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Operational instrument based on indices to assess the marine sectors activities' direct impacts on the marine environment

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Operational instrument based on indices to assess the marine sectors activities' direct impacts on the marine environment (Work Package 5 - Activity 1)

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Abstract

This study develops a first attempt to build a theoretical index based on a set of indicators which have the potential to assess the cumulative impacts of human maritime activities on the Atlantic Area of the European Union. This research improves the exposure-effect approach followed by previous literature to assess the risk to marine ecosystem from human activities by incorporating, among others, the blue economy assessment (business indicator and other proxies) for each of the considered activities. The index will provide evidence how the different sectors size measured in through their contribution to the blue economy can impact ecological component to the ecosystem. The sensibility of the benthic habitat to the activities and their impact on the so-called ecosystem services (i.e. food provision, carbon regulation and cultural services) represent some of the linkages between the economic activities and the marine environment.

Keywords: Blue economy indicators; Ecosystem services, Human pressures, Atlantic Area

1 Description of the Work Package 5

The Blue Growth Agenda (BGA) has placed the importance of marine resources for economic development in its forefront. Most of the reports on blue growth have focused on the potential value added creation of the maritime sectors whose growth depends on healthy marine ecosystems. Following the implementation of the Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008), the European Union (EU) member states started to assess the environmental status of their marine waters.

The goal of the MSFD is to achieve Good Environmental Status (GES) of EU marine waters. The MSFD provides descriptors, associated criteria and indicators that include biological, physic-chemical and pressure indicators to interpret what GES means. However, and as highlighted by the

European Environment Agency, following the initial assessments under the MSFD, more effort is needed to improve the understanding of the linkages between marine economic activities and their pressures and impacts on marine environment. Following this sequence, the aim of this work package is to define a set of activity specific pressure indicators and, where appropriate, identify cross-sectoral pressures that, in addition to the state indicators, can be used to implement a sustainable management regime within EU marine waters.

The work of developing a common set of pressure indicators, that can be used in the whole Atlantic Arc, requires coherence, coordination and cooperation: It is the correct way to provide an inter-regional comparative analysis of the environmental impact of the blue economy across the Atlantic Arc.

Activity 1: Develop methods to assess the maritime sector's pressures on the marine environment

Action 1 determines the potential contribution of marine related activities (pressures) to changes in the marine environment. A literature review of pressure assessment models will be carried out and an interdisciplinary methodology will be proposed to assess the pressures generated by maritime sectors on the marine environment in the Atlantic Area. Information from Member State Initial Assessments under the MSFD will also be used to generate a matrix of pressures by sector and regions.

2 Introduction

The Blue Growth Agenda (BGA) has placed the importance of marine resources for economic development in its forefront. Most of the reports on Blue Growth have focused on the potential for value added creation of the maritime sectors whose growth depends on healthy marine ecosystems. Following the implementation of the Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008), the European Union (EU) member states started to assess the environmental status of their marine waters. The goal of the MSFD is to achieve Good Environmental Status (GES) of EU marine waters. The MSFD provides descriptors, associated criteria and biological and physical–chemical indicators to interpret what GES means. However, following the initial assessments under the MSFD, the European Environment Agency (EEA) has highlighted the need to improve our understanding of the linkages between marine economic activities and the pressures and impacts exerted on the marine environment.

This work package aims at making a modest contribution in this direction, by defining a set of activity specific pressure indicators and, where appropriate, identifying cross-sectoral pressures that, in addition to the state indicators, can be used to implement a sustainable management regime of EU marine waters. One of the main goals of the MOSES project is to implement an inter-regional comparative analysis of the environmental impact of the blue economy across the Atlantic Arc. In order to do that, we have to develop a common set of indicators that can be used in the whole Atlantic Arc, something that will definitely require coherence, coordination and cooperation among the partners in the consortium.

This first deliverable will be structured in four sections. After this brief introduction, Section 3 will provide an overview of the literature on pressure assessment models. Section 4 will describe the proposed methodology and the data required to assess the pressures generated by the maritime sectors on the marine environment in the Atlantic Arc. Finally, Section 5 will discuss the potential use and limitations of the methodology.

3 Literature (over) view

Much research effort has been devoted in the past few decades to determining and assessing the links between human activities and state-changes in marine and coastal ecosystems. Most of the studies (e.g. Halpern et al., 2008; Knights et al., 2013; Oberle and Schaal, 2011) follow the recommendation made in the early 1990s by international institutions such as the Organisation for Economic Co-operation and Development (OECD) and the EEA for describing these links between the so-called "Drivers, Pressures, State, Impact and Response (DPSIR)" conceptual framework. Gari et al. (2015), Lewison et al. (2016) and Patricio et al. (2016) provide comprehensive reviews of articles, reports and projects that apply this framework to coastal socio-ecological systems.

To appeal for a consistent agreement on the DPSIR terminology we follow Oesterwind, et al. (2016). We define:

Driver: A superior complex phenomena governing the direction of the ecosystem change, which could be both of human and nature origin. The term "superior complex phenomena" is used to put emphasis on the inescapability of drivers which are beyond direct control or management. Thereby the anthropogenic drivers are based on economic, social and political fundamental needs (demands) like food, health, clean water, employment, energy, reproduction or the wish for re-election.

Pressure: a driver-initiated mechanism (human activity/ natural process) causing an effect on any part of an ecosystem that may alter the environmental state.

State: the actual condition of the ecosystem and its components established in a certain area at a specific time frame, that can be quantitatively-qualitatively described based on physical (e.g. temperature, light), biological (e.g. genetic-, species-, community-, habitat-levels), and chemical (e.g. nitrogen level, atmospheric gas concentration) characteristic.

Impact: Consequence of environmental state change in terms of substantial environmental and/or socio-economic effects which can be both, positive or negative.

