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Research article

Exploring multi-use platforms: A literature review of marine, multifunctional, modular, and mobile applications (M4s)

Maria Xylia [*], Marlon Vieira Passos, Tommaso Piseddu, Karina Barquet

Stockholm Environment Institute, Linnégatan 87D, 104 51 Stockholm, Sweden

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ABSTRACT

Multi-purpose offshore infrastructure, integrated with various user functions within the same space, is increasingly hailed as a way to address issues arising from multiple demands placed on coasts and seas. In this paper, we review how recent literature addresses the conditions enabling marine-multifunctional-modular-mobile (M4) solutions' contribution to a sustainable transition in the provision of critical services on islands and along coastlines. We are particularly interested in understanding the synergies and the most common themes surrounding their deployment as analyzed in previous research. We find that mobility and modularity have been less researched compared to multifunctionality of marine applications, despite the benefits these could have in decreasing operation costs and improving resiliency in coastal environments. With multifunctionality, wave-wind is the most common combination of services, followed by wind-aquaculture and wave-aquaculture. However, so far, the literature has mostly focused on European marine applications of this kind, so there need to be explorations of other methodologies that capture other regions, as well as explorations of nonscientific literature. We recommend more detailed evaluations of impacts, benefits, drawbacks, and institutional frameworks needed for realizing mobile and modular multifunctional applications in marine environments.

1. Introduction

As use of ocean space intensifies and new ocean areas become available, new industry sectors are moving offshore, and new structures are being developed to accommodate them, including energy, water, sanitation, and even aquaculture operations. The marine environment has high development potential for crowded areas. The intensification of economic activity in seas creates new conditions in terms of logistics, operations, governance, and financial arrangements. Multi-purpose offshore infrastructure is increasingly hailed as a way to address the issues arising from multiple demands being placed on coasts and seas [1], because it can meet growing demands by integrating various user functions within the same space.

Combining technologies for delivering several critical services through a common physical structure is nothing new, per se. Many of today's water infrastructures provide multiple services. Worldwide, there are more than 8000 large water systems that are multi-purpose by design, plus a significant number of systems operated as multi-purpose that were designed for single-purpose use [2].

Offshore multifunctional floating solutions are increasingly highlighted as viable options for providing services [3,4] while making resource use more effective, decreasing economic risks for investors, and avoiding potential conflict over land disputes, as they are perceived as less intrusive to existing socioeconomic activity. The best-known example of these are multi-purpose platforms (MPPs),

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* Corresponding author.
E-mail address: maria.xylia@sei.org (M. Xylia).

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also called multi-use platforms (MUPs), which are offshore platforms serving the needs of multiple offshore industries (e.g., energy and aquaculture). These platforms exploit the synergies and manage the tensions when systems from these industries are closely collocated [5].

Many of today's technologies powering desalination plants, or turning waste into energy, or turning wastewater into potable water, are cleaner, more affordable, and more modular than before. Since many islands have no room for the expansion of utilities necessary for providing water and electricity to their growing populations, and their existing utility networks are not resilient to the many environmental and demographic fluctuations islands face today, new flexible solutions are needed. Beyond the specific use case of spatial efficiency for islands, there is potential for reducing operating and capital costs (OPEX – operational expenditure and CAPEX – capital expenditure) by maintaining common infrastructure or reducing material costs, motivating the application of multi-use solutions in a variety of contexts.

However, there are several challenges with MUPs. Many MUPs remain fixed structures, connecting activities either through co-located systems, combined structures, or island structures [6]. The governance issues that arise when permanently combining operations from different industrial sectors could contribute to uncertainty and potentially slow implementation, creating a need to align laws, regulations, and policies across sectors [7]. More importantly, fixed infrastructures are not well suited to dealing with the varying demands in water or energy consumption resulting from seasonal tourism or semipermanent settlement, for example. Innovations in design, size, and cost present opportunities for more agility and flexibility in providing critical services, potentially remaining more responsive to challenging infrastructural contexts, changing socioeconomic conditions, and climatic uncertainty.

By contrast, if multifunctional infrastructures were made more modular or mobile by design, coping with climatic challenges, infrastructural constraints, and demographic fluctuations could become easier, avoiding some of the challenges that single-use offshore technologies already face, such as the forecast for massive development of offshore infrastructures increasing pressures on the anthropogenic exploitation of the ocean. Administratively, packaging multi-purpose infrastructure into floating containers can boost the benefits of project bundling as a strategic program delivery solution. Project bundling is the awarding of a single contract for the preservation, rehabilitation, or replacement of multiple projects. Contracts may be procured in several different ways and may include both design and construction in the overall scope, depending on the procurement method [8].

Based on these noted benefits, we hypothesized that the combination of what we refer to as marine-multifunctional-modular-mobile (M4) solutions could reduce installation and real estate costs, eliminate impacts on waterfront property, minimize impacts on ecosystems, and reduce time spent processing permits and licenses compared with shore installation. Offshore solutions can provide redundancy in existing infrastructure or become the main source of energy or water in, for example, industrial operations, since they can be connected to the grid or remain off-grid.

In this paper, we explore the extent to which literature has addressed M4 solutions for the sustainable provision of critical services on islands and along coastlines (including continental nations' coastlines). In particular, we wanted to understand the solutions discussed in research and the synergies and most common themes surrounding their deployment. While previous studies reviewed concepts and analyzed projects related to MUPs, there are fewer studies that classify the different technologies and services in a systematic way. Here we propose the M-degrees (marine, multifunctional, modular, mobile) to understand the current state of this research field and to offer insights for directing future research. More specifically, we aim to answer the following questions:

- How are the different types of M4s defined?
- What are their characteristics (types of technologies deployed and geography)?
- What technologies are most often discussed in literature, what are the most prevalent technology combinations, and what can be inferred from these combinations?
- What are the most common themes raised in the literature, and how do they shift depending on M-degree combinations (marine and multifunctional, modular, and mobile)?

Addressing those questions gives us a more nuanced understanding of the most influential system components of innovative offshore deployment around the world. Our review of the literature offers insights into high-potential applications and synergies; the institutional, business, technical, and legal gaps; and the geographical relevance of M4 solutions, depending on local circumstances.

In the following sections, we discuss the methods applied for this study (Section 2), presenting the necessary definitions and study limitations. Section 3 details the results, with a focus on analyzing technology synergies and the main emerging deployment themes. In Section 4, we reflect on the results, and we present our overarching conclusions and recommendations in Section 5.

2. Method

We combined methods for reviewing how M4s have been addressed in literature so far. First, we applied systematic literature review methods to screen, classify, and analyze recent research in the field. Then we applied data visualization and keyword text-mining techniques with the reviewed articles as our data input to showcase research trends, common technology synergies, and aspects not covered in the current literature. This way, we could look back at the areas already researched in the literature, and also identify key areas in need of more research to better assess the benefits and tradeoffs of M4s.

2.1. Conceptual definitions, scope, and limitations of the research

M4s are systems that present four characteristics – marine, multifunctionality, modularity, and mobility – to different extents. We reviewed both peer-reviewed publications and “gray” literature to gather insights from previous research on these four system characteristics. Our study scope included only marine technologies, which was a constant and equal characteristic across all reviewed papers.

We adopted specific definitions based on previous research to objectively classify the literature, as follows:

- **Marine technologies**: The European Association of Universities in Marine Technology (WEGEMT) defines marine technology as “technologies for the safe use, exploitation, protection of, and intervention in, the marine environment.” It may involve naval architecture, marine engineering, ship design, ship building and ship operations; oil and gas exploration, exploitation, and production; hydrodynamics; navigation; sea-surface and sub-surface support; underwater technology and engineering; marine resources (both renewable and nonrenewable); transport logistics and economics; inland, coastal, short-sea and deep-sea shipping; protection of the marine environment; leisure and safety [9].
- **Multifunctionality:** We defined multifunctionality as the simultaneous provision of multiple functions by clustering two or more services using the same structure, resource, or location [10,11]. It integrates sharing and use of marine resources and space by single or multiple users, which differs from the concept of exclusive resource rights [12]. Alternative terms for multifunctionality include multi-use and multi-purpose. Multifunctionality can be classified as co-located, combined/hybrid, or island structures [6].
- **Mobility:** In the offshore space, mobility refers to floating platforms (as opposed to fixed-bottom platforms) that can adjust to environmental forces (e.g., waves and winds) and therefore can resist lateral forces, mitigating their effects [13]. Mobile structures can be relocated at relatively low cost. Examples of mobile solutions include self-propelled ships and barges, as well as floating offshore wind farms. Mobile structures are flexible, versatile, and less intrusive than permanent ones [14,15]. Mobile offshore platforms have been classified as active mobile assets (ships), passive mobile assets (floats), stationary assets (moorings), and shore-mounted assets [16].
- **Modularity:** Defined as the division of a system into independent components [17,18], modularity is a design approach involving a central unit that connects satellite units or modules. Individual modules have their own foundations, moorings, or floating structures and can provide the same functions for a particular service (e.g., wind power) or can provide different functions from different sectors [17,18]. Elements of modularity include redundancy and interchangeability when providing the same function, and autonomy when providing multiple services [19].

One of the study’s limitations is the assumption of the M4s as the classification framework. As with all similar systems, classifications are subjective, based on previous research. Though alternative classifications for MUPs at sea exist in previous research [6,12,20] and may offer new insights. It is thus not possible to identify an optimal classification system since what is optimal is relative to each study’s context and scope.

