Investigating the water, energy, marine land uses, food, climate interlinkages in marine environment

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Abstract The conflicts observed in the marine environment between the installation of renewable energy production, aquaculture activities and tourism, highlight the need for a more coherent management. To this end, maritime spatial planning is being developed at the cross-sectoral level, so that human activities at the ocean could be carried out in an efficient, safe and sustainable way. Along these lines, this paper is focusing on identifying the interlinkages between water, energy, marine land use, food and climate in the marine environment (Marine NEXUS). For the marine environment of Greece, an analysis of the interlinkages and the complex pathways are qualitatively analyzed based on their impacts on all aspects of the marine environment.

Keywords: Marine NEXUS, coastal and off-shore environment

1. Introduction

The marine and ocean environment is an important player in socio-economic development of Europe, as it supports many economic activities in coastal and off-shore regions. In the last decade, there has been a rapid technological progress in the development of coastal and marine activities, in short distance from the shoreline (Cariou et al., 2019). It is obvious that due to the finite resources of terrestrial land, there is a need to examine the maritime space in terms of the supply of goods such as food and energy, in a more sustainable way (Clement and McCullen, 2002). In addition, the need to mitigate greenhouse gas emissions (GHGs) resulted in the development of off-shore facilities for the exploitation of renewable energy sources (Currie and Wowk, 2009), food production and tourist attractions. As a result, the concept of Marine NEXUS is introduced in this paper, trying to determine the effects between the various elements of the marine environment as previously defined, under the influence of climate change in order to identify the pressures and the potential of marine natural resources for the development of a coastal community.

Similarly to the work of Levistona and Walkerb (2018) to identify interlinkages between ecosystems and human wellbeing, the analysis of Marine NEXUS interlinkages in this paper, attempts to correlate the impacts of each element variability to the others in the marine environment. The elements studying under the framework of climate change, are related to the characteristics of seawater, the uses taking place in marine space such as energy production and its relationship with the marine environment and production of food from the sea. The paper attempts to first identify and then to quantify those interdependencies between these element in the Greek marine territory. The aim is to determine the interdependencies and obtain data in relation to the maritime sectors in which special attention should be given, in the context of the development of maritime spatial planning policy. More specifically, to identify the hot-spots that are difficult to manage, but also the areas of the maritime space that relatively affect.

2. The Marine NEXUS

Climate change, seawater, energy, food, and marine land use are defined in this analysis as the five elements of the Marine NEXUS. Each element of the Marine NEXUS is connected and interact with each other through numerous interconnections. Laspidou et al (2019) had proposed a quantitate and qualitatively methodology to assess interlinkages among water-energy-food-land use and climate in the terrestrial environment. In this paper the approach proposed by Laspidou et al. (2019) was adapted to the marine environment.

A direct interconnection between two elements is defined as the influence that one element (eg climate) has on another (eg seawater), assuming that the rest (e.g. marine land use, energy, food) remain unaffected, as well as that they do not affect the state of direct interface variables. Symbolically, the direct interconnection of climate (C) and seawater (W) is represented by CW and includes all cases where a climate change may affect seawater in all its parameters. Accordingly, the WC represents the direct interlinkages of seawater and climate and in particular seawater changes that can directly affect the climate. Collectively, all direct interlinkages of the Marine NEXUS components are twenty and are listed below symbolically and schematically in Figure 1

It is important to note that each interlinkage is unique and has an opposite direction characterized by different link elements. The process of defining interlinkages is done through analyzes and reviews of the literature to ensure that all aspects are included.

In addition to the first-order interlinkages, the 5 elements under study can also be affected through indirect second-to-fourth-class interlinkages, depending on the number of elements that interact. More specifically, a second order interconnection between climate (C) and seawater (W) can be formed through energy (E), i.e. through the chain effect that climate change can have on the energy sector and then the influence that will have in the sea water.