According to the DPSIR framework, there is a chain of causal links starting with "Drivers" (D) through "Pressures"(P) to "States"(S) and "Impacts" (I) and eventually leading to "Responses" (R). Through identifying this chain of causal links, the DPSIR framework has proved to be a useful and flexible tool for analysing complex interactions and transferring knowledge from science to management. However, as suggested by Oesterwind et al. (2016) and Scharin et al. (2016), there is high degree of variation in the interpretation of the different components, in particular, with the use of terms D and P, that may lead to confusion and pose difficulties for interdisciplinary collaboration and communication between natural and social sciences. Recently, Elliot et al. (2017) have advocated an extension of the DPSIR framework to DAPSI(W)R(M) in which (D)rivers of basic human needs require (A)ctivities which lead to (P)ressures. This extended structure of the causal chain fits much better the purpose of our analysis that tries to explicitly link economic (A)ctivities with (P)ressures. However, as noted by Elliot et al. (2017), confusion may also arise if we use interchangeably "activities" and "sectors" and we do not distinguish between (A)ctivities and (P)ressures. .

With regard to “activities” and “sectors”, it should be noted that the term “sector” is more ambiguous, as it encompasses different activities that result in different pressures. On top of that, we should also be careful when linking (A)ctivities with (P)ressures, given that when prevention, mitigation or compensation mechanisms are in place the same activity may result in a much more lower pressure.

Finally, it is worth mentioning in this overview an emerging branch of the literature that uses quantitative methods to map cumulative human impacts on marine ecosystems. Halpern et al. (2008) is a pioneering work developing an ecosystem-specific, multiscale spatial model of the world’s oceans to study the distribution and intensity of human activities and the overlap of their impacts on marine ecosystems. Subsequently, several studies have applied a similar approach to different marine and freshwater regions around the world to assess spatial patterns of cumulative impact (Crain et al., 2008; Halpern et al., 2009; Selkoe et al., 2009; Micheli et al., 2013; Allan et al., 2013), assess the location and intensity of change in cumulative impacts over time (Halpern et al., 2015) and to explore how cumulative impacts affect or relate to biodiversity conservation (Tittensor et al., 2010; Maxwell et al., 2013).

4 Methodology

Our objective is to define a index based on a set of indicators that will allow us to assess the linkages between marine economic activities and their associated pressures on marine ecosystem services. These indicators will serve to create a common ground to conduct an inter-regional comparative analysis for the environmental pressure exerted by the blue economy across the Atlantic Arc.

As it has been mentioned above, it is very important for a correct interpretation of the analysis to be conducted that we start by clarifying the terminology that will be used. Thus, and relating it to the D(A)PSI(W)R(M) framework described in Elliot et al. (2017), here we will focus on the A(ctivities)-(P)ressure link of the causal chain. We depart from a characterization of the maritime economy for the European Atlantic Periphery developed by the Marine Atlantic Regions Network (MARNET) project (EC, 2011) for which a wide range of business indicators, physical indicators (also referred to as proxies) and population and social data were collected for each industry by NACE (Nomenclature Generale des Activites Economiques dans les Communautes Europeennes) code. Here, some confusion of terms may arise from the fact that the above mentioned indicators are named as “activity” indicators, but they really refer to subsets or aggregate maritime “sectors” (see Appendix A). Besides, we should bear in mind that within these sectors (for instance, commercial fishing) there are many types of activity (for instance, trawling, long-lines, etc.) which each result in different Pressures. Our approach will thus be using indicators for sectors and “correct” their information with other simple measures of the presence of prevention, mitigation or compensation in order to have a link between the indicators of (A)ctivities and the associated (P)ressures. Under this study we consider the impact of activities on marine environment through the namely ecosystem services.

Once the underlying context is setted, the index was created by building a sector-pressure-ecological component linkage (namely impact chain in Knights et al. 2013). This index introduces some pressure assessment criteria and categories considering the ecological component in two ways: on the one hand, the sensibility of the benthic habitats to the maritime economic activities is introduced. On the other, the impact of these activities on the so-called marine ecosystem good and services.

Borja et al, 2015 developed an overview of the criteria used to classify marine goods and services which vary between authors, having changed over time. For example, Primack (1993) proposed classifying marine services into those that generate direct (e.g. production) and indirect values (e.g. climate regulation, existence value). For comparison, Pearce and Moran (1994) classified the value of environmental assets into use and non-use values (existence and bequest values, respectively). Use values have been classified into direct use values (e.g. food provision) and indirect use values (e.g. the bio-remediation of waste). These authors follow with the most recent classifications of marine services according to their function. For example, Daily (1997) identified in her classification the following marine ecosystem services or functions: the production of goods; regeneration processes; stabilizing processes; life-fulfilling functions; and the preservation of options. De Groot et al. (2002) classified ecosystem services according to the functions displayed by the system: production, regulatory, habitat, and information. Similarly, the Millennium Ecosystem Assessment (MEA, 2005) and Armstrong et al. (2012) classified ecosystem services into: provisioning (e.g. food, fuel, freshwater); regulatory (e.g. climate regulation, water purification); support (e.g. primary production, soil formation); and cultural (e.g. cognitive development, recreation). This work follows the MEA classification given that it provides the most widely-acknowledged reference framework. However, given the huge complexity of involving all the potential services, the study sets the emphasis on the following ecosystem services: provisioning services (food provision), cultural services (tourism and recreational services) and finally, regulatory services (carbon fluxes regulation and the carbon footprint from economic activities).

Our methodology for translating (A)ctivities to (P)ressure indicators is based on previous literature, Halpern et al. (2008). As described in the overview of the literature, Halpern et al. (2008) mapped human impacts on marine ecosystems combining impact weights (representing expert opinion on vulnerability of each ecosystem to each driver) with anthropogenic drivers of ecosystem change. In a similar vein, our method for translating (A)ctivities to (P)ressure on ecosystem services of the marine environment will combine a matrix of weights (representing the sign of the pressure exerted by the activity). These weights will take the -1, 0 or 1 values, where:

- 1 means that the economic activity adds pressure on the environment;
- -1 means that it relieves pressure;
- 0 means that the activity does not exert any effect.

To this end, we searched the literature in order to define those weights as the sign of the potential pressure of n blue economy activities on m ecosystem services. Then, for those $n \times m$ sector-ecosystem service pairs for which the weight is not 0, we define pressure indicators that are directly linked to the scale and qualitative aspects of the activity of economic sectors.