Our classification system, defined using the four “M″s, created some limitations in keyword extraction. For example, there could be publications that address mobile or modular solutions but never explicitly mention the words “mobile” or “modular” in the text. If the keywords that suggest the presence of one or more of the characteristics of the M4 applications are deemed relevant by the model, these words are assigned a high score and become proxies for one of the features of M4s: a “ship,” if such a word is found to be relevant, can of course be interpreted as an example of a mobile solution, even if the term “mobile” does not appear in the text.

Language bias is another limitation of such literature reviews. We limited our reviews to English-only literature, which likely skewed the regional representation. Previous research has concluded that non-English publications often fall outside the parameters of systematic reviews [21].

Another limitation of text-mining methods is how hyphenated words are treated when a hyphenated word is broken into two individual terms. This was not a problem in our application, as the hyphen is found in almost every occurrence of the terms “multi-use” and “multi-purpose.” These two expressions have the same meaning, even when broken into “multi” and “use” and “multi” and “purpose” and still indicate a multi-purpose or a multi-use feature of the application. These words are still taken into consideration by the model, with or without the hyphen.

Since we reviewed only peer-reviewed publications and gray literature, there is a chance that publications of interest have not been included in our analysis that are not peer reviewed, e.g., websites or newspaper articles. We recommend including these types of publications in future reviews for better regional representation and more up-to-date insights into the latest trends in M4 testing and deployment.

Finally, addressing the broad theme of marine platforms and multi-use applications in this review means that several different technologies and combinations of solutions are documented. The variety of characteristics and combinations makes in-depth cross-solution comparisons not possible. In this paper we focus on the development of a classification framework giving the opportunity to discuss emerging themes in the complex area of multi-use. More detailed evaluation would require subsequent development of applicable evaluation frameworks, potentially focusing on specific aspects of the M4s or specific technology combinations.

2.2. Literature review

We took a systematic approach in reviewing and mapping method principles [22,23], which took less time and required fewer resources than a full systematic review but captured some systematic review advantages, including “a low risk of bias; repeatability and increased procedural objectivity; consistency; comprehensiveness; and transparency” [24]. The review process steps are presented in Fig. 1.

We identified some initial sources on the topic of interest through online prescreening that we then used as the starting point and preparatory stage for the literature-database screening. In this prescreening, we reviewed eight papers that provided an initial understanding of the predefined keywords and criteria that should be used for the database search and comprehensive review, respectively. Some of these sources were published prior to 2016, and others, after 2021 (see Fig. 2).

The review protocol specified the study's aim, scope, and research questions as presented in Section 1, leading to the following search string in the Web of Science (WoS) database:

Search string: ((((ALL = energ*) AND ALL=(off$shore OR marine OR aquaculture) AND ALL=(multi$purpose OR multi$use OR multi$mod* OR platform OR mobil*) AND (LIMIT-TO (LANGUAGE, "English"))))

The search was limited to the following basic conditions:

- the search period was set for 2016–2021 (research published in the last five years)
- the research had to be within a research field related to the scope of the study
- the language had to be English.

The search yielded 3156 documents, whose titles and abstracts we extracted and uploaded to Rayyan, the online tool for screening and crosschecking [25]. We entered the same search query into Scopus, which yielded 1958 results, so we focused only on the results from WoS. We used a predefined coding structure in Excel with the parameters listed in Appendix Table 1 for the subsequent coding of the documents.

One researcher performed the prescreening and screening stages, and four researchers did the coding, checking the selected articles individually and then crosschecking findings with the rest of the team. The synthesis of results addresses the research questions as defined in Section 1. At the next stage, after analyzing the database query results, we reviewed additional articles and gray literature. For a schematic of the process see Fig. 3. A full list of the reviewed literature can be found in Appendix Table 2.

2.3. *Analysis*

2.3.1. *Scoring, classification, and visual data analysis*

We scored the coded literature with the aim of getting a relative classification degree in terms of how many of the M4s are discussed. One point was given for each characteristic discussed per article (marine, multifunctional, modular, mobile). Thus, articles were scored in terms of how many M4s they addressed. All articles discussed marine solutions, so the minimum score was 1, and the maximum score was 4, when all aspects were discussed. The relationship between the "M″s, and the result scores is neither quantitative nor ordinal. The conceptual definition of the classification scheme is illustrated in Fig. 4.

We visually summarized the results from the article reviews in terms of their M-degree classifications and geographic focus. And we visually explored the linkages between various technologies discussed in the literature, i.e., the types of technologies that are discussed together in a given article. This gave us an overview of the most prominent correlations.

2.3.2. *Keyword extraction*

Extracting keywords from paper abstracts is a useful tool in understanding the relevant topics discussed in the literature. Much like the lists of keywords that accompany scientific publications, the extraction of key terms from a paper's abstract helps determine whether the paper goes deeper into the topic, beyond the title. In our research, keyword extraction had to allow for identification of the themes and the points of interest that previous literature has raised around M4 solutions.

Computational improvements and new developments in the field of artificial intelligence (AI) and machine learning (ML) have made these applications more popular in recent years. Term frequency – inverse document frequency (TF-IDF) [27] is a computational methodology that allows for the extraction of relevant terms by accounting for discrimination, the power of each term to mark the difference between treated themes, popularity, and estimated probability of term occurrence. It is assumed that frequent terms are also significant [28].

There are many applications of this method in the literature. Previous research employs TF-IDF to identify "informative" words, i.e., those terms whose high scores suggest frequent appearances in a small number of articles [29]. TF-IDF is also used as the basis for their clustering research, as this methodology is particularly suited to distinguishing individual documents and keywords from a text pool [30]. Another study uses TF-IDF as the initial tool for constructing a semantically sensitive application to identify relevant words in a collection of documents [31]. This methodology is highly relevant in the field of bibliometrics for identifying publication keywords [32].

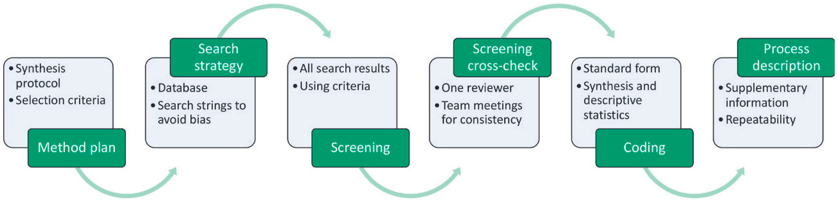


Fig. 1. Schematic illustration of the literature review process adapted from Dawkins et al. (2019).

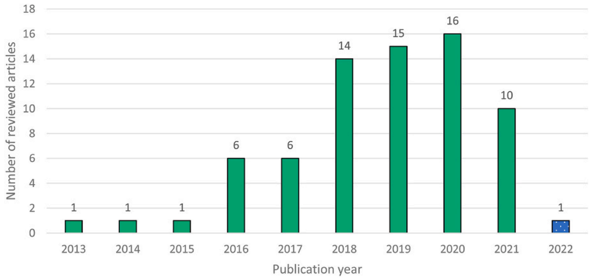


Fig. 2. Number of reviewed articles per publication year. Information on 2022 articles was not fully recorded in WoS by the time of the analysis.

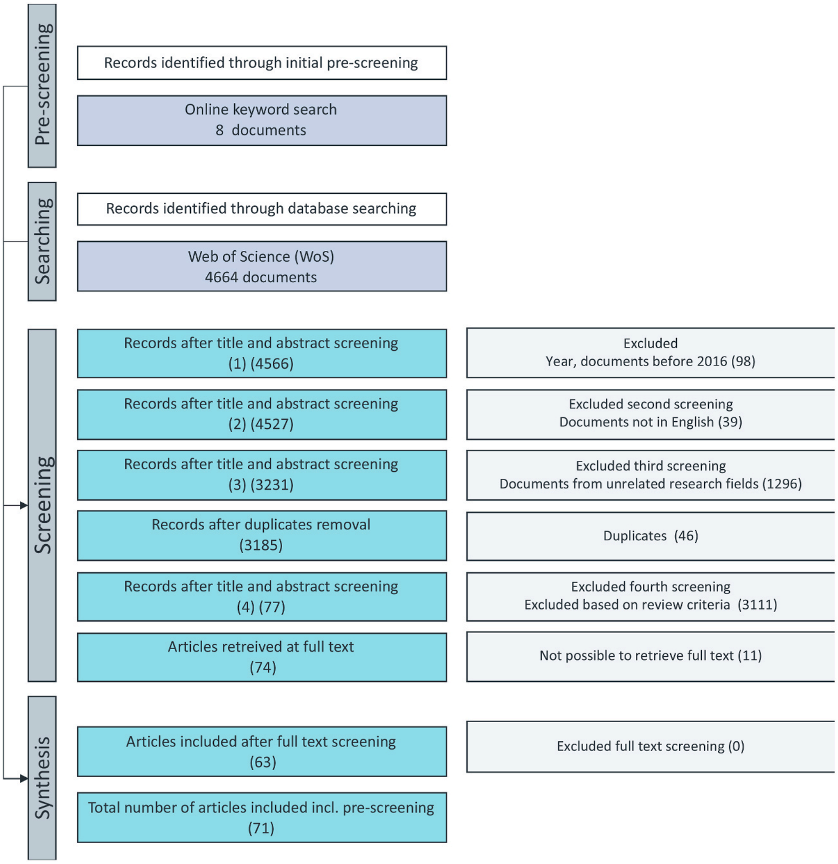


Fig. 3. Document selection process adapted from Haddaway et al. [26].