Water	WL | WE | WF | WC
Land Use	LW | LE | LF | LC
Energy	EW | EL | EF | EC
Food	FW | FL | FE | FC
Climate	CW | CL |CE | CF

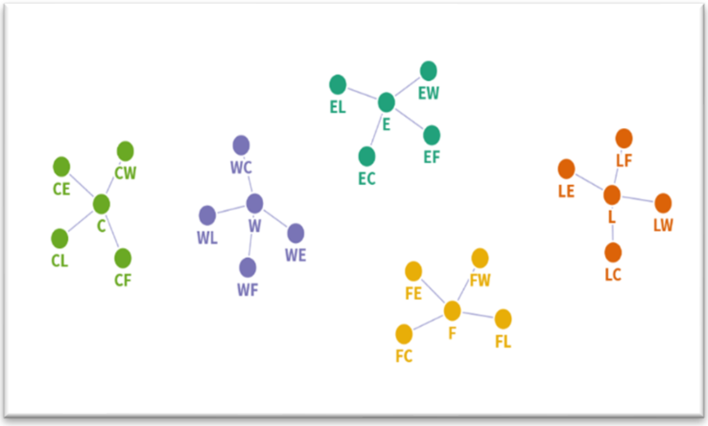

Figure 1. Schematic representation of the five marine NEXUS elements and their direct interlinkages

This interlinkage is denoted as CEW, while similarly, the CEFW and CELFW interlinkages are the third and fourth order respectively. All intermediate connections (such as CE in CELFW, EL in CELFW, LF in CELFW and FW in CELFW) are direct. In order to identify all indirect interconnections between two elements, e.g. climate (C) and seawater (W), all classes of interlinkages starting from C and ending in W are progressively constructed, resulting in all possible combinations (Figure 2).

C → W	=	CW	+										
		CLW	+	CEW	+	CFW	+						
		CLEW	+	CLFW	+	CELW	+	CEFW	+	CFLW	+	CFEW	
		CLFEW	+	CLEFW	+	CFLEW	+	CFELW	+	CELFW	+	CEFLW	

Figure 2. Detailed description of interconnections between climate (C) and seawater (W)

These "routes", direct and indirect, represent the various ways that climate can affect seawater. Therefore, the total impact of climate change on seawater will be the sum of the direct and all indirect interconnections as they emerged (Figure 3). It should be noted that some high-end interlinkages will be rejected, as internal direct interfaces will be considered negligible

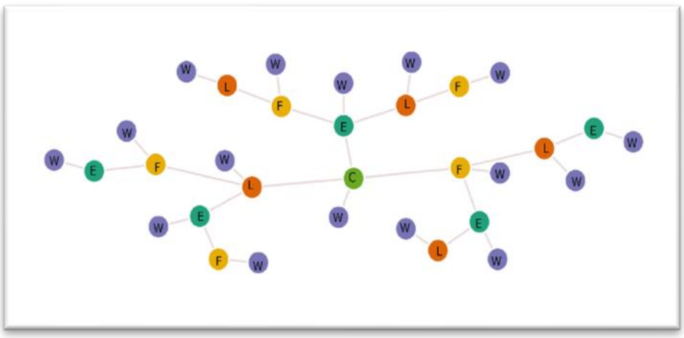

Figure 3. Tree diagram representing the Climate to Seawater interconnection

3. Preliminary Analysis

In order to model the Marine NEXUS interlinkages, a first-class classification system was developed. The aim was to classify the direct correlations of the Marina NEXUS elements, in order to create an initial assessment of each interlinkages in the Greek marine territory. This initial assessment was based on maintaining simplicity, without the need to make many assumptions and introduce uncertainty, based on information obtained from the literature. A three-point typology was used to evaluate the intensity of the interlinkages, where all first-class interfaces were described as "strong", "weak" or "negligible" (Laspidou et al, 2019). In Table 1, the physical interpretation of all marine NEXUS direct interlinkages are listed with a corresponding rating as "strong", "weak" and "negligible" influence. The resulting direct interfaces and their characterization are shown schematically in Figure 4.

