, where values closer to 1 correspond to a greater adaptive capacity of the country to climate change, see methodology.

7.2.4. Shipbuilding, ports, and maritime transport sensitivity to climate change

In order to calculate sensitivity, the impact of climate change in the different maritime sectors was considered, adapting the work developed by Frazão-Santos *et al*., 2016. However, as mentioned in the methodology, the sensitivity of three ocean uses (*i.e.* shipbuilding and repair, ports and maritime transport) were also calculated within the scope of this project. This is of extreme importance because, although these sectors are not in the work of Frazão-Santos *et al*., where combined ocean use shipping was used, they are present in the EU blue economy reports from where the exposure values, necessary for calculating vulnerability, were withdrawn (Frazão-Santos *et al*., 2016; European Commission, 2018; European Commission, 2019; European Commission, 2020c). Therefore, for the coherence of the vulnerability calculation, there is a need to inquire about the impact of climate drivers in these three sectors.

The calculation for the three sectors followed the methodological steps, outlined by Frazão-Santos *et al*., 2016. For this, a search for articles related to the impact of climate change in these three maritime sectors was carried out on the ISI Web of Knowledge website, throughout the entire database and for all available years, 1990 to 2020. This research aimed to find information from the scientific community that can justify the impact, or lack of it, that climate change can cause to the targeted ocean uses. It is important to highlight, that following the steps of Frazão-Santos *et al*., the climatic impact in the sectors had to be individualized into eight climate drivers (*i.e*. ocean warming; ocean acidification; deoxygenation; sea level rise; extreme events; shifting in currents and winds; species distributional shifts; increase in pathogens and HABs), allowing a greater coherence and greater perception of how climatic phenomena can affect these sectors (Frazão-Santos *et al*., 2016). The final value of climate drivers impact on these ocean uses, as well as their impact classes, are described and presented, in a detailed manner in Table S8, being this assessment based on information taken and interpreted from the various articles related to the purpose of this assignment. The climate driver impact scales were also the same as those used in the work of Frazão-Santos *et al*., with four impact classes: high impact (score 3), medium (score 2), low (score 1) and none (score 0). It should be noted that these sectors, in addition to being maritime sectors, very much depend on the coastal environment for their existence. Therefore, when analysing the impacts of climate change in these sectors, attention was taken to observe impacts that occurred in the maritime environment and impacts that occurred in the coastal environment.

Table S8| Global impact of climate change on shipbuilding, ports and maritime transport. Four impact classes were defined, where high impact has a score of 3, medium has a score of 2, low has a score of 1 and null has a score of 0. Each climate driver, as well as its impact on the sector are justified through a brief description. N/A – inexistent information or not applicable.