The TF-IDF score is the result of two components: a "term frequency" component, which accounts for the relative frequency of each term within a document, and an "inverse document frequency," which investigates the amount of information that the term provides, i.e., how common or rare the term is across the whole set of documents.

We proceeded with the standard specification found in Python's scikit-learn library. We set the range for the n-grams options between 1 and 4. *N*-grams represent groups of consecutive words that are treated as a unique term. This allows for terms such as "renewable energy" to be considered as a single term and able to be compared to 1-g, such as "decommissioning." Our range setting implies that individual terms and groups of up to four consecutive words are considered in the application.

Finally, we applied an iterative process to identify those terms that fall outside the common definition of stopwords (words automatically omitted from machine-learning algorithms) but are still irrelevant to include, since they do not really provide any new insights [33]. Stopwords already included in the scikit-learn module [34] include, for example, "and," "if," "has," and "so." After a first round of results, we adjusted the approach by adding some additional terms to the standard stop word set to allow for more suitable potential keywords to emerge. We applied the same methodology repeatedly until irrelevant terms were fully eliminated.

There is no way to identify those irrelevant terms a priori. The iterative process stops when the list of top-20 terms includes only

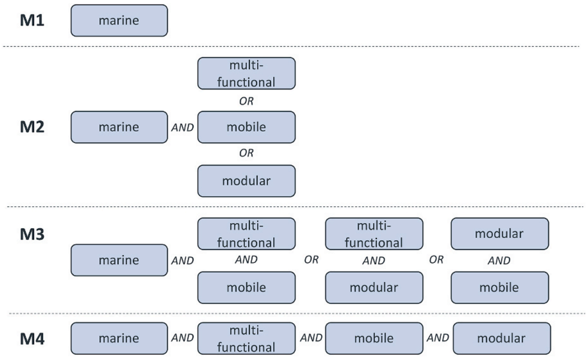


Fig. 4. Conceptual definition of the M-degree classification scheme: M1 refers to only marine; M2 to marine with multifunctional or modular or mobile; M3 to either a combination of marine and multifunctional and modular or marine and multifunctional and mobile or marine and modular and mobile; and M4 refers to marine, multifunctional, modular, and mobile.

terms that exclusively allude to M4 applications. The results (see Appendix Tables 3, 4, 5, and 6, respectively) show that irrelevant terms may appear among top scorers if not properly addressed.

3. Results

3.1. M-degree classification

We manually classified the selected papers according to their characterizing themes and adopted the conceptual definitions outlined in Section 2.1 to understand how often themes are combined in the literature.

The review indicates that multifunctionality is the most explored theme in the literature, with approximately 70% (50 papers out of 71) covering multifunctional solutions in the marine environment (see Fig. 5). Modularity is the least explored, found in approximately 20% of the reviewed literature. The majority of the articles discussed mobile solutions (see Fig. 5), primarily in comparisons of floating-structure advantages over fixed-bottom structures.

After reviewing how often the four concepts are separately addressed in the reviewed literature, we analyzed their combinations, developing the M-scores in line with the conceptual definitions presented in Fig. 4. Exclusively marine solutions (M1) comprise 11% of the total number of papers reviewed (see Fig. 5). M2 solutions are the most frequent, occurring 39% of the time in the reviewed literature. M3 solutions come next, discussed in 35% of the reviewed papers. Only 15% of the literature discusses all four attributes for an M4 classification.

Regarding overlapping themes, multifunctional and mobile solutions are the most common, occurring 20 times (see Fig. 6). The marine classification is not included in the analysis of overlapping themes in Fig. 6, since every reviewed paper belongs to this category. Only 13 papers explored modular solutions. Modularity was always associated with either mobility or multifunctionality and most often, with both.

We also classified the literature by locality. The potential for multifunctional offshore solutions to succeed in various geographic regions has been explored to some degree in the literature. Some studies assessed geographical feasibility of marine sea-space use at European regional levels [35–37]. Other studies include an exploration of the potential of multi-purpose energy platforms for all U.S.

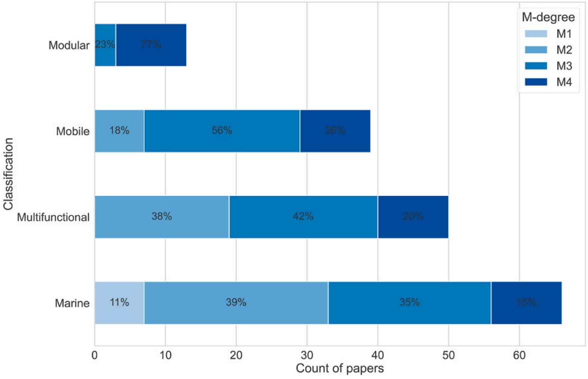


Fig. 5. Composition of M-degree scores per thematic classification. A conceptual definition of the M1, M2, M3, and M4 classifications can be found in Fig. 4.

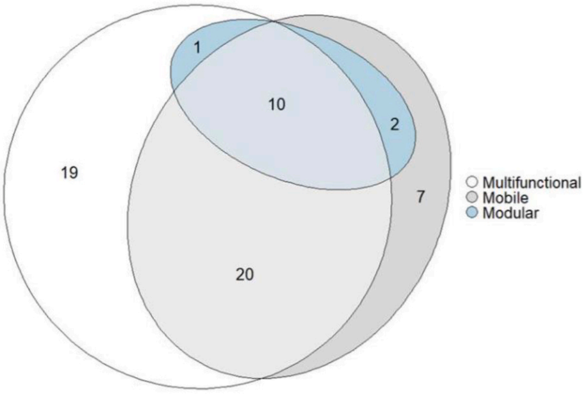


Fig. 6. Overlapping themes from M4 classification of the reviewed articles. Marine classification is not included, since all papers are under this classification.

coastal waters [1] and a global feasibility study for the application of wind-energy ships [38].

Overall, research including global applications accounted for 29% of the total. Europe dominates the regional output of papers, which might indicate a higher interest in offshore solutions (Fig. 7) and is supported by the EU's development in recent years of several research programs promoting multifunctional blue-economy development such as MULTIFRAME, MERMAID, H2OCEAN and TROPOS, H2020 Space@Sea, Blue Growth Farm, MUSES, and MARIBE [39]. We found no papers focused on South America, and only one on the African continent. The North Sea was the most common specific location in the literature, with six major studies. The Adriatic and Mediterranean, and the Gulf of Mexico are selected sites for three studies each. Italy, the United States, and the Netherlands are the three most referenced countries (see Fig. 8).

We categorized offshore platform functions by the specific services provided, such as various types of energy production, desalination, or mineral extraction. To determine how these functions are combined in the literature, we investigated the connections between pairs of solutions. The most studied combination was wind-and-wave energy, found among 29 papers. Aquaculture combined with wind or wave facilities were mentioned 21 and 19 times, respectively. The 13 combinations are visualized in the matrix and chord diagrams in Fig. 9.

The results indicate strong emphasis on wind-and-wave technologies in the existing literature, but we also find solar, oil and gas, hydrogen, nuclear, and electrofuels. The focus on wind-wave synergies may be due to their cost-saving and vast harvesting potentials in high seas. Attaching wave energy converters to floating offshore wind platforms can reduce costs by improving lateral motion stability [40]. Besides the cost reduction of sharing common infrastructure, combining of wave and wind technologies seems to reduce ecological footprint and extend energy output due to the possibility of swells when wind conditions are calm [41]. Additionally, wind and wave technologies have been researched for a longer time, compared to other technologies such as hydrogen (on its own or in combination), especially in marine applications. Some of the "Other" solutions shown in Fig. 9 include ocean thermal energy, current and tidal energy, "blue" biotechnology, and floating islands.

3.2. Keyword analysis

The keyword analysis provided insight into the main themes accompanying our analyses of multifunctionality, modularity, and mobility in the marine context. Fig. 10 shows the top keywords in the reviewed abstracts as discussed per type of "M-degree".

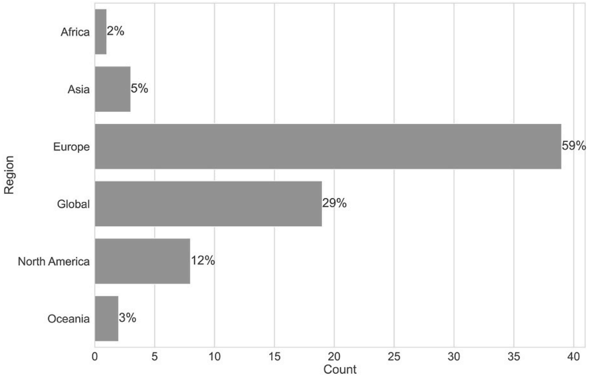


Fig. 7. Regional location of the classified papers.