We define μ_{ik} as the weight of the pressure exerted by one activity (i) of the economic sector (j) on ecosystem service k. Kryvenko et. al. 2014 identified unmanageable pressures identified in previous works resulting in a list consistent with that being used in the ODEMM project (Koss et al., 2011). HELCOM 2010 also offers a list of relationship between MSFD pressures and economic activities. These two lists were combined to build the list of Appendix B. Helcom 2010 also provide useful outcome of the top 20 pressures over 14 ecosystem components according to an expert survey. These pressures will be later more detailed and linked to the ecosystem services (provisioning, regulating, supporting and cultural services).

- the dredged material produces smothering
- oil spills attached to maritime transport, or coastal industry introduce synthetic compounds
- aquaculture or passenger ships are responsible of introducing microbial pathogens
- Finally, commercial fisheries are linked to the extraction (selective or not) of species.

We also define A_{ik} as the economic activity indicator associated (directly or indirectly) to activity of sector j on ecosystem service k. A_{ik} also allows the transition from a specific sector j to its related economic activity (i) (see Table A of potential list of activities), related to each sector, j. Table 4 shows how to apply the general structure of A_{ik} for each sector, j or activity, i.

We can compute the aggregated pressure of economic activities on ecosystem service k (P_k) by region (r) as:

$$P_{k,r} = \sum_{i=1}^{n} \sum_{k=1}^{m} w_{ik} \mu_{ik} A_{ik}$$

where,

$$\sum_{i=1}^{n} \sum_{k=1}^{m} w_{ik} = 1$$

Note that, $P_{k,r}$ is a pressure generated by a regional activity, but that may affect beyond the region in which the activity is located. It represents a complex index which add the information of the different partial components.

w_{ik} is the weighted factor that allows the linear aggregation[1] of weighted pressure indicators ($\mu_{ik} A_{ik}$). It should be noted that μ_{ik} can be positive or negative. Therefore, to obtain the strong (compensations among pressures are not allowed,) version of it, we have to compute P_k for these positive and negative μ_{ik}, separately. Additionally, we note that for simplicity we can start using an equal weighted system for the different economic activity indicator associated to the sector j A_{ik} and later, when empirical evidence from stakeholders arrive to use that expert knowledge to change the weighted criteria. However, these A_{ik} have to be normalized (see for example, OECD (2008), for normalization techniques) across ecosystem services and regions (NUTS -related areas) at least if comparisons among different ecosystem services and countries/NUTS areas are to be made. Examples of normalisation techniques are now showed:

- Standardisation (or z-scores)
- Min - Max
- Distance to a reference
- Indicators above or below the mean

[1] An undesirable feature of additive aggregations is the implied full compensation, therefore in some cases it is better to use geometric aggregation or deprivation indexes

- Percentage of annual differences over consecutive years
- Categorical scale

This weighted factor w_{ik} can be also understood as a social factor that will be obtained differently according to the stakeholders´perceptions. Helcom, 2010 states thast varsios anthropogenic pressures are not directly comparable to each other because their impacts on the marine ecosystem have different spatial and temporal scales and, they affect different parts of the ecosystem. However, many scientific studies try to include many activities/pressures. This work, also produce an index which combine a set of key economic sectors, and therefore, pressures are combined. To do this, this study considers four different criteria to define the value of this social factor. Stakeholders evaluate the importance of each activity impact in relation to the rest of activities in a different way but all of them useful. This work shows the potential options by considering researchers, private sector stakeholders, and policy-makers, among others:

1. Researchers. Moses carried out a questionnaire among a group researchers to make an expert estimation of the main three sectors, that is, those sectors they consider to impact the most on the marine environment;
2. Maritime sector related stakeholders might provide different view than researchers or policy-makers.
3. Maritime sectors included in the blue growth strategy (or sectors included in the Atlantic strategy) can also be taken into account to enter into the index with a higher degree of impact.
4. Finally, a last criteria results from introducing all sectors with equal weight into the index. This is the equal weighting criteria (EW) to be used when the absence of an empirical basis exist, e.g. when there is insufficient knowledge.

Finally, this weighted factor can be modified by multiplying it by the inverse of the standard deviation of each of the components in $P_{k,r}$. It is important to minimize the influence over the index of those individual components with a high degree of volatility (Mondejar and Vargas-Vargas, 2008). Notice that, the sum of all the weighted factors multiplied by the inverse of their standard deviation should be equal to 1. We now can compute the aggregated pressure of the local economy on marine environment through ecosystem services as:

$$P_r = \sum_{k=1}^{k=K} P_{kr}$$

The final step on the index building process is to develop a sensitibity and uncertainty analysis. this composite index depends on a high number of choices as the choice of the aggregation model and the weights. In addition, the collected data related to the used indicators (business and proxies from MOSES WP4) might also represent a source of uncertainty. A sensitibity analysis will be performed to assesst the robustness of the index, how it depends upon the information fed to it.

4.1 Economic activity indicator associated

The general structure for A_{ik} to convert qualitative criteria and categories of gross economic magnitude into standardized numeric scores, was constructed by us based on the works of Knights et al.

(2013) and Robinson and Knights (2011):

$$A_{ik} = a_{ik} \times \% \text{ Area} \times (1 + \% \text{ Spatial Extent}) \times (1 + \% \text{ Frequency})$$

Thus, the criteria and categories used to build the index are based on the severity or degree of impact exerted by each activity (comprising the two first component of the equation), its frecuency and finally, the spatial extent. These all are now explained in detail. It is important to note that each criteria/component of the index is added and expected to be evaluated independently before combined into the aggregate index (score without unit).