Ocean Use	Climate Driver	Brief description of the climate driver impact on the ocean use	Global Impact
Shipbuilding and repair	Ocean warming	Due to the increase in ocean temperature and melting, new sea routes will emerge, as in the case of sea routes in the Arctic (Heij C. and Knapp S., 2015; Adolf *et al*., 2018). This event will trigger new investigations and changes regarding maritime safety, the design of ships (stability and structure) and the quality of support boats and search-rescue systems, in view of the exploration of this new route (Heij C. and Knapp S., 2015; Adolf *et al*., 2018).	3
	Ocean acidification	N/A	0
	Deoxygenation	N/A	0
	Sea level rise	Sea level rise will have little direct impact on the design of ships but may affect their coastal infrastructures (Bitner-Gregersen *et al*., 2018).	2
	Extreme events	The increase in adverse conditions and, consequently, the increase in wind strength and wave height, caused by climate change, will increase the risk of ship accidents leading to ship repairs (Heij C. and Knapp S., 2015).	2
	Shifting in currents	Associated with climatic problems and the consequent increase in the wind strength, the bet on wind energy for ship propulsion, may imply greater manufacture of towing kites, flettner rotors and sails (Heij C. and Knapp S., 2015; Rojon I. and Dieperink C., 2014).	2
	Distributional shifts	N/A	0
	HABs	N/A	0
Ports	Ocean warming	Variations in the ocean surface temperature, accentuated by climate change, will affect the frequency of cyclone occurrences, adding uncertainty regarding the inherent risk of these phenomena in ports (Jian W. *et al*., 2019).	2
	Ocean acidification	The increase in acidification and ocean salinity will make corrosion increase on port infrastructures (Nursey-Bray M. *et al*., 2013; Becker *et al*., 2018).	1
	Deoxygenation	N/A	0
	Sea level rise	Sea level rise will be one of the main impacts for ports, given their proximity to the coast, leading to loss of operability and consequent economic losses, and leading to redesign, strengthen or relocate port structures if necessary (Izaguirre C. *et al.* , 2020; Gracia V. *et al*, 2019; Monioudi *et al*., 2018; Nursey-Bray M. *et al*., 2013; Sánchez-Arcilla *et al*., 2016; Becker A. *et al*., 2013). Associated with sea level rise, wave propagation patterns will undergo some changes and will affect ports in terms of maritime agitation and structure stability (Gracia V. *et al*., 2019).	3
	Extreme events	The increase in the frequency and intensity of extreme events due to climate change will significantly affect ports that may suffer from flooding, structure damage and interruption of port activities, affecting their productivity and causing necessary interventions in terms of planning, operation and maintenance of port structures (Izaguirre C. *et al*., 2020; Kontogianni A. *et al*., 2019; Garcia-Alonso L. *et al*., 2020; Christodoulou A. *et al*., 2019; Monioudi *et al*., 2018; Lee Lam *et al*., 2017; Becker A. *et al*., 2013).	3
	Shifting in currents	N/A	0
	Distributional shifts	The change in the distribution of economically important species for fishermen and tourist companies, associated with the increase in temperature, will have consequences for the supporting infrastructures of these activities (Brooke, 2015).	1
	HABs	N/A	0
Maritime Transport	Ocean warming	The reduction of ice cover in the Arctic, due to increased ocean warming, will lead to the opening of new maritime routes, which will lead to new challenges and new risks, requiring training and education to reduce the risk associated with navigation in this location (Smith L.C. and Stephenson S.R., 2013; Yuan C. *et al*., 2020; Stevenson T. *et al*., 2019; Bitner-Gregersen *et al*., 2018).	3
	Ocean acidification	N/A	0
	Deoxygenation	N/A	0
	Sea level rise	Sea level rise can have a major impact on support structures for maritime transport, such as ports, affecting all transport logistics (Christodoulou A. *et al*., 2019).	2
	Extreme events	The increase in the frequency and strength of storms, with the consequent increase in wind strength and wave height, will create a greater risk of accidents and pollution incidents during shipping (Heij C. and Knapp S., 2015).	3
	Shifting in currents	Changes in wind patterns and currents may lead to a variation in maritime routes, seeking to avoid areas more prone to navigation accidents (Heij C. and Knapp S., 2015).	2
	Distributional shifts	N/A	0
	HABs	N/A	0

7.2.5. Non-normalized data of the exposure of ocean uses that correspond to maritime activities

Table S9| Non-normalized data for exposure based on employment, GVA and productivity of the analysed countries.