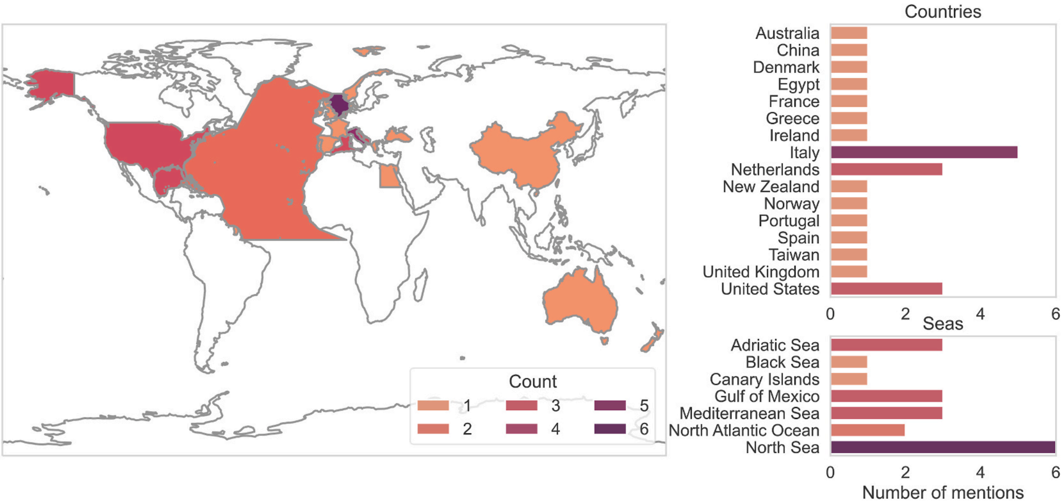
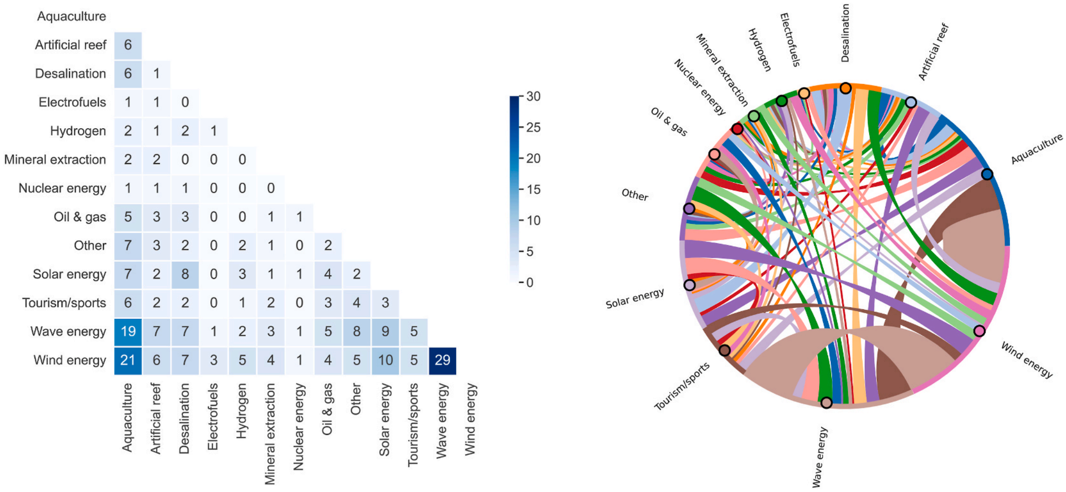


Fig. 8. Map of specific locations mentioned in the literature.



	Aquaculture	Artificial reef	Desalination	Electrofuels	Hydrogen	Mineral extraction	Nuclear energy	Oil & gas	Other	Solar energy	Tourism/sports	Wave energy	Wind energy
Aquaculture													
Artificial reef	6												
Desalination	6	1											
Electrofuels	1	1	0										
Hydrogen	2	1	2	1									
Mineral extraction	2	2	0	0	0								
Nuclear energy	1	1	1	0	0	0							
Oil & gas	5	3	3	0	0	1	1						
Other	7	3	2	0	2	1	0	2					
Solar energy	7	2	8	0	3	1	1	4	2				
Tourism/sports	6	2	2	0	1	2	0	3	4	3			
Wave energy	19	7	7	1	2	3	1	5	8	9	5		
Wind energy	21	6	7	3	5	4	1	4	5	10	5	29	

Fig. 9. Number of combinations between pairs of offshore multifunctional applications presented as a matrix (left) and chord (right) diagram.

We found terms like “marine,” “offshore,” “platforms,” “environmental,” and “energy” to be relevant in all the groups. This is not surprising, since these terms are identical or similar to the keywords used for the initial literature search. However, some terms do not rank high for all four classifications. For instance, the term “decommissioning” ranks first among the M1 applications (M1 = marine) and is present in the results for M2 (M2 = marine and multifunctional or marine and mobile) applications but ranks much lower here. The term “nuclear” is only found in the results for the M2 applications, and the 2-g “floating platforms” and “offshore platforms” are only found in M4 (M4 = marine, multifunctional, modular, and mobile) applications. “Decisions” is another term that only scores high in the results from M1 applications.

3.2.1. M1 (marine) themes in the reviewed literature

Nine of the reviewed papers consider M1 (marine-only) applications. The results from the keyword analysis for these papers have the term “decommissioning” ranking first (see Appendix Table 3). Five of the papers in this group focus on strategies to deal with the decommissioning of oil and gas platforms at the end of their lifecycles [42–46]. This should be expected, since the engineering challenge of platform decommissioning is independent of multifunctionality or modularity.

Terms such as “platforms” and “offshore” often occur in the texts linked to decommissioning analyses. The need for better data collection for guiding research directions in marine environmental management is another recurring theme. Data routinely collected by marine industries could contribute to marine ecosystems management [46]; local and global information to produce models for sustainable development is important in this context [47].

Furthermore, while some environmental assessment frameworks recommend complete removal of decommissioned oil and gas platforms, research indicates that, from an environmental perspective, leaving in place, partially removing, repurposing, or relocating

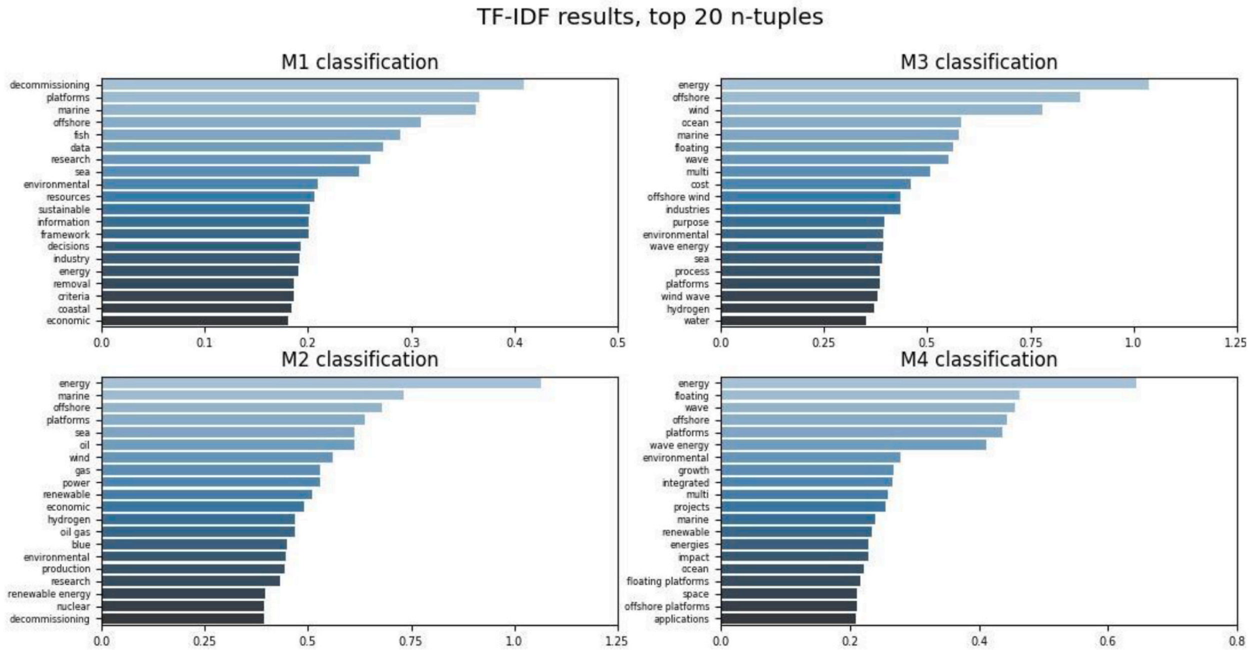


Fig. 10. Scores and rankings from the TF-IDF (text-frequency inverse – document-frequency) for every M – classification, showing top 20 most significant terms for M1 (upper left), M2 (lower left), M3 (upper right), and M4 (lower right) classification.

might be better options [43]. Decommissioning oil platforms provides an opportunity to change how marine space is managed, where "blue growth" can improve attractiveness, competitiveness, and innovation at the local, regional, and national levels, deviating from the current business-*as*-usual approach to marine space [42].

3.2.2. M2 (marine and multifunctional or marine and mobile) themes in the reviewed literature

M2 applications consider multifunctional (nineteen papers in our dataset) or mobile (seven papers in our dataset) solutions in marine environments. The term "energy" now appears in the top position for this group, on its own and as part of the 2-g "renewable energy" (see Appendix Table 4). Decommissioning or reusing oil and gas platforms is still a relevant theme in this group, with many papers suggesting use of existing infrastructure to produce renewable energy [48–53]. The "oil gas" 2-g emerged as one of the most relevant terms for this group, likely from the prevalence of decommissioning as a topic in these papers.

Two of the papers in this group we classified as mobile solutions, as they deal with shipboard applications. These same two papers justify "nuclear" being among the top terms, in reference to ships providing off-grid nuclear energy. For two of the papers classified as mobile, the mobility aspect is manifested as energy production in ships. Nuclear energy is considered in both cases and is also a keyword for this category (see Fig. 10).