- a_{ik} represents an economic indicator, different for each ecosystem service (k), that will be selected from the Moses WP4 framework. Notice, this terms is the way we use to link the blue economy assessment of each activity with the rest of physical and ecosystem-related variables. The index incorporates for the first time, according to the previous literature, the link between the economy and the most traditional disciplines. The objective of this conceptual framework is to define a classification system for maritime activities to make it possible to collect data meeting the aforementioned requirements of comparability and reliability, as well as accounting consistency and replicability (Kildow and McIlgorm, 2010). The conceptual framework used is based on the proposal of Kalaydjian et al. (2010), and it organises economic activities using the four-digit level NACE 3 classification of economic. Over the course of the last decade, many Member States have started to try to organise their industries in the sector in national clusters (Viederyte, 2013). In relation to this, in November 2005, European Network of Maritime Clusters (ENMC) was created, as a forum for regularly bringing together national clusters and coordinating efforts to promote the maritime sector. NACE (Nomenclature statistique des Activités économiques dans la Communauté Européenne) is the statistical classification of economic activities in the EU. The NACE four-digit classification assigns unique two, three and four-digit codes to each industry and it provides a framework for collecting and presenting a wide range of statistics by economic activity. The socio-economic weight of each of the activities was characterised using a series of indicators. These were selected for the entire European Atlantic Arc, under the framework of the Marnet project.

- **% Area** represents the percentage of the economic indicators value created within the studied area for which the synthetic index is being build. Consider, for example, the fishing sector for which the gross economic value includes the total fishing value related to the vessels with based-port in an area, even if part of their activity and related impacts are produced outside this area.

- **Spatial extent** assesses the economic activity overlap with the ecological components of the marine environment. The higher the spatial extent the higher the impact considered by the index (see Table 1).

The academic present different ways of dealing with the spatial extent. Remarkables are the works made by Knights et al. 2013 and Knights et. al. 2015. However, this work considers not only the extension in Km2, as those previous works, but it also introduces a way of measuring the senbility of the habitas to the different activities over the extension in Km2. With this aim, the study extends the

Table 1: Spatial extent

Extension in km2	Habitat sensitivity to economic activities	Numeric score (standardized value to 100 %)
Widespread	High	100 %
Widespread	Medium	90 %
Widespread	Low	80 %
Local	High	100 %
Local	Medium	70 %
Local	Low	60 %
Site	High	100 %
Site	Medium	50 %
Site	Low	40 %

Table 2: Frequency

Qualitative Value	Description	Numeric score (standardized value to 100 %)
Persistent	Where the economic activity pressure is introduced throughout the year	100 %
Common	Where the economic activity pressure is introduced in mainly 5 months of the year	70 %
Occasional	Where the economic activity is introduced in 3-4 months of the year	40 %
Rare	Where the economic activity is introduced in 1-2 months of the year	20 %

work made by Alkiza et al (2016) for the entire Atlantic Area, getting the sensibility of all the benthic habitat in the Atlantic Area to the different economic activities. A total number of 62 benthic habitats were mapped (updated to the 2019 data on the distribution of the habitat (EMODNET)). These two variables, the extension in Km2 and the sensibility are therefore merged into one variable, namely the spatial extent. Notice, the categories for the extension in Km2 of each activity is obtained thanks to the private sector stakeholder´s empirical knowledge.

- **Frequency** represents how often a pressure type and ecological characteristic interaction occurs measured in months per year and standardized to 100% (Table 2). Previous literature (Knights et al. 2013, Knights et. al. 2015) is considered when defining this varialbe but updated to also consider the stationary character of certain economic activities, which are usually developed across the whole year although with more emphasis through some specific months.

4.2 Generic indicators

GI_z represents the generic economic indicators, not related to any activity, but associated to the specific area A (see Table 3). K, represents the number of ecosystem services considered, z stands for the pressures not related to a particular economic activity of the area (e.g bathing sites extension) and Z are the number of these pressured indicators considered. General indicators, GI_z, are expressed in percentage terms sometimes obtained from other indicators, i, not entering in the equation (see Table 3). Notice that it is important to complement the developed index with an additional one for

Table 3: General indicators (GI_z) related to the coastal areas, policies, ...

Indicator	Description	Units
GI_1	Environmental taxes as a percentage of the inverse of GDP	%
GI_2	Number of households (multiplied by the average in each household) in coastal area extension as a percentage of the population density The higher the number the higher the pressure	%
GI_3	Public beaches extension in coastal area as a percentage of the coastal area extension	%
GI_4	Bathing sites extension in coastal area as a percentage of the coastal area extension	%
GI_5	Marine protected areas extent as percentage of the coastal area extension	%
GI_6	Average atmospheric tenperature as percentage of a baseline temperature	%
...	...	...
GI_Z	Average price per usable square meter of the housing units for sale in coastal (Euro) as a percentage of the inverse of the average price per usable square meter of the housing units for sale in non - coastal (Euro) The higher the number the higher the pressure	%

estimating the potential impact of regional drivers, not related to the economic activities operating the area, such as management or economic oriented drivers. Examples of these are showed in Table 3. The operational index shoud be understood under the context of a general index related to the region.

4.3 Operationalizing the economic activities pressures framework

The developed index is a tool for estimating the potential impacts of human pressures on the EU Atlantic marine environment. Its main aim is to provide overview of the sum of potential impacts through the ecosystem services. The index scores will be produced for the five countries in the Atlantic Area at NUTS 2 regional level. The index is calculated using R language.

4.3.1 Economic sectors (i) considered

The European Atlantic Arc is a wide geographical area stretching from the north to the south of Europe, principally connected by the Atlantic Ocean. This area is host to a wide range of maritime activities in both traditional (fisheries, aquaculture, tourism and maritime transportation) and emerging (renewable energy and marine biotechnology) sectors. Individually, European Atlantic Member States (Ireland, France, Portugal, Spain and the United Kingdom) have been active in all of these sectors and some of them have developed their own maritime strategies. The synthetic index is flexible enough to be applied to these sectors. In particular, this work is developed for the following six sectors and nineteen activities (see Table 4).These human activities cause multiple pressures on different components of the marine ecosystem as it is described in next paragraph.

1. Blue Biotechnology (NACE division 72, activity 72.11);
2. Marine aquaculture (NACE division 3, activity 3.11);
3. Tourism and recreation (NACE division 55 and 56; activities 55.10, 55.20, 55.30, 56.0, 56.30, 77.34, 93.11 and 93.29)
4. Blue Energy (NACE division 35, activity 35.11);
5. Water transport (NACE division 50, activities 50.10 and 50.20);
6. Marine fishing (NACE division 3, activity 3.21).