Exposure	Country	Fisheries	Aquaculture	Renewable Energy	Ports	Shipbuilding and Repair	Maritime Transport	Tourism	Mining
Employment	Belgium	363	0	200	10682	1718	1052	6408	48
	Bulgaria	1554	132	0	5150	5414	657	107203	102
	Croatia	5673	1127	0	5292	12915	4127	130226	4670
	Cyprus	1216	310	0	1077	662	2264	28496	0
	Denmark	1440	141	670	4899	3684	19683	59863	2777
	Estonia	2067	2	0	3960	2705	876	35031	0
	Finland	1427	94	0	7982	9120	8990	23322	0
	France	13996	15627	0	57325	33613	12976	192548	393
	Germany	1631	85	0	90054	38802	21816	168274	365
	Greece	25452	3511	0	10644	7780	15761	324556	86
	Ireland	3494	1784	0	2547	753	705	36525	37
	Italy	27199	4212	0	35237	37189	37024	263151	8228
	Latvia	857	0	0	5671	2629	779	21230	0
	Lithuania	588	0	0	3905	4729	1339	5464	0.2
	Malta	1227	199	0	497	365	102	15743	0
	Netherlands	2058	263	309	30084	17623	10199	38346	1967
	Poland	2566	0	0	29125	23217	2170	44921	355
	Portugal	16464	2371	0	4287	4260	962	123920	122
	Romania	375	9	0	15541	24844	439	13830	5832
	Slovenia	111	27	0	2299	753	200	3033	116
	Spain	34527	20520	0	41178	24068	6849	596187	119
	Sweden	1627	63	0	3859	6961	13492	71553	0
	UK	12065	2357	1359	107110	43283	13832	240577	35119
GVA	Belgium	38.24	0	61.09	1668.88	118.93	547.99	289.51	6.61
	Bulgaria	3.37	5.90	0	86.16	63.37	17.36	631.82	19.37
	Croatia	26.71	19.13	0	122.86	171.60	135.57	2380.48	75.84
	Cyprus	1.45	10.86	0	81.95	27.91	59.69	760.87	0
	Denmark	267.18	11.85	260.65	549.80	261.35	2929.01	2614.96	4186.11
	Estonia	9.22	0.01	0	270.40	63.34	24.30	436.34	0
	Finland	15.97	4.76	0	576.20	455.91	648.49	904.18	0
	France	624.39	415.09	0	4417.94	2202.62	801.39	9083.24	31.41
	Germany	76.95	9.99	0	5142.24	2636.37	5763.81	4252.48	45.46
	Greece	5.42	125.80	0	505.94	226.45	841.58	5408.38	4.45
	Ireland	125.84	53.17	0	212.21	51.54	173.61	1151.28	2.84
	Italy	590.16	117.18	0	2033.47	1892.13	3275.24	8191.44	1452.96
	Latvia	9.50	0	0	190.41	31.80	9.46	221.16	0
	Lithuania	9.89	0	0	139.50	76.87	42.67	54.34	0.02
	Malta	5.33	11.31	0	34.66	9.30	0	319.86	0
	Netherlands	181.23	41.82	0	3823.51	957.82	1309.51	1059.09	2565.81
	Poland	25.99	0	0	649.90	573.40	132.83	633.20	14.36
	Portugal	238.95	44.51	0	326.82	121.82	53.93	2456.18	1.60
	Romania	1.72	-0.07	0	271.43	303.92	11.10	121.91	32.81
	Slovenia	1.90	1.95	0	128.59	24.43	10.71	71.36	3.48
	Spain	970.53	162.95	0	3234.28	1054.53	535.53	17818.74	17.25
	Sweden	68.10	1.03	0	313.36	418.16	666.13	2714.52	0
	UK	527.99	220.71	269.81	6413.44	2816.22	2824.69	7618.42	15550.25
GVA *per* employment (productivity)	Belgium	107007.55	0	706573.06	595377.27	516210.35	848495.06	140633.55	217921.80
	Bulgaria	7947.70	113662.36	0	68091.53	77401.04	36488.31	20660.44	358570.64
	Croatia	9704.26	27274.34	0	103060.53	135443.59	100942.11	55633.40	168490.85
	Cyprus	4800.29	47579.96	0	285686.91	68511.41	-5864.18	73338.54	0
	Denmark	269285.21	159722.65	904227.83	407340.12	581388.24	275952.80	145167.95	5531837.60
	Estonia	36283.08	11408.33	0	248029.41	175994.60	107231.87	47419.63	0
	Finland	71638.87	50104.94	0	308049.44	478951.28	161316.05	119798.28	0
	France	183912.06	98071.87	0	420315.24	555422.01	123986.98	150965.30	181985.63
	Germany	91855.68	122495.78	0	283395.78	503558.19	519843.42	81083.81	328846.93
	Greece	2391.51	50410.13	0	157436.03	258289.15	107196.90	51834.73	170718.41
	Ireland	68751.27	149872.39	0	302638.79	568067.33	502690.86	116947.45	71536.32
	Italy	90403.30	94547.81	0	238107.03	506666.97	210387.01	103498.31	3022596.47
	Latvia	24664.93	0	0	131104.51	97838.37	40218.73	36379.86	0
	Lithuania	42048.62	0	0	171568.96	134746.19	32936.41	31992.35	111666.67
	Malta	15139.42	53021.09	0	139699.27	27119.26	0	54482.59	0
	Netherlands	112146.29	235504.36	0	560383.61	166416.82	162036.50	136904.51	7467409.71
	Poland	24752.59	0	0	101127.54	165778.52	108461.90	42379.31	126408.33
	Portugal	70668.60	74842.68	0	274343.99	259744.35	102908.29	66065.95	13114.75
	Romania	15852.24	-1858.97	0	73270.01	87742.89	47282.89	26144.66	31013.86
	Slovenia	36950.80	127287.20	0	229606.74	199319.85	79831.94	87869.62	30218.17
	Spain	102644.76	44080.65	0	290940.30	416376.64	156350.15	98517.24	583872.11
	Sweden	96316.16	16192.24	0	292604.53	599176.13	112007.84	120119.71	0
	UK	84548.40	151980.26	584384.83	357696.16	587957.02	439053.77	121299.97	1801942.77