The keyword extraction results align with our analysis in Section 3.1, with wind ranking the highest. Hydrogen production also appears to be relevant in the M2 applications, with five papers [48,51,53–55] mentioning the possibility of using renewable energy produced at a MUP for hydrogen production. Most M2 applications in the reviewed literature share characteristics with M1 applications, such as focusing on oil and gas platforms, but the literature highlights the synergy of renewable and initial explorations of multifunctionality energy at these platforms.

One of the studies classified as M2 concludes that a high potential for development is related to tourism-driven (e.g., pescatourism) combinations with floating offshore applications [36]. Desirable features for marine multifunctional platforms include:

- low storm frequency and intensity
- adequate distance from shipping lanes
- proximity to loading and transmission centers (cities, coastal communities)
- coastal land limitations, such as lack of space or high purchase costs [56].

Another study identifies wind speed, wave power density, depth range, and distance from the shore as the criteria for installing offshore renewable-energy platforms, such as wind- and wave-power combinations [57]. Platform locations and characteristics need to be further analyzed to determine how new opportunities can be created through adaptations [49].

Reviewed studies applied different methods to evaluate theoretical economic potentials with different multifunctional applications. For example, one study concluded that the most profitable product would be hydrogen, followed by electricity and synthetic natural gas. The authors of a North Sea study concluded that adding wind farms leads to higher profitability [51]. Other studies discussed the lack of involvement by citizens and certain stakeholder groups in consultations where inclusiveness is an issue [58,59].

3.2.3. M3 (marine, multifunctional, and mobile) themes in the reviewed literature

The co-production of renewable energy through different sources really stands out in the keyword analysis of M3 applications, as the 2-g "wind wave" appears among the top results and "wind energy" and "wave energy" also rank high, individually (see Appendix Table 5). This is in line with the results shown in Fig. 9, where the combination wave-and-wind energy production occurs most often in the reviewed literature.

The term "floating" in Fig. 10 is in line with mobility being one of the defining elements of M3 applications, as discussed in Section 2.1. Of the 23 papers classified, 22 proposed a mobile solution. Financial considerations emerge in literature when M3 applications are discussed [5,40,60–66]. This is confirmed by the term "cost" appearing among the top-scoring keywords, contrary to M1 and M2 applications, where "cost" was not among the top 20 keywords.

The colocation of multiple renewable-energy production technologies – in most cases, wind and wave energy – reduces fixed costs, as one structure can be the foundation for both of these technologies [67,68]. The mobility of these MUPs in M3 applications has other potential financial benefits, such as increasing utilization rates and operational income if operators can move the MUPs to areas with more stable wind and waves or where customers are more willing to pay, for example.

Several articles in this category discussed hydrogen and electrofuels. Wind-powered-energy ships used for PtX (conversion of electricity to carbon-neutral hydrogen, synthetic gas, methanol and other fuels) are currently in the prototyping stage. FARWIND estimated the cost of the methanol produced to be four-to five-times higher than current market price, excluding CO_2 cost [61].

The key obstacles to efficient and cost-competitive offshore hydrogen operations compared to onshore production are:

- Need for on-site desalination plants due to low-quality water supply, increasing cost, and complexity
- Interrupted electricity supply due to disconnection from the onshore grid
- Need for high-pressure hydrogen pipelines to counteract pressure loss from electrolyzer to shore [62].

Floating moored systems are convenient and simple to install with a plug-and-play design, which involves towing and mooring on site. They are removable for relocation or major repairs, with simple maintenance primarily performed near or on the surface [69].

According to studies, promising sites where wind and wave colocation would be particularly suitable for development of M3 solutions include the Gulf of Mexico [1] and the waters southeast of Tenerife and Fuerteventura in the Canary Islands, [70].

Stakeholders need policymakers to disseminate information and facilitate communication in the relevant sectors to advance development of these floating moored systems. Various strategies must be implemented in sea basins to prevent negative impacts. Sustainability is underrepresented in policy documents, at least at the EU and sea-basin levels, possibly due to a lack of research on the broader socioeconomic benefits of MUPs [10].

3.2.4. M4 (marine, multifunctional, mobile, and modular) themes in the reviewed literature

The last category, M4, encompasses all the characteristics that we defined: multifunctionality, modularity, and mobility in marine applications. The terms "modular" and "modularity," however, did not appear among the top scorers in the keyword analysis (see Appendix Table 6) for two reasons: First, four of the papers (40% of the papers in this group) we classified as marine, multifunctional, modular, and mobile applications [71–74] mention modularity in their abstract but with different suffixes. "Modularity" [71], "modular platforms" [72], "modularization" [73], or "modular islands" [74] are among the terms used. Many authors who apply text-mining approaches recognize that the presence of different suffixes is an issue [75,76].

The second reason "modularity," against expectations, is not among the top-scoring keywords in this group, has to do with the type of publications we classified as M4. These papers represent reviews of a variety of (mostly theoretical) projects or test beds. Though "modular" solutions are among those reviewed, these articles do not focus exclusively on modularity, therefore the term is not highlighted in the abstracts and thus does not earn a high score due to the low appearance frequency using this text-mining method. This indicates that although modularity is somewhat addressed in literature, more research is needed focusing exclusively on benefits, drawbacks, and effects of such applications. Currently, modularity is discussed mostly as part of MUPs' theoretical future capabilities in the context of sustainable development.

One of the articles noted attempts to introduce marine, multifunctional, and modular solutions in the 1970s, but technology was not yet advanced enough for implementation [71]. Floating-platform technology is closely linked to M4 implementation in the literature. They are larger than conventional platforms and offer more flexibility, such as the capability of platform modules to be connected and the ability to deform under loads and waves thanks to their elasticity [77].

Lastly, studies highlight that the social and cultural aspects of MUPs are often overlooked, and comparisons of these platforms to existing ocean-space usage are limited [78]. Other important synergies to consider include: shipping and ports, ocean resources and exploration, coastal defense and surveillance, water desalination, fishing and aquaculture, and oil and gas platforms [20].

4. Conclusions

In this paper, we reviewed the governing themes in literature on multi-use/multi-purpose platforms at sea, often called MUPs. As island and coastal geographies need to increase resilience while transitioning to fossil-free paradigms, solutions such as the MUPs could deliver services in the fields of energy, water, sanitation, and food. We reviewed studies that present different combinations of purposes and technologies for MUPs. Our systematic review classified these studies and identified emerging trends for MUPs that could be useful in policy design and future governance planning for these complex solutions.

We use the concept of M4s for classifying MUPs: systems that present four characteristics – marine, multifunctionality, modularity, and mobility – to varying extents. We performed a systematic review of 71 articles relevant to MUPs and scored them in terms of how many "M″s out of the M4s are discussed in a given article. We applied machine-learning techniques and extracted keywords from all of the abstracts to identify top themes in the reviewed articles, classified per number of "M″s they discussed.

The status of MUPs/M4 research and implementation outside of Europe should be further investigated, since the majority of literature we reviewed indicates potentially significant benefits from introducing such solutions in coastal environments around the world. Literature so far has focused mostly on European marine applications of this kind. This can be attributed to several research projects focusing on oil and gas platforms and MUPs in the region, but we only reviewed English publications, which excluded publications in other languages from other parts of the world.

Our analysis shows that the combination of wind and wave energy is the most common of the M4 technologies in the articles, followed by this combination with aquaculture. Solar and hydrogen solutions are also mentioned, but to a lesser extent. We assume that the number of peer-reviewed publications will increase in the future as the technologies become more commercial, especially regarding hydrogen.

The geographical focus of the studies may be why we saw the synergies between technologies that we did. As mentioned above, Europe dominated the articles we reviewed, specifically, the North Sea. It is possible that the interest in wind-and-wave energy is because of the large potential these technologies have in those regions. Understanding where most potential exists might lead to additional interesting technology combinations in M4 solutions. The use of M4 solutions in tourism applications is identified as one of the most attractive options for some regions in the reviewed literature.

The text analysis sheds light on the evolution of themes addressed in the articles as one moves from M1 (only marine), to M2 (marine and multifunctional or marine and mobile), to M3 (marine, multifunctional, and mobile), and finally to M4 (marine, multifunctional, modular, and mobile) applications. Focus shifts as the M-score changes. For example, solutions for sustainable decommissioning and repurposing of oil and gas platforms is a dominating theme in discussions of M1 applications, but not so for discussion of applications classified as M2, M3, or M4. Indeed, one of the themes in literature discussing M2 applications is renewable energy: applications of wind, solar, wave (and combinations of them) in MUPs. Discussions of M3 applications continue in this direction, but we observed "cost" emerging as a top keyword in our thematic analysis, highlighting that when higher MUP complexity comes into play, economic parameters of implementation enter the spotlight.

While mobility, in the sense of floating platforms that can be easily relocated, is the defining aspect of M3s, "mobility" does not appear among the key themes in the text analysis. We also observed that "modularlity" – required for an M4 application in our classification system — was not a central focus and did not emerge as a top theme. We found that, so far, mobility and modularity have been less researched than other aspects of MUPs. These concepts are loosely addressed in literature that presents several types of solutions, and there are no detailed evaluations of impacts, benefits, drawbacks, or institutional frameworks needed for realizing M3 or M4 applications, compared with richer research output for M1 and M2 applications.