Direct Interlinkage	Score	Physical Interpretation of Marine NEXUS interlinkages
WL	Strong	Changes in sea water quantity or quality, or even in topogragraphy of the seabed will affect direct the sea uses that can be developed. The characteristics of seawater are a primary evaluation factor for the development of various sea uses.
WE	Weak	A change in the characteristics of the sea water and the topograchy of the seabed can affect exploitation of energy sources in the marine area. In Greece, the utilization of marine energy sources is underdeveloped.
WF	Strong	The seawater is the living environment for all sea organisms, so the minimum change in the environment will affect their growth.
WC	Negligible	Seawater does not have a direct effect on greenhouse gas emissions.
LW	Strong	Marine land uses, including aquaculture areas and maritime transport routes, have an affect on changing the composition of seawater.
LE	Strong	A change in marine land uses can impact energy through the hydrocarbon mining facilities and renewable energy infrastructure.
LF	Strong	Marine space is critical for food production including aquaculture and fishery. Sites for marine species protection and Protected Areas in general are important for ensuring biodiversity.
LC	Strong	Marine spatial planning to define area for energy production by RES contributes to the reduction of greenhouse gas emissions.
EW	Weak	Marine power infrastructure changes the characteristics of sea water. The interconnection is considered as "weak" because it is an underdeveloped industry in Greece.
EL	Weak	The energy potential of the sites determines the marine land uses.
EF	Strong	Marine power infrastructure has an impact on marine habitats.
EC	Strong	Changes in energy production and consumption directly affect greenhouse gas emissions.
FW	Strong	The minimum change in the field of marine living beings will strongly affect seawater, as it is the place of their development.
FL	Strong	Food production defines the marine uses such as aquaculture or fishery areas
FE	Weak	Changes in marine biodiversity and food regime will change the amount of energy required for production and consumption, and will also affect the biofuel sector from marine stems.
FC	Negligible	The seafood sector has a direct influence on the climate only during the collection and processing of food, which is negligible compared to other interlinkages.
CW	Strong	Temperature, extreme weather events and changing seasonal patterns affect sea levels and alter water quality.
CL	Weak	Climatic conditions determine the allocation of marine uses. The overall influence is considered weak compared to others.
CE	Weak	Climatic conditions regulate the production of energy from renewable sources.
CF	Weak	Wave potential and weather fluctuations determine food regime in the sea. The overall influence is considered weak relative to others.

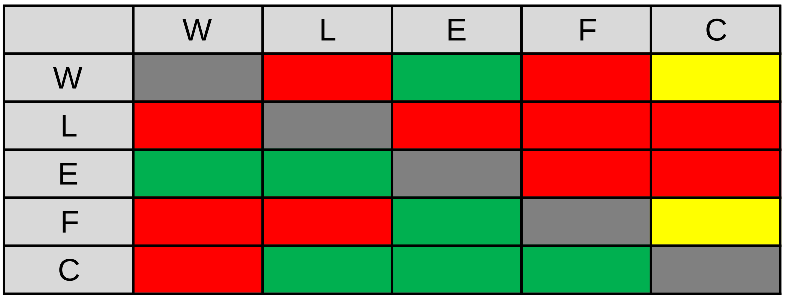

Figure 4 Schematic representation of various interlinkages between the five elements of Marine NEXUS. Green represents a "weak" interlinkage, red a "strong" and yellow a "negligible". The influential NEXUS element appear in the row and the affected one in the column

4. Conclusions

Based on the literature all possible direct interlinkages between the five elements of Marine NEXUS, namely seawater (W), marine land use in the sea (L), energy (E), food (F) and climate (C) -twenty in total- were investigated and their interactions were developed focusing on the cause and the influence on the elements' parameters. An interlinkage is direct or indirect, depending on whether a change to one element of the Marine NEXUS causes a change to another directly or through a third element or through several. A conceptual methodological approach is proposed for the quantification of the effects between the 5 basic elements, water-energy-marine land use-food-climate, effecting the marine environment of Greece. At the same time, the strong importance of each element and its role, which is inseparable from the overall environment and crucial for any policy intervention, is highlighted. The aim of this analysis is to determine the interdependencies, to obtain data in relation to the maritime sectors in which special attention should be given, in the context of the development of maritime spatial policy.

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