7.2.6. Non-normalized data of the adaptive capacity of ocean uses that correspond to maritime activities

Table S10| Non-normalized data for adaptive capacity representative variables, by country. Baseline data from World Bank, 2018 and UNDP, 2019. PPP - purchasing power parity.

Country	Income	Education		Health	Governance					
	GNI per capita (constant 2011 PPP international dollars)	Expected years of schooling	Mean Years of schooling	Life expectancy at birth	Voice and accountability	Political stability and absence of violence/terrorism	Government effectiveness	Regulatory quality	Rule of law	Control of corruption
Belgium	43,821.00	19.7	11.8	81.5	1.4	0.4	1.2	1.2	1.4	1.5
Bulgaria	19,646.00	14.8	11.8	74.9	0.3	0.4	0.3	0.6	0	-0.2
Croatia	23,061.00	15	11.4	78.3	0.5	0.8	0.5	0.4	0.3	0.1
Cyprus	33,100.00	14.7	12.1	80.8	1	0.5	0.9	1	0.8	0.6
Denmark	48,836.00	19.1	12.6	80.8	1.6	1	1.9	1.7	1.8	2.1
Estonia	30,379.00	16.1	13	78.6	1.2	0.6	1.2	1.6	1.2	1.5
Finland	41,779.00	19.3	12.4	81.7	1.6	0.9	2	1.8	2	2.2
France	40,511.00	15.5	11.4	82.5	1.2	0.1	1.5	1.2	1.4	1.3
Germany	46,946.00	17.1	14.1	81.2	1.4	0.6	1.6	1.7	1.6	1.9
Greece	24,909.00	17.3	10.5	82.1	0.9	0.1	0.3	0.3	0.2	-0.1
Ireland	55,660.00	18.8	12.5	82.1	1.3	1	1.4	1.6	1.5	1.5
Italy	36,141.00	16.2	10.2	83.4	1	0.3	0.4	0.7	0.2	0.2
Latvia	26,301.00	16	12.8	75.2	0.8	0.4	1	1.2	1	0.3
Lithuania	29,775.00	16.5	13	75.7	0.9	0.8	1.1	1.1	1	0.5
Malta	34,795.00	15.9	11.3	82.4	1.1	1.3	1	1.3	1.1	0.6
Netherlands	50,013.00	18	12.2	82.1	1.6	0.9	1.9	2	1.8	2
Poland	27,626.00	16.4	12.3	78.5	0.7	0.5	0.7	0.9	0.4	0.6
Portugal	27,935.00	16.3	9.2	81.9	1.2	1.1	1.2	0.9	1.1	0.8
Romania	23,906.00	14.3	11	75.9	0.5	0.1	-0.3	0.4	0.3	-0.1
Slovenia	32,143.00	17.4	12.3	81.2	1	0.9	1.1	0.7	1.1	0.9
Spain	35,041.00	17.9	9.8	83.4	1.1	0.3	1	0.9	1	0.6
Sweden	47,955.00	18.8	12.4	82.7	1.6	0.9	1.8	1.8	1.9	2.1
UK	39,507.00	17.4	13	81.2	1.4	0	1.3	1.8	1.6	1.8