Our review includes a broad set of different technologies and applications, with varying characteristics in terms of basic engineering, architecture, economic principles, and environmental impacts. For this reason, in-depth comparisons were not possible in the methodological context of this review. Our M4 framework can give a first classification to these solutions and point towards the direction of technologies more widely addressed in literature, such as wind and wave energy. Our identification of literature gaps can then help development of new methodological frameworks to address technologies that serve the same purpose or deliver similar effects, in order to make meaningful comparisons possible.

Further research should focus on whether including modularity and mobility (M4) can more effectively solve multiple challenges compared to existing multifunctional (M2) configurations. We observed a literature gap for studies systematically comparing benefits and costs of M4 or M3 with M2 solutions. Out of all reviewed articles, only five provided an economic analysis of the proposed solutions. Most of the studies praised the potential economic advantages of multifunctional, modular, and mobile solutions, but failed to quantify them.

Analyzing platform geographical placements and characteristics is a necessary next step for understanding how concepts can be adapted to create new business initiatives. We recommend exploring the state-of-the-art beyond European studies and theoretical explorations to understand what is feasible, where, and at what scale. For that, future research should focus on information that has not been peer-reviewed or traditionally published. A possible next step would be to adapt and apply the methods introduced in this paper to classify, organize, and systematically analyze additional information found in non-English, nonscientific literature.

The M4 framework we defined and applied for the analysis could facilitate classification of applications and subsequent communication of main trends and insights to researchers, decision-makers, and practitioners. The use of machine-learning techniques in analyzing texts could be adopted for defining key themes in larger datasets of peer-reviewed articles, news resources, and reports addressing M4 applications.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Appendix Table 1
Predefined parameters used for coding in Excel.

Parameter	Variables
Source type	Journal article Other Report
Region	Europe Africa Asia Global North America Oceania South America
Specific location	*Open field*
M4 type	Co-located: applications sharing same area, as well as common operation and maintenance equipment and activities, but they do not share their foundation. Hybrid/combined: application share foundation and connections as a unit Island: generally larger platform where many applications exist. Can be grid connected or not. Vessel: Motor vessel with multiple capabilities, including energy production, oceanographic studies, goods or passenger transport etc. Other (e.g. oil platforms) Review of multiple
Type of structure	Floating Mobile Static
Combination of technologies	Aquaculture Artificial reef Desalination Electrofuels: manufactured with hydrogen and captured carbon dioxide or monoxide Hydrogen Mineral extraction Nuclear energy Oil & gas Other Solar energy Tourism/sports Wave energy Wind energy
Object description	*Open field*
Focus of study	*Open field*
Challenge addressed	*Open field*
Trade-offs	*Open field*
Benefits	*Open field*
Risks	*Open field*
Institutional frameworks	*Open field*
Governance/Business models	*Open field*
Other key takeaways	*Open field*

Appendix Table 2
Full list of reviewed literature.

Title	Year	Authors	doi (if available)
Offshore multi-purpose platforms for a Blue Growth: A technological, environmental and socio-economic review	2020	Abhinav et al.	https://doi.org/10.1016/j.scitotenv.2020.138256
Investment efficiency of floating platforms desalination technology in Egypt	2020	Abozaid et al.	
Research hub for an integrated green energy system reusing sealines for H2 storage and transport	2020	Antoncecchi et al.	
Reliability of multi-purpose offshore-facilities: Present status and future direction in Australia	2021	Aryai et al.	https://doi.org/10.1016/j.psep.2020.10.016

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Appendix Table 2 (*continued*)

Title	Year	Authors	doi (if available)
Energy and economic performance of the FARWIND energy system for sustainable fuel production from the far-offshore wind energy resource	2019	Babarit et al.	
The usefulness of sustainable business models: Analysis from oil and gas industry	2020	Basile et al.	https://doi.org/10.1002/csr.2153
The Offshore Floating Nuclear Plant Concept	2016	Buongiorno et al.	https://doi.org/10.13182/NT15-49
Toward a Sustainable Decommissioning of Offshore Platforms in the Oil and Gas Industry: A PESTLE Analysis	2021	Capobianco et al.	https://doi.org/10.3390/su13116266
Powering the Blue Economy: Progress Exploring Marine Renewable Energy Integration with Ocean Observations	2020	Cavagnaro et al.	https://doi.org/10.4031/MTSJ.54.6.11
On the potential synergies and applications of wave energy converters: A review	2021	Clemente et al.	https://doi.org/10.1016/j.rser.2020.110162
Multi-criteria site selection for offshore renewable energy platforms	2016	Cradden et al.	https://doi.org/10.1016/j.renene.2015.10.035
Towards green transition of touristic islands through hybrid renewable energy systems. A case study in Tenerife, Canary Islands	2021	Dallavelle et al.	https://doi.org/10.1016/j.renene.2021.04.044
Feasibility of investment in Blue Growth multiple-use of space and multi-use platform projects; results of a novel assessment approach and case studies	2019	Dalton et al.	https://doi.org/10.1016/j.rser.2019.01.060
Integration of Shipboard Microgrids Within Land Distribution Networks	2019	Dagostino et al.	https://doi.org/10.1109/MELE.2019.2943979
Exploring Multi-Use potentials in the Euro-Mediterranean sea space	2019	Depellegrin et al.	https://doi.org/10.1016/j.scitotenv.2018.10.308
Economically Feasible Mobile Nuclear Power Plant for Merchant Ships and Remote Client	2019	Freire et al.	https://doi.org/10.1080/00295450.2018.1546067
Platform Optimization and Cost Analysis in a Floating Offshore Wind Farm	2020	Ghigo et al.	https://doi.org/10.3390/jmse8110835
Planning for a safe and sustainable decommissioning of offshore hydrocarbon platforms: complexity and decision support systems. Preliminary considerations	2017	Grandi et al.	
AMBEMAR-DSS: A Decision Support System for the Environmental Impact Assessment of Marine Renewable Energies	2018	Guinda et al.	
A symbiotic approach to the design of offshore wind turbines with other energy harvesting systems	2018	Haji et al.	https://doi.org/10.1016/j.oceaneng.2018.07.026
An offshore solution to cobalt shortages via adsorption-based harvesting from seawater	2019	Haji et al.	https://doi.org/10.1016/j.rser.2019.01.058
Introducing ocean energy industries to a busy marine environment	2017	Hammar et al.	https://doi.org/10.1016/j.rser.2017.01.092
Recreational use of offshore wind farms: Experiences and opinions of sea anglers in the UK	2017	Hooper et al.	https://doi.org/10.1016/j.marpol.2017.01.013
Tackling Climate Change, Air Pollution, and Ecosystem Destruction: How US-Japanese Ocean Industrialization and the Metabolist Movement's Global Legacy Shaped Environmental Thought (circa 1950s Present)	2020	Huebner et al.	https://doi.org/10.1093/envhis/emz080
Dedicated large-scale floating offshore wind to hydrogen: Assessing design variables in proposed typologies	2022	Ibrahim et al.	https://doi.org/10.1016/j.rser.2022.112310
Layout Optimization Process to Minimize the Cost of Energy of an Offshore Floating Hybrid Wind-Wave Farm	2020	Izquierdo et al.	https://doi.org/10.3390/pr8020139
Feasibility Study of the Methods of Hydrogen Distribution from Ocean Thermal Energy Conversion Power Plant: An Initial Proposed OTEC-Hydrogen Logistics Roadmap	2016	Kaeochuen et al.	
Establishing an agenda for social studies research in marine renewable energy	2013	Kerr et al.	https://doi.org/10.1016/j.enpol.2013.11.063
Rights and ownership in sea country: implications of marine renewable energy for indigenous and local communities	2014	Kerr et al.	https://doi.org/10.1016/j.marpol.2014.11.002
Alternate uses of retired oil and gas platforms in the Gulf of Mexico	2018	Kolian et al.	https://doi.org/10.1016/j.ocecoaman.2018.10.002
REFOS: A Renewable Energy Multi-Purpose Floating Offshore System	2021	Konispoliatis et al.	
New Engineering Approach for the Development and Demonstration of a Multi-purpose Platform for the Blue Growth Economy	2019	Lagasco et al.	https://doi.org/10.1115/OMAE2019-96104
Study of a Hybrid Renewable Energy Platform: W2Power	2018	Legaz et al.	https://doi.org/10.1115/OMAE2018-77690
Multi-purpose Offshore Platforms: Past, Present and Future Developments	2017	Leira et al.	https://doi.org/10.1115/OMAE2017-62691
Reconversion of offshore oil and gas platforms into renewable energy sites production: Assessment of different scenarios	2018	Leporini et al.	https://doi.org/10.1016/j.renene.2018.12.073
REEFS: An artificial reef for wave energy harnessing and shore protection – A new concept towards multipurpose sustainable solutions	2017	Lopes	https://doi.org/10.1016/j.renene.2017.07.076
Site Selection of Hybrid Offshore Wind and Wave Energy Systems in Greece Incorporating Environmental Impact Assessment	2018	Loukogeorgaki et al.	https://doi.org/10.3390/en11082095
Development of an Eco-Sustainable Solution for the Second Life of Decommissioned Oil and Gas Platforms: The Mineral Accretion Technology	2020	Margheritini et al.	https://doi.org/10.3390/su12093742
Forecasting the legacy of offshore oil and gas platforms on fish community structure and productivity	2020	Meyer-Gutbrod et al.	https://doi.org/10.1002/eap.2185

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Appendix Table 2 (*continued*)