4.3.2 Ecosystem services (k) considered

We distinguish two big groups of ecosystem services (Liu et al, 2019): fundamental services (including regulatory and supporting services) which help to maintain ecosystem functioning and resilience, and demand-derived services including provisioning and cultural services derived from human values. This study uses this broad MEA classification together with the CICES Common International Classification of Ecosystem Services (CICES) V5.1 (Haines-Young, R. and M.B. Potschin, 2018). More specifically, when dealing with provisioning services we refer to food (fish) provisioning. Additionally, when reffering to cultural services we consider coastal and marine recreation and tourism. More specifically, the economic sectors´activity is linked to specific ecosystem services. Kryvenko et. al. 2014, Koss et al., 2011, HELCOM 2010 identify linkages between pressures on the marine environment and economic activities, which is important to identify which ecosystem services are directly linked with economic sectors 'activities. Marine fishing (NACE 3.11) through selective extraction of species stresses the food provision service, but also, the supporting (e.g. the food web, biodiversity) and the regulating (e.g. Impairs the fish stocks ability to recovery from diseases) services. The effects on the ecosystem from fishing differ by gear-type. Fishing with bottom contacting gears (trawls and dredges) affects production in the habitats while pelagic fishing gears affect marine mammals and sea birds (IFRO 2015). The influence of NACE 3.11 on cultural ecosystem services is also relevant. Again, it is necessary to distinguish commercial large-scale fishing from small-scale commercial and recreational fishing because their contribution to come of the cultural services differs – the touristic value of a small-scale fishery might differ distinctly from a full-scale industrialized fishery. However, this study introduces the NACE 3.11 sector without splitting in the different activities. Marine aquaculture (NACE 3.21), stresses the regulation services given that untreated wastewater laden with uneaten feed and fish faeces may contribute to nutrient pollution near coastal ponds and cages. Also, this sector produces habitat modification affecting the supporting services. Hundreds of thousands of hectares of mangroves and coastal wetlands have been transformed into milkfish and shrimp ponds. This transformation results in loss of essential ecosystem services generated by mangroves, including the provision of nursery habitat, coastal protection, flood control, sediment trapping and water treatment. Finally, this sector might also affect negatively cultural services (Naylor et al, 2000). Notice that, Recreational interests arise from yachts and pleasure boats, divers, snorkellers, windsurfers and swimmers and sports fishermen. All these activities require good water quality, windsurfers and swimmers and sports fishermen and large areas of uncluttered water surface. The effects of aquaculture can be deleterious to these by increasing turbidity through over-feeding and poor waste management. Aquaculture can conflict with yachting by causing navigational hazards (Deniz et al, 2001). Operation of gravel and sand pits; mining of clays and kaolin (NACE 8.12) produces changes in siltation affecting regulating service. Notice that, disposal of dredged spoils produces smothering (harmful algae blooms) but this activity is only related to dredging. Ships building (NACE 30.11 and 30.12), these activities might affect and produce changes of the coastline, loss/changes of the habitats and landscapes, loss of biodiversity (Gomoiu, 2001). Contamination by hazardous substances, CHS, (Introduction of synthetic compounds) is also linked to coastal industries. Heavy metals, at concentrations exceeding natural levels, can accumulate in the marine food web up to levels which are toxic to marine organisms. The main waterborne inputs of non-synthetic substances to the marine environment are from rivers, and from industrial wastewater and municipal wastewater either discharged directly or transported via rivers. Moreover, these sectors might impact positively on cultural ecosystem services if linked to a more traditional ship building industry. Energy production (NACE 35.11) is closely linked to the underwater noise which will affect the regulating and supporting services. Sea and coastal passenger water transport (NACE 50.10) and Sea and coastal freight water transport (NACE 50.20) impact the marine environment due to garbage pollution generated by ships. Ship-sourced food waste can reduce water and sediment quality, damage marine biota, increase turbidity and nutrient levels (Walker et al, 2017). Underwater noise and the introduction of synthetic components are also directly caused by ships. Of special relevance is the Introduction of synthetic compounds due to expected polluting ship accidents, oil slicks and spills. Regulating and supporting services are therefore affected. Hotels and similar accommodation and other tourism-related sectors (NACE 55.10, 55.20, 55.30, 56.10, 56.30, 77.34, 93.11, 93.29) impact positively on cultural services but no other impacts on marine environment services are identified except for the estimation of the carbon footprint impact. Finally, in addition to the previously described ecosystem services, we introduce for all economic sectors an impact on regulating services through the carbon footprint estimation by using the air emissions accounts variable

1. Provisioning services, food (fish) provision affected by selective extraction of species;
2. Regulating services affected by nutrient pollution, food control, water treatment; poor waste management of the water, underwater noise, among others.
3. Supporting services affected by habitat modification, biodiversity, changes in the food webs,...
4. Cultural services, in particular, recreation and tourism, affected both positively (linked to the more traditional activities and sectors) and negatively (due to increasing water turbidity,...).