7.2.7. Countries’ vulnerability profile

Figure S1| Ocean uses vulnerability by analysed countries. Vs – vulnerability based on employment; Ve – vulnerability based on GVA; Vp – vulnerability based on productivity; Vmc – marine conservation vulnerability.

Figure S1| (Continuation)

Figure S1| (Continuation)

Figure S1| (Continuation)

7.2.8. Countries MSP and BE vulnerability values and corresponding ranks

Table S11| Final data and rank of the analysed countries MSP vulnerability to climate change. Data is represented in an interval from 0 to 100, being 100 the maximum vulnerability score. Vs – MSP vulnerability based on employment, Ve – MSP vulnerability based on GVA, Vp – MSP vulnerability based on productivity.

Country	Vs [0-100]	Ve [0-100]	Vp [0-100]	Rank (Vs)	Rank (Ve)	Rank (Vp)
Belgium	52.74	52.32	85.95	17	13	3
Bulgaria	62.91	56.68	63.71	12	10	14
Croatia	65.96	56.59	62.50	8	12	16
Cyprus	54.00	50.23	59.56	15	14	18
Denmark	65.06	68.92	100	10	6	1
Estonia	54.07	49.85	59.51	14	15	19
Finland	52.67	48.28	66.51	19	19	12
France	81.81	81.71	82.95	4	2	5
Germany	74.04	72.92	75.32	5	5	7
Greece	73.58	59.69	63.64	6	8	15
Ireland	50.61	48.39	74.25	21	18	8
Italy	86.60	74.94	77.58	3	4	6
Latvia	47.40	43.64	49.15	23	22	23
Lithuania	49.17	45.23	52.04	22	21	21
Malta	51.70	42.91	49.69	20	23	22
Netherlands	65.57	59.76	83.61	9	7	4
Poland	56.21	48.02	52.56	13	20	20
Portugal	63.18	56.62	67.91	11	11	10
Romania	68.58	58.64	61.79	7	9	17
Slovenia	52.70	49.51	65.40	18	16	13
Spain	87.15	76.17	70.91	2	3	9
Sweden	53.58	48.96	66.97	16	17	11
UK	100	100	90.57	1	1	2

Table S12| Final data and rank of the analysed countries BE vulnerability to climate change. Data is represented in an interval from 0 to 100, being 100 the maximum vulnerability score. Vs – BE vulnerability based on employment, Ve – BE vulnerability based on GVA, Vp – BE vulnerability based on productivity.

Country	Vs [0-100]	Ve [0-100]	Vp [0-100]	Rank (Vs)	Rank (Ve)	Rank (Vp)
Belgium	44.49	44.56	82.17	21	13	3
Bulgaria	57.55	50.77	58.15	12	12	15
Croatia	61.49	51.05	57.16	8	10	16
Cyprus	48.31	44.37	54.44	14	14	18
Denmark	60.79	65.51	100	10	6	1
Estonia	47.35	42.96	53.41	16	18	19
Finland	47.01	42.37	62.54	18	19	12
France	76.78	77.00	77.53	4	2	5
Germany	68.66	67.73	69.67	6	5	8
Greece	71.01	55.25	59.09	5	7	14
Ireland	45.94	43.70	72.52	20	16	7
Italy	85.94	72.61	74.78	3	4	6
Latvia	40.02	36.19	42.01	23	23	23
Lithuania	41.42	37.42	44.70	22	21	21
Malta	46.08	36.37	43.64	19	22	22
Netherlands	61.12	54.75	81.16	9	8	4
Poland	49.88	40.91	45.59	13	20	20
Portugal	58.07	50.88	63.10	11	11	10
Romania	62.57	51.57	54.55	7	9	17
Slovenia	47.34	44.04	61.55	17	15	13
Spain	86.87	74.30	67.50	2	3	9
Sweden	48.01	43.09	63.00	15	17	11
UK	100	100	88.18	1	1	2

7.2.9. Limitations and constraints

Here, are placed the main limitations and constraints on the index that allows the calculation of the MSP and BE vulnerability of the analysed countries to climate change.