Title	Year	Authors	doi (if available)
A Multipurpose Marine Cadastre to Manage Conflict Use with Marine Renewable Energy	2018	Michalak	https://doi.org/10.1007/978-3-319-74576-3_31
Data challenges and opportunities for environmental management of North Sea oil and gas decommissioning in an era of blue growth	2018	Murray et al.	https://doi.org/10.1016/j.marpol.2018.05.021
Assessment of Multi-Use Offshore Platforms: Structure Classification and Design Challenges	2020	Nassar et al.	https://doi.org/10.3390/su12051860
Wave energy converter and large floating platform integration: A review	2020	Nguyen et al.	https://doi.org/10.1016/j.oceaneng.2020.107768
Marine Concrete Structures for the Future	2018	Olsen	
Floating Offshore Renewable Energy Farms. A Life-Cycle Cost Analysis at Brindisi, Italy	2020	Pantusa et al.	https://doi.org/10.3390/en13226150
Wind Energy Ships: Global Analysis of Operability	2021	Pascual et al.	https://doi.org/10.3390/jmse9050517
A review of combined wave and offshore wind energy	2015	Perez-Collazo et al.	https://doi.org/10.1016/j.rser.2014.09.032
Renewables, Shipping, and Protected Species: A Vanishing Opportunity for Effective Marine Spatial Planning?	2016	Petruny et al.	https://doi.org/10.1007/978-1-4939-2981-8_100
From decision-making to Oceans Accounts: a case study	2019	Pinheiro et al.	https://doi.org/10.1109/OCEANSE.2019.8867584
Mobile offshore platforms for power generation: the energy ship	2018	Platzer et al.	https://doi.org/10.1115/IOWTC2018-1022
Multi-Use of the Sea as a Sustainable Development Instrument in Five EU Sea Basins	2021	Przedrzymirska et al.	https://doi.org/10.3390/su13158159
Catamaran or semi-submersible for floating platform – selection of a better design	2018	Qasim et al.	https://doi.org/10.1088/1755-1315/121/5/052041
Offshore power generation with carbon capture and storage to decarbonise mainland electricity and offshore oil and gas installation: A techno-economic analysis	2019	Roussanaly et al.	https://doi.org/10.1016/j.apenergy.2018.10.020
Electrical Power Supply of Remote Maritime Areas: A Review of Hybrid Systems Based on Marine Renewable Energies	2018	Roy et al.	https://doi.org/10.3390/en11071904
Scaling strategies for multi-purpose floating structures physical modeling: state of art and new perspectives	2021	Ruzzo et al.	https://doi.org/10.1016/j.apor.2020.102487
New Opportunities for Offshore Oil and Gas Platforms – Efficient, Effective, and Adaptable Facilities for Offshore Research, Monitoring, and Technology Testing	2019	Satterlee et al.	https://doi.org/10.1109/OCEANS.2018.8604935
Toward a Common Understanding of Ocean Multi-Use	2019	Schupp et al.	https://doi.org/10.3389/fmars.2019.00165
Offshore gas production infrastructure reutilisation for blue energy production	2019	Sedlar et al.	https://doi.org/10.1016/j.rser.2019.03.052
Stakeholders Opinions on Multi-Use DeepWater Offshore Platform in Hsiao-Liu-Chiu, Taiwan	2018	Sie et al.	https://doi.org/10.3390/ijerph15020281
Combining offshore wind farms, nature conservation and seafood: Lessons from a Dutch community of practice	2021	Steins et al.	https://doi.org/10.1016/j.marpol.2020.104371
The Governance of Multi-Use Platforms at Sea for Energy Production and Aquaculture: Challenges for Policy Makers in European Seas	2016	Stuiver et al.	https://doi.org/10.3390/su8040333
The application of hybrid photovoltaic system on the ocean-going ship: engineering practice and experimental research	2019	Sun et al.	https://doi.org/10.1080/20464177.2018.1493025
Developing an Environmental Impact Assessment for Floating Island Applications	2021	Tamis et al.	https://doi.org/10.3389/fmars.2021.664055
Social network analysis as a tool for marine spatial planning: Impacts of decommissioning on connectivity in the North Sea	2020	Tidbury et al.	https://doi.org/10.1111/1365-2664.13551
Participatory Design of Multi-Use Platforms at Sea	2016	van den Burg et al.	https://doi.org/10.3390/su8020127
Assessment of the geographical potential for co-use of marine space, based on operational boundaries for Blue Growth sectors	2019	van den Burg et al.	https://doi.org/10.1016/j.marpol.2018.10.050
Development of multi-use platforms at sea: Barriers to realizing Blue Growth	2020	van den Burg et al.	https://doi.org/10.1016/j.oceaneng.2020.107983
Business case for mussel aquaculture in offshore wind farms in the North Sea	2017	van den Burg et al.	https://doi.org/10.1016/j.marpol.2017.08.007
Offshore multi-purpose platform efficacy by U.S. coastal areas	2020	Weeks et al.	https://doi.org/10.1016/j.renene.2020.02.079
Co-location opportunities for renewable energies and aquaculture facilities in the Canary Archipelago	2018	Weiss et al.	https://doi.org/10.1016/j.ocecoaman.2018.05.006
Off-shore PV and Wind Based Energy Generation	2019	Solomin et al.	

Appendix Table 3

M1 TF-IDF results with no additional stopwords and alternative n-gram specifications.

1 – Gram	2 – Gram	3 – Gram	4 – Gram
decommissioning (0.75)	decommissioning 0.54	decommissioning 0.45	decommissioning 0.40
platforms (0.67)	platforms 0.49	platforms 0.41	platforms 0.36

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Appendix Table 3 (*continued*)

1 – Gram	2 – Gram	3 – Gram	4 – Gram
marine (0.67)	marine 0.49	marine 0.40	marine 0.35
offshore (0.58)	offshore 0.42	offshore 0.35	offshore 0.30
data (0.52)	data 0.37	fish 0.32	fish 0.28
development (0.48)	fish 0.37	data 0.31	data 0.27
fish (0.47)	research 0.35	research 0.29	research 0.26
research (0.47)	development 0.35	development 0.29	development 0.25
sea (0.47)	sea 0.33	sea 0.28	sea 0.24
environmental (0.40)	environmental 0.28	environmental 0.23	environmental 0.20
sustainable (0.39)	sustainable 0.28	resources 0.23	resources 0.20
industry (0.38)	information 0.27	sustainable 0.23	information 0.20
framework (0.38)	resources 0.27	information 0.23	sustainable 0.20
information (0.38)	framework 0.27	framework 0.22	framework 0.19
resources (0.37)	industry 0.27	industry 0.22	industry 0.19
decisions (0.37)	decisions 0.26	decisions 0.22	decisions 0.19
criteria (0.36)	energy 0.26	energy 0.21	platform 0.19
energy (0.35)	platform 0.25	platform 0.21	energy 0.19
platform (0.34)	criteria 0.25	criteria 0.21	removal 0.18
coastal (0.34)	coastal 0.25	coastal 0.20	criteria 0.18
management (0.33)	removal 0.24	removal 0.20	coastal 0.18
economic (0.33)	economic 0.24	mre 0.20	mre 0.18
social (0.33)	social 0.24	economic 0.20	economic 0.18
removal (0.32)	mre 0.24	social 0.20	social 0.17
mre (0.32)	management 0.23	management 0.19	management 0.17
mineral (0.31)	renewable 0.22	renewable energy 0.19	renewable 0.16
business (0.31)	renewable energy 0.22	renewable 0.19	renewable energy 0.16
blue (0.30)	business 0.22	business 0.18	access 0.16
access (0.30)	access 0.22	access 0.18	business 0.16
renewable (0.30)	mineral 0.22	resource 0.18	resource 0.16

Appendix Table 4
M2 TF-IDF results with no additional stopwords and alternative n-gram specifications.

1 – Gram	2 – Gram	3 – Gram	4 – Gram
energy 2.05	energy 1.44	energy 1.18	energy 1.03
offshore 1.31	marine 0.95	marine 0.80	marine 0.71
marine 1.30	offshore 0.92	offshore 0.75	offshore 0.66
platforms 1.26	platforms 0.87	platforms 0.71	platforms 0.62
oil 1.21	oil 0.84	oil 0.68	oil 0.59
sea 1.14	sea 0.82	sea 0.68	sea 0.59
wind 1.08	wind 0.76	wind 0.62	wind 0.54
gas 1.04	gas 0.72	gas 0.59	gas 0.51
renewable 1.01	renewable 0.70	power 0.58	power 0.51
power 0.95	power 0.69	renewable 0.57	renewable 0.49
economic 0.94	economic 0.66	economic 0.55	economic 0.48
potential 0.92	potential 0.65	potential 0.53	potential 0.46
environmental 0.88	oil gas 0.64	oil gas 0.52	oil gas 0.46
development 0.87	development 0.62	development 0.52	hydrogen 0.45
blue 0.86	environmental 0.61	hydrogen 0.51	development 0.45
production 0.85	hydrogen 0.60	blue 0.50	blue 0.43
use 0.83	blue 0.60	environmental 0.50	environmental 0.43
research 0.80	production 0.60	production 0.49	use 0.43
hydrogen 0.80	use 0.59	use 0.49	production 0.43
floating 0.76	research 0.57	research 0.48	research 0.42
platform 0.76	renewable energy 0.55	platform 0.45	platform 0.39
decommissioning 0.76	platform 0.54	renewable energy 0.44	nuclear 0.39
paper 0.73	decommissioning 0.53	decommissioning 0.44	decommissioning 0.38
reefs 0.71	floating 0.53	nuclear 0.44	renewable energy 0.38
nuclear 0.70	reefs 0.52	reefs 0.43	reefs 0.38
pv 0.70	paper 0.52	floating 0.43	pv 0.37
analysis 0.64	nuclear 0.51	pv 0.43	floating 0.37
sustainable 0.64	pv 0.51	paper 0.43	paper 0.37
based 0.64	analysis 0.46	analysis 0.38	analysis 0.33
different 0.62	based 0.45	based 0.37	based 0.32

Appendix Table 5
M3 TF-IDF results with no additional stopwords and alternative n-gram specifications.