Table 4: Indicators for the economic activities pressures framework

NACE Section	NACE Division	NACE Class	Description of each sector j and/or activity, i	Full (F) or Partial (P)	Sector j Activity i number	Ecosystem Service k	Weight μ_{jk}	Economic indicator	Logic and references
A	3	03.11	Marine Fishing	F	1	Food Prov. (1)	μ_{11}	A_{11} = **Production in value (turnover or added value)**	Selective extraction of species
						Regulatory (2)	μ_{12}	A_{12} = **Production in value, carbon footprint**	
						Supporting (3)	μ_{13}	A_{13} = **Production in value**	
						Cultural (4)	μ_{14}	A_{14} = **Jobs (persons employed or total equivalent employment)**	
		03.21	Marine Aquaculture	F	2	Food Prov. (1)	μ_{21}	A_{21} = **Production in value (turnover or added value)** Average price Aquaculture / Average price Fishing	
						Regulatory (2)	μ_{22}	$A_{22} = Productioninvalue, carbonfootprint$	stresses the regulation services given that untreated wastewater laden with uneaten feed and fish faeces may contribute to nutrient pollution near coastal ponds and cages
						Supporting (3)	μ_{23}	A_{23} = **Production in value**	
						Cultural (4)	μ_{24}	$A_{24=\text{Jobs} \times}$	This sector might also affect negatively cultural services (Naylor et al, 2000). Notice that, Recreational interests arise from yachts and pleasure boats, divers, snorkellers, windsurfers and swimmers and sports fishermen.
B	8	08.12	Operation of gravel and sand pits; mining of clays and kaolin	P	3	Food Prov. (1)	μ_{31}	–	
						Regulatory (2)	μ_{32}	A_{32} =Overall sand and gravel production value / Atlantic dredge areas, carbon footprint	Disposal of dredged spoils produce smothering (harmful algae blooms) but this activity is only related to dredging which produce changes in siltation
						Supporting (3)	μ_{33}	$A_{33} = Overallsandandgravelproductionvalue/Atlanticdredgeareas$	
						Cultural (4)	μ_{34}	–	
	9	09.90	Support activities for other mining and quarrying	P	4	Food Prov. (1)	μ_{41}	–	
						Regulatory (2)	μ_{42}	$A_{42} = carbonfootprint$	
						Supporting (3)	μ_{43}	A_{43} = **carbon footprint**	
						Cultural (4)	μ_{44}	–	
C	30	30.11	Building of ships and floating structures	F	5	Food Prov. (1)	μ_{51}	–	
						Regulatory (2)	μ_{52}	$A_{52} = productionvalue, andcarbonfootprint$	Contamination by hazardous substances, CHS, (Introduction of synthetic compounds) is also linked to coastal industries. Heavy metals, at concentrations exceeding natural levels, can accumulate in the marine food web up to levels which are toxic to marine organisms.
						Supporting (3)	μ_{53}	$A_{53} = productionvalue$	These activities might affect and produce changes of the coastline, loss/changes of the habitats and landscapes, loss of biodiversity (Gomoiu, 2001).
						Cultural (4)	μ_{54}	$A_{54} = Jobsorfulltotalequivalent$	
		30.12	Building of pleasure and sporting boats	F	6	Food Prov. (1)	μ_{61}	A_{61} = **Production** × CHS on fish × habitat extent	Contamination by hazardous substances, CHS, (Introduction of synthetic compounds) linked to coastal industries (HELCOM, 2010)
						Regulatory (2)	μ_{62}	$A_{62} = productionvalueandcarbonfootprint$	Contamination by hazardous substances, CHS, (Introduction of synthetic compounds) is also linked to coastal industries. Heavy metals, at concentrations exceeding natural levels, can accumulate in the marine food web up to levels which are toxic to marine organisms.
						Supporting (3)	μ_{63}	A_{63} = **Production value** × These activities might affect and produce changes of the coastline, loss/changes of the habitats and landscapes, loss of biodiversity (Gomoiu, 2001) × habitat extent	Contamination by hazardous substances, CHS, (Introduction of synthetic compounds) linked to coastal industries (HELCOM, 2010)
						Cultural (4)	μ_{64}	A_{64} = **Jobs or full time equivalent** × habitat extent	
D	35	35.11	Production of electricity	P	16	Food Prov. (1)	μ_{71}	A_{71}	
						Regulatory (2)	μ_{72}	$A_{72} = Installedcapacityofmarinerenewableenergy/typeoftechnology/AtlanticNUTS2$	closely linked to the underwater noise
						Supporting (3)	μ_{73}	$A_{73} = Installedcapacityofmarinerenewableenergy/typeoftechnology/AtlanticNUTS2$	closely linked to the underwater noise
						Cultural (4)	μ_{74}	A_{74}	
H	50	50.10	Sea and coastal passenger water transport	F	7	Food Prov. (1)	μ_{81}	A_{81}	
						Regulatory (2)	μ_{82}	$A_{82} = Overallpassengertraffic/mainAtlanticports, carbonfootprint$	impact the marine environment due to garbage pollution generated by ships. Ship-sourced food waste can reduce water and sediment quality, damage marine biota, increase turbidity and nutrient levels (Walker et al, 2017). Underwater noise and the introduction of synthetic components are also directly caused by ships.
						Supporting (3)	μ_{83}	$A_{83} = Overallpassengertraffic/mainAtlanticports$	impact the marine environment due to garbage pollution generated by ships. Ship-sourced food waste can reduce water and sediment quality, damage marine biota, increase turbidity and nutrient levels (Walker et al, 2017). Underwater noise and the introduction of synthetic components are also directly caused by ships.
						Cultural (4)	μ_{84}	$A_{84} = jobsorfulltimeequivalent$	
		50.20	Sea and coastal freight water transport	F	8	Food Prov. (1)	μ_{91}	A_{91}	
						Regulatory (2)	μ_{92}	$A_{92} = Overallgoodsthroughput/mainAtlanticports, carbonfootprint$	impact the marine environment due to garbage pollution generated by ships. Ship-sourced food waste can reduce water and sediment quality, damage marine biota, increase turbidity and nutrient levels (Walker et al, 2017). Underwater noise and the introduction of synthetic components are also directly caused by ships.
						Supporting (3)	μ_{93}	$A_{93} = Overallgoodsthroughput/mainAtlanticports$	impact the marine environment due to garbage pollution generated by ships. Ship-sourced food waste can reduce water and sediment quality, damage marine biota, increase turbidity and nutrient levels (Walker et al, 2017). Underwater noise and the introduction of synthetic components are also directly caused by ships.
						Cultural (4)	μ_{94}	$A_{94} = jobsorfulltimeequivalent$	
		50.30	Inland passenger water transport	F	9	Food Prov. (1)	μ_{101}	A_{101}	
						Regulatory (2)	μ_{102}	A_{102}	
						Supporting (3)	μ_{103}	A_{103}	
						Cultural (4)	μ_{104}	A_{104}	
		50.40	Inland freight water transport	F	10	Food Prov. (1)	μ_{111}	A_{111}	
						Regulatory (2)	μ_{112}	A_{112}	
						Supporting (3)	μ_{113}	A_{113}	
						Cultural (4)	μ_{114}	A_{114}	

Table 5: Indicators for WP 5 (Cont)