With regard to the exposure dimension, the different ocean uses used to calculate the MSP and BE vulnerability to climate change, were based on the economic uses used in the EU Blue Economy Reports of 2019 and 2020, as well as in the works developed on this theme, by Frazão Santos *et al*., see methodology (European Commission, 2019; European Commission, 2020c; Frazão-Santos *et al*., 2016; Frazão-Santos *et al*., 2018b; Frazão-Santos *et al*., 2018c). It should be noted that the ocean uses present in the EU Blue Economy reports and corresponding database are made up of numerous activities, and it was necessary to reflect on which activities to include in the index (European Commission, 2018; European Commission, 2019 European Commission, 2020c). It is recognized that such approach implies an over or undervaluation of certain used maritime sectors. It is important to remember, that in addition to the ocean uses present in these reports, there was also a concern to include the marine conservation use, see methodology. Considering all these assumptions, the exposure dimension ended up including 8 ocean uses and 31 corresponding activities, based only on the EU Blue Economy reports, see Table 2.4 (European Commission, 2019; European Commission, 2020c).

Firstly, the marine living resources sector, consisting of 13 activities and 3 sub-sectors (*i.e.* capture fisheries, aquaculture, and processing and distribution), has undergone major changes when considered in this study, see Table 2.4. For this project, it was considered the ocean uses fisheries and aquaculture separately, ending up excluding the processing and distribution of fish sub-sector from this study. This happens, because all the activities in this sub-sector end up including the resources from aquaculture and fishing together, and not independently, being impossible to distinguish in each activity, the importance given to each use. This is a clear limitation and may undervalue fisheries and aquaculture ocean uses, mainly because processing and distribution of fish is the sub-sector that employed more people in the marine living resources sector, although, this may be justified by the fact that they treat aquaculture and fisheries together. In addition, for the aquaculture use, freshwater aquaculture was not considered, giving that the aim of this study was to calculate the vulnerability in the marine environment. Still, it is recognized that by including shellfish aquaculture in the study, together with marine aquaculture, there may be an overvaluation of the ocean use due to the possibility that shellfish aquaculture may include inland production.

Looking at the marine renewable energy use, it should be noted that despite including all activities of this ocean use, the offshore wind energy sub-sector is the only one considered, see Table 2.4. This is related to the fact that renewable energy is an emerging sector, and for the moment, wind energy is the only sub-sector with information on its commercialization, thus excluding tidal or wave energy, leading to a possible undervaluation of ocean use (European Commission, 2019 European Commission, 2020c). About ports and shipbuilding, despite including all activities in the index, see Table 2.4, it is recognized that both are mostly coastal activities, leading to an overvaluation of the ocean use. However, due to the importance of ports in the global trade and in supporting other maritime sectors, and the relevance of shipbuilding for maritime transport, the decision fell on the inclusion of these sectors (European Commission, 2019; European Commission, 2020c).

Regarding the maritime transport sector, two activities and one sub-sector were excluded from the project scope, which could lead to an undervaluation of the ocean use, see Table 2.4. The exclusion of inland passenger and inland freight transport activities followed the same exclusion line from freshwater aquaculture activity, since they are activities that do not occur in the marine environment. The services for transport sub-sector, on the other hand, followed the contours of the exclusion of the processing and distribution of fish sub-sector, which despite being recognized as a limitation to the model, ended up not being included in the index for treating the sea and coastal transport, and inland transport together.

With regard to coastal tourism, as the name implies, it is mostly done at the coastal level and is treated in reports as a set of activities undertaken by a specific type of consumer, the tourist, being the sub-sectors accommodation, transport and other services (European Commission, 2019; European Commission, 2020c). Tourism includes beach-based tourism and recreational activities like swimming, sunbathing and coastal walks, mostly coastal activities, but also other activities such as wildlife watching, water-based activities, nautical sports and scuba-diving (European Commission, 2019; European Commission, 2020c). Being that said, although this sector has a strong coastal component, which will lead to an overvaluation of the sector, the demand for the report to calculate its maritime component and the fact that this sector is of enormous importance for the blue economy, which is one of the objects of this study, led to the inclusion of this ocean use in the index, see Table 2.4 (European Commission, 2019; European Commission, 2020c).

Marine conservation use, which is not recognized as an economic use in the EU Blue Economy reports, had as its only variables the MPA coverage and the Biodiversity OHI. The use of only these variables is recognized as a limitation, since it expresses only the presence of a place with legal means of preservation and conservation, as well as how successfully marine life is being maintained around Europe, and may not necessarily reflect the importance of marine conservation in the country, underestimating the role it may also have for others sectors. However, because the EU Blue Economy reports do not recognize marine conservation as an economic ocean use, there is no employment or GVA data for this use, necessary for calculating exposure based on employment, GVA and productivity, hence the use of the variables previously mentioned (European Commission, 2019; European Commission, 2020c). Another of the limitations is related to the fact that the databases from which the MPA Coverage and Biodiversity OHI was taken, considers only countries EEZ (UNEP-WCMC, 2020; OHI, 2020). This means that the territory beyond 200 nautical miles is not counted in this study. However, the choice to maintain the use of this database was based on two premises: that EEZs produce most of the ocean's goods and services used by man, and that many of the countries proposals that exist to extending the continental shelf beyond 200 nautical miles, has not yet been approved by the United Nations, as is the case with Portugal, Spain, United Kingdom and Ireland (Halpern *et al*., 2012; UN, 2020). In addition, with the United Nations Convention on the Law of the Sea, only the subsoil and resources resulted from it, beyond 200 nautical miles, can be explored, influencing the MSP processes present here (UNCLOS, 1982). It is also important to say that the territories recognized as not belonging to the European space were not counted in the database used, nor in this work, these being the overseas territories of France, UK and Netherlands, and Greenland and Faroe Islands for Denmark (UNEP-WCMC , 2020).

In order to calculate the exposure based on employment, GVA, and productivity of each ocean use, in each country, employment and GVA data from the European Commission's database on the Eu Blue Economy Reports 2019 and 2020 were used together with GVA *per* employment data, this calculated manually, see methodology (European Commission, 2018; European Commission, 2019; European Commission, 2020c). The choice of these variables fell on the fact that they are easy to obtain, because they are available national data, because they are easily compared between countries, and because they have socioeconomic importance (European Commission, 2019). However, some constraints may arise from the employment and GVA data of the different activities, which constitute the ocean uses of each analysed country. In the employment data, the constraint observed is related to the presence of jobs in the support activities for petroleum and natural gas extraction activity in Ireland, where there are no employment data for the petroleum and natural gas extraction activities. This lack of data in Ireland, whether in the extraction of petroleum, in the extraction of natural gas, or both, is justified in the EU Blue Economy reports by confidentiality problems that implied the lack of data for the oil and gas sub-sector, and consequently for the mining sector in the scope of this study (European Commission, 2019; European Commission, 2020c). For the GVA data, it was also possible to observe some constraints related to the lack of data, namely in the sectors of fisheries, renewable energy, shipbuilding, maritime transport and mining.