NACE Section	NACE Division	NACE Class	Description of each activity	Full (F) or Partial (P)	Activity number j	Ecosystem Service k	Weight μ_{jk}	Economic indicator A_{jk}	Logic and references
I	55	55.10	Hotels and similar accommodation	P	11	Food Prov. (1)	μ_{121}	A_{121}	
						Regulatory (2)	μ_{122}	$A_{122} = carbonfootprint$	
						Supporting (3)	μ_{123}	A_{123}	
						Cultural (4)	μ_{124}	$A_{124} = Numberofnights/AtlanticNUTS3$	impact positively on cultural services but no other impacts on marine environment services are identified except for the estimation of the carbon footprint impact.
		55.20	Holiday and other short-stay accommodation	P	12	Food Prov. (1)	μ_{131}	A_{131}	
						Regulatory (2)	μ_{132}	$A_{132} = carbonfootprint$	
						Supporting (3)	μ_{133}	A_{133}	
						Cultural (4)	μ_{134}	$A_{134} = Numberofnights/AtlanticNUTS3$	impact positively on cultural services but no other impacts on marine environment services are identified except for the estimation of the carbon footprint impact.
		55.30	Camping grounds recreational vehicle parks and trailer parks	P	13	Food Prov. (1)	μ_{141}	A_{141}	
						Regulatory (2)	μ_{142}	$A_{142} = carbonfootprint$	
						Supporting (3)	μ_{143}	A_{143}	
						Cultural (4)	μ_{144}	$A_{144} = Numberofnights/AtlanticNUTS3$	impact positively on cultural services but no other impacts on marine environment services are identified except for the estimation of the carbon footprint impact.
	56	56.10	Restaurants and mobile food service activities	P	14	Food Prov. (1)	μ_{151}	A_{151}	
						Regulatory (2)	μ_{152}	$A_{152} = carbonfootprint$	
						Supporting (3)	μ_{153}	A_{153}	
						Cultural (4)	μ_{154}	$A_{154} = Numberofestablishments/AtlanticNUTS3$	impact positively on cultural services but no other impacts on marine environment services are identified except for the estimation of the carbon footprint impact.
		56.30	Beverage serving activities	P	15	Food Prov. (1)	μ_{161}	A_{161}	
						Regulatory (2)	μ_{162}	$A_{162} = carbonfootprint$	
						Supporting (3)	μ_{163}	A_{163}	
						Cultural (4)	μ_{164}	$A_{164} = Numberofestablishments/AtlanticNUTS3$	impact positively on cultural services but no other impacts on marine environment services are identified except for the estimation of the carbon footprint impact.
N	77	77.34	Renting and leasing of water transport equipment	F	16	Food Prov. (1)	μ_{171}	A_{171}	
						Regulatory (2)	μ_{172}	$A_{172} = carbonfootprint$	
						Supporting (3)	μ_{173}	A_{173}	
						Cultural (4)	μ_{174}	$A_{174} = Numberofestablishments/AtlanticNUTS3$	
R	93	93.11	Operation of sports facilities	P	17	Food Prov. (1)	μ_{181}	A_{181}	
						Regulatory (2)	μ_{182}	$A_{182} = carbonfootprint$	
						Supporting (3)	μ_{183}	A_{183}	
						Cultural (4)	μ_{184}	$A_{184} = Numberofnauticalsportfacilities/AtlanticNUTS3$	
		93.29	Other amusement and recreation activities	P	18	Food Prov. (1)	μ_{191}	A_{191}	
						Regulatory (2)	μ_{192}	$A_{192} = carbonfootprint$	
						Supporting (3)	μ_{193}	A_{193}	
						Cultural (4)	μ_{194}	$A_{194} = Numberofmarinaberths,mooringsandashoreplaces/AtlanticNUTS3$	

5 Discussion

This index can be used as a tool to assiss in the blue growth governance of the Atlantic maritime affaires under the context of the Atlantic Strategy by providing a measure of the static impact assessment on marine environment for each sector. This work illustrates how this generic index can be used to assess human impacts through ecoystem services on marine environment considering a large number of sector and activities. Specific impacts could be differentiated within and between groupings (e.g. activity, ecosystem compontnent) allowing policy-makers and stakeholders getting knowledge and managing according to them. A significant benefit of the approach is that it can be appplied to link the sentitibity of the marine habitats together with the socio-economics.

However, the followed approach does not assure which is the degree of sustainability of the assessed impact, and therefore, it is also necesary to add additional criteria to stablish sustainability-thresholds/new criteria for each impact. For instance, it is key to split the 3.11 NACE sector (marine fishing) into specific activities because the different fishing technologies employed contribute in a different way to the sustainability of the activity.

Further development of the index is necesary to introduce cross-border interactions between sectors. For instance, e.g. the introduction of synthetic compounds attached to coastal industries affect food provisioning ecosystem service, provided by the 3.11 NACE activity marine fishing sector, due to the accumulation of these on fish. However, his study considers the 30.11 and 30.12 NACE activities, related to building of ships, only impact on intermediate ecosystem services (regulatory and supporting) but, not their impact on food provision linked to the (marine fishing). In a similar way, the potential impact of the 3.21 NACE activity, related to the aquaculture sector, on the food provision, again linked to the marine fishing sector, is not introduced as part of the index given that, it is not considered the potential impacts comming from market and management decisions about the production of the 3.11 NACE sector (marine fishing) as a result of the marine aquaculture growth. Those impacts are not residuals, as Naylor et. al. (2000) remark global production growth of farmed fish and shellfish doesn´t relieves pressure on ocean fisheries, but the opposite is true for some types of aquaculture which demand lare inputs of wild fish for feed.

Somer special risk factors also need further research, as por innstance, the accidental shipwrecks. Their impact on marine environment carry unintended consequences (Walker et. al. 2017). However, these accidental pressures mainly linked to the NACE 3.11, 50.10 and 50.20 activities are out of the scope of this index. The potential introduction of synthetic compounds due to expected polluting ship accidents, oil slicks and spills is to be considered under the impact on the regulating services.