For fishing, the capture fisheries DWF activity in France, in 2018, has no employment data, however, it has GVA in that year. In the same activity, Poland has employment data from 2009 to 2018, but has no GVA for any of the years. The reason why these contractions occurred is not explained in both reports (European Commission, 2019; European Commission, 2020c). For marine renewable energy, in both activities (*i.e.* production of electricity and transmission of electricity), the Netherlands has employment data from 2009 to 2018, but not for GVA. The lack of GVA data for these activities in Netherlands is justified by the lack of data availability and confidentiality problems in both EU blue economy reports (European Commission, 2019; European Commission, 2020c). For Shipbuilding and repair, in the building of ships and floating structures activity, Malta ends up not presenting employment data from 2009 to 2018, despite having GVA data in the period 2009-2011. In addition, in the building of pleasure and sporting boats activity, Malta and Bulgaria present employment data from 2009 to 2018, but do not have GVA data for the same period. The constraints that led to the probable lack of data in these activities, are not explained in both reports (European Commission, 2019; European Commission, 2020c). Still in the shipbuilding and repair sector, Netherlands for the activities: repair and maintenance of ships and boats; manufacture of cordage, rope, twine and netting; manufacture of instruments for measuring, testing and navigation; manufacture of textiles other than apparel; manufacture of other fabricated metal products n.e.c.; manufacture of sport goods and, manufacture of engines and turbines, except aircraft presents employment data in the period from 2009 to 2018, which ends up not happening in GVA data, in the same period, for these activities. These constraints in GVA data for Netherlands, in this ocean use activities, are justified by the lack of data availability and confidentiality problems in both EU blue economy reports (European Commission, 2019; European Commission, 2020c). It is important to mention, that still in the manufacture of engines and turbines, except aircraft, the same problem happened in Latvia, however, there was no justification on the part of the reports for the lack of data (European Commission, 2019; European Commission, 2020c). As for the maritime transport sector, in the sea and coastal passenger transport activity, Latvia and Netherlands end up not presenting GVA data, when there are employment data from 2009 to 2018. In the sea and coastal freight transport, the same happens with Malta. However, only for Netherlands is lack of data associated with problems of data availability and confidentiality in both EU blue economy reports, while the other countries have no justification (European Commission, 2019; European Commission, 2020c). Finally, for mining, in the oil and natural gas extraction activity there are constraints for Romania where there is a lack of GVA data, despite the existence of employment data from 2009 to 2018. In support activities for other mining and quarrying, the same happens in Netherlands, but only for the year 2010. The justification is presented again, only for Netherlands by data availability and confidentiality problems in both EU blue economy reports (European Commission, 2019; European Commission, 2020c).

It should be noted that all these limitations and constraints related to the lack of data in some activities, whether they are justified or not, by the EU blue economy reports, ended up not being changed. Therefore, all data taken from the platform responsible for reports data was maintained in order to not influence the sample, recognizing only the limitations that this data omission may have in the final calculation of vulnerability (European Commission, 2018). In addition, it is also recognized that due to the problems of data availability and confidentiality, and due to the existence of emerging sectors, certain data on certain maritime activities are not included in this index, ending up under- or overvaluation a certain sector.

With regards to the sensitivity dimension, the obtained data were adapted from the work of Frazão-Santos *et al.*, having the need to calculate, within the scope of this project, the sensitivity to climate change of three specific sectors, see methodology (Frazão-Santos *et al*., 2016). The steps for calculating sensitivity were the same as Frazão-Santos *et al*, in order to minimize any influences (Frazão-Santos *et* *al*., 2016). However, the inherent subjectivity of the process, as well as the fact that data are global, due to the impossibility of ascertaining the sensitivity of each ocean use in each country, due to the lack of national data on sensitivity to climate change, ended up giving certain limitations to the model (Frazão-Santos *et al*., 2016).

Thus, during the development of this project, the main constraints and limitations regarding the different variables used are: the difficulty in deciding which activities to exclude from ocean uses because they are not relevant to the MSP; the lack of detail of certain countries employment and GVA data; the inability to correct or add the lack of data due to confidentiality problems; the possible non intentional exclusion of data on maritime activities due to problems of confidentiality or because they are emerging sectors, and the lack of national data on the sensitivity of ocean uses to climatic change. With the recognition of these problems, the future objective will be the need to develop mechanisms that allow a greater capacity to obtain the missing data and to encourage its sharing, always focusing on the most reliable calculation of MSP and BE vulnerability to climate change.

7.2.10. References of MSP and BE vulnerability supplementary materials

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