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A Appendix A

A.1 List of activities, i related to each sector, j (Kryvenko et. al. 2014). (Just an example, not exhaustive)

Marine Fishing (NACE 3.11)

1. Benthic trawls and dredges - operations
2. Benthic trawls and dredges - mooring/anchoring
3. Benthic trawls and dredges - general
4. Nets (fixed/set/gillnets/other nets/lines) - set up/recovery
5. Nets (fixed/set/gillnets/other nets/lines) - operational
6. Nets (fixed/set/gillnets/other nets/lines) - general
7. Pelagic trawls - operations
8. Pelagic trawls - mooring/anchoring
9. Pelagic trawls - general
10. Potting/creeling - set up/recovery
11. Potting/creeling - operational
12. Potting/creeling - general
13. Suction/hydraulic dredges - operations
14. Suction/hydraulic dredges - mooring/anchoring
15. Suction/hydraulic dredges – general

Marine Aquaculture (NACE 3.21)

1. Fin-fish - set-up
2. Fin-fish - operational
3. Macro-algae - set-up
4. Macro-algae - operational
5. Shellfish - setup
6. Shellfish - operational

Renewable Energy, 35.11 and Construction of utility projects for electricity and communication 42.22

1. Renewable Energy Wind farms – construction - installation/deinstallation of turbines on seafloor
2. Wind farms - operational (active cables laying on seafloor, moving turbines)
3. Wave energy – construction, cable laying/removing
4. Wave energy - operational
5. Tidal sluices - construction
6. Tidal sluices - operational
7. Tidal barrages - construction
8. Tidal barrages - operational

Non-renewable Energy (oil, gas and hydro)

1. Oil and Gas -exploration/construction/deinstallation
2. Oil and Gas - operational
3. Hydro - operational
4. Power stations (land-based on coast) - construction
5. Power stations (land-based) - operational

Non-renewable Energy (Nuclear)

1. Power stations (land-based on coast) - construction
2. Power stations (land-based) - operational

Extraction of substrate

1. Maerl - spoil/waste disposal
2. Rock/Minerals - coastal quarrying - extraction of substrate
3. Rock/Minerals - coastal quarrying - spoil/waste disposal
4. Sand/gravel aggregates - extraction of substrate 8.12
5. Sand/gravel aggregates - spoil/waste disposal

Coastal Infrastructure, Artificial reefs - construction

1. Land-based Industry with discharges into rivers and coastal waters - operational
2. Artificial reefs - operational
3. Beach replenishment - operational
4. Culverting lagoons - construction
5. Culverting lagoons - operational
6. Marinas and dock/port facilities - construction
7. Marinas and dock/port facilities - operational
8. Land claim - construction
9. Land claim - operational
10. Coastal defence - Sea walls/breakwaters/groynes - construction
11. Coastal defence - Sea walls/breakwaters/groynes - operational

Tourism/Recreation

1. Boating/Yachting/Diving/Water sports - mooring/anchoring/beaching/launching
2. Boating/Yachting/Diving/Water sports - general
3. Public beach - general
4. Tourist Resort - construction
5. Tourist Resort - operational

B Appendix B

Physical loss

1. Smothering - By man-made structures, disposal of dredged spoils at sea, wind farms, bridges, oil platforms under constructions, cables and pipelines which are under construction.
2. Sealing/substratum loss - Sealing by permanent construction (coastal defences/wind turbines), change in substratum due to loss of key physical/biological features, replacement of natural substratum by another type (e.g. sand/gravel to mud).

Physical damage

3. Changes in siltation - Change in concentration of suspended solids in the water column (dredging, run - off of organic matter, dredging, coastal shipping, bathing sites, beaches and beach replenishment).

4. Abrasion - Physical interaction of human activities with the seafloor/seabed flora and fauna causing physical damage (e.g. commercial bottom-trawling fishery, dredging).

5. Selective extraction of non-living resources - Aggregate extraction/removal of surface substrata.

Other physical disturbance

6. Underwater noise-Shipping, acoustic surveys, coastal and offshore shipping, recreational boating and sports, operational wind farms, wind farms, bridges, oil platforms which are under constructions, oil rigs (operational).

7. Marine Litter-Litter.

8. Thermal regime changes - Temperature change (average, range, variability) due to thermal discharge (local). Nuclear power plants.

9. Salinity regime changes - Salinity change (average, range, variability) due to thermal constructions affecting water flow (at local scale). Bridges and coastal dams/ coastal wastewater treatment plants.

Contamination by hazardous substances

10. Introduction of Synthetic compounds - Pesticides, anti-fouling, pharmaceuticals, atmospheric deposition of dioxins, polluting ship accidents, oil slicks and spills, coastal industry, oil terminals, oil platforms and refineries, harbours, population density.

11. Introduction of non - synthetic compounds -Waterborne load of heavy metals, hydrocarbons, atmospheric deposition of metals.

12. Introduction of Radionuclides -discharges of radioactive substances.

Nutrient and organic matter enrichment

13. Nitrogen and Phosphorus enrichment - Input of nitrogen and phosphorus (e.g. fertiliser, sewage), aquaculture, atmospheric deposition of nitrogen, waterborne discharges of nitrogen, waterborne discharges of phosphorus.

14. Input of organic matter - Input of organic matter (industrial/sewage effluent, agricultural runoff, aquaculture, discards, etc.).

Introduction of non-indigenous species

15. Introduction of nonindigenous spp. and translocations -Through fishing activity/netting/aquaculture/ shipping.

Biological disturbance

16. Introduction of microbial pathogens - Aquaculture, coastal wastewater treatment plants, passenger ships outside 12nm.
17. Selective extraction of species - Removal and mortality of target (e.g. fishing) and non-target (e.g. by catch, cooling water intake) species.

Others not included in the MSFD

18. Death or injury by collision: Caused by impact with moving parts of a human activity (ships, propellers, wind turbines).
19. Barrier to species movement: Obstructions preventing natural movement of mobile species.
20. Barrages, causeways, wind turbines etc. along migration routes.
21. pH changes Change in pH (mean, variation, range) due to run-off/change in freshwater flow etc. (local).
22. Change in wave exposure Change in size, number, distribution and/or periodicity of waves along a coast due to man-made structures (local) or climate change (large scale).
23. Water flow rate changes: Change in currents (speed, direction, variability) due to man made structures (local).