1 – Gram	2 – Gram	3 – Gram	4 – Gram
energy 1.99	energy 1.41	energy 1.16	energy 1.01

(*continued on next page*)

Appendix Table 5 (*continued*)

1 – Gram	2 – Gram	3 – Gram	4 – Gram
offshore 1.62	offshore 1.16	offshore 0.96	offshore 0.84
wind 1.48	wind 1.06	wind 0.87	wind 0.76
platform 1.14	platform 0.81	platform 0.66	platform 0.58
marine 1.12	ocean 0.78	ocean 0.65	ocean 0.57
ocean 1.11	marine 0.78	marine 0.64	marine 0.56
wave 1.07	wave 0.76	wave 0.62	floating 0.54
floating 1.04	floating 0.75	floating 0.62	wave 0.54
multi 0.94	multi 0.67	multi 0.55	multi 0.49
cost 0.86	cost 0.62	cost 0.51	cost 0.45
industries 0.84	offshore wind 0.59	offshore wind 0.49	offshore wind 0.42
purpose 0.77	industries 0.58	industries 0.48	industries 0.42
use 0.77	use 0.55	use 0.46	use 0.40
potential 0.75	purpose 0.54	potential 0.45	potential 0.39
environmental 0.72	potential 0.54	purpose 0.44	purpose 0.38
platforms 0.72	wave energy 0.53	wave energy 0.44	environmental 0.38
paper 0.71	wind wave 0.52	environmental 0.43	wave energy 0.38
process 0.71	environmental 0.52	platforms 0.42	platforms 0.37
hydrogen 0.67	platforms 0.51	wind wave 0.42	paper 0.37
development 0.66	paper 0.51	paper 0.42	sea 0.37
sea 0.65	process 0.51	process 0.42	process 0.37
water 0.64	hydrogen 0.49	sea 0.42	wind wave 0.37
aquaculture 0.63	sea 0.49	hydrogen 0.41	hydrogen 0.36
new 0.60	development 0.48	development 0.40	development 0.35
maritime 0.58	water 0.46	water 0.38	water 0.33
design 0.58	multi purpose 0.45	multi purpose 0.36	multi purpose 0.32
production 0.57	aquaculture 0.44	aquaculture 0.36	maritime 0.31
sustainable 0.56	maritime 0.43	maritime 0.36	aquaculture 0.31
power 0.56	new 0.43	new 0.35	new 0.31
based 0.54	design 0.42	design 0.35	design 0.31

Appendix Table 6
M4 TF-IDF results with no additional stopwords and alternative n-gram specifications.

1 – Gram	2 – Gram	3 – Gram	4 – Gram
energy 1.20	energy 0.84	energy 0.70	energy 0.61
offshore 0.85	offshore 0.60	floating 0.50	floating 0.44
wave 0.85	floating 0.60	offshore 0.50	offshore 0.43
floating 0.85	wave 0.59	wave 0.49	wave 0.43
platforms 0.83	platforms 0.58	platforms 0.47	platforms 0.41
growth 0.52	wave energy 0.53	wave energy 0.44	wave energy 0.38
environmental 0.51	environmental 0.37	environmental 0.31	environmental 0.27
large 0.51	growth 0.37	growth 0.30	growth 0.26
integrated 0.50	multi 0.35	multi 0.29	large 0.25
multi 0.50	integrated 0.35	large 0.29	multi 0.25
projects 0.49	large 0.35	integrated 0.28	integrated 0.25
paper 0.44	projects 0.34	projects 0.28	projects 0.24
renewable 0.44	large floating 0.33	large floating 0.27	large floating 0.24
marine 0.44	marine 0.32	marine 0.26	marine 0.23
potential 0.42	paper 0.31	paper 0.25	paper 0.22
impact 0.42	renewable 0.31	renewable 0.25	impact 0.22
ocean 0.41	impact 0.30	impact 0.25	renewable 0.22
energies 0.41	potential 0.30	potential 0.25	energies 0.22
systems 0.41	energies 0.30	energies 0.25	potential 0.22
blue 0.40	ocean 0.29	ocean 0.24	ocean 0.21
applications 0.39	systems 0.29	systems 0.24	systems 0.21
space 0.38	offshore platforms 0.28	offshore platforms 0.23	applications 0.20
different 0.38	applications 0.28	applications 0.23	offshore platforms 0.20
use 0.37	blue 0.27	floating platforms 0.23	islands 0.20
islands 0.36	blue growth 0.27	space 0.22	floating platforms 0.20
review 0.36	floating platforms 0.27	islands 0.22	space 0.20
approach 0.36	space 0.27	blue growth 0.22	blue growth 0.19
wind 0.35	different 0.27	blue 0.22	blue 0.19
scaling 0.34	islands 0.26	different 0.22	different 0.19
farm 0.34	use 0.26	approach 0.21	approach 0.19

References

[1] K. Weeks, M. Safa, G. Kenyon, S. Levius, Offshore multi-purpose platform efficacy by US coastal areas, Renew. Energy 152 (2020) 1451–1464, Jun, https://doi.org/10.1016/j.renene.2020.02.079.

[2] OECD, Multi-Purpose Water Infrastructure. Recommendations to Maximise Economic Benefits, OECD Environment Directorate, 2017. https://www.oecd.org/env/outreach/MPWI_Perspectives_Final_WEB.pdf.

[3] K.A. Dafforn, T.M. Glasby, L. Airoldi, N.K. Rivero, M. Mayer-Pinto, E.L. Johnston, Marine urbanization: an ecological framework for designing multifunctional artificial structures, Front. Ecol. Environ. 13 (2) (Mar. 2015) 82–90, https://doi.org/10.1890/140050.

[4] Z. Huang, F. Wang, Y. Zhou, L. Sui, P. Krishnan, J. Yuen, R. Liew, A novel, multifunctional, floatable, lightweight cement composite: development and properties, Materials 11 (10) (2018) 2043, https://doi.org/10.3390/ma11102043.

[5] K.A. Abhinav, et al., Offshore multi-purpose platforms for a Blue Growth: a technological, environmental and socio-economic review, Sci. Total Environ. 734 (2020) 138256, https://doi.org/10.1016/j.scitotenv.2020.138256.

[6] W.M. Nassar, O. Anaya-Lara, K.H. Ahmed, D. Campos-Gaona, M. Elgenedy, Assessment of multi-use offshore platforms: structure classification and design challenges, Sustainability 12 (5) (2020) 1860, https://doi.org/10.3390/su12051860.

[7] T. Michler-Cieluch, G. Krause, B.H. Buck, Reflections on integrating operation and maintenance activities of offshore wind farms and mariculture, Ocean Coast Manag. 52 (1) (2009) 57–68, https://doi.org/10.1016/j.ocecoaman.2008.09.008.

[8] V. Vazhinskaya, M. Björk, The Export and Scaling Concept – "Ecobarge", Accessed: Feb. 09, 2023. [Online]. Available:, RISE, 2022 https://www.swashgrow.org/wp-content/uploads/2022/11/The-export-and-scaling-concept-ECOBARGE.pdf.

[9] TechSouthWest, MarineTech, 2022. https://www.techsouthwest.co.uk/awards/marine/ (accessed Jul. 03, 2022).

[10] J. Przedrzymirska, et al., Multi-use of the sea as a sustainable development instrument in five EU sea basins, Sustainability 13 (15) (2021) 8159, https://doi.org/10.3390/su13158159.

[11] K. Barquet, J. Green, Towards multifunctionality: adaptation beyond the nature–society dichotomy, in: Stockholm+50 Background Paper series., Stockholm, 2022.

[12] M. Schupp, et al., Toward a common understanding of ocean multi-use, Front. Mar. Sci. 6 (2019).

[13] N. Amiri, M. Shaterabadi, K. Reza Kashyzadeh, M. Chizari, A comprehensive review on design, monitoring, and failure in fixed offshore platforms, J. Mar. Sci. Eng. 9 (12) (2021) 1349, https://doi.org/10.3390/jmse9121349.

[14] L. Guo, H. Wang, Non-intrusive movable energy harvesting devices: materials, designs, and their prospective uses on transportation infrastructures, Renew. Sustain. Energy Rev. 160 (2022), 112340, https://doi.org/10.1016/j.rser.2022.112340.

[15] F.N. Catbas, M. Gul, H.B. Gokce, R. Zaurin, D.M. Frangopol, K.A. Grimmelsman, Critical issues, condition assessment and monitoring of heavy movable structures: emphasis on movable bridges, Struct. Infrastruct. Eng. 10 (2) (2014) 261–276, https://doi.org/10.1080/15732479.2012.744060.

[16] R. Cavagnaro, et al., Powering the blue economy: progress exploring marine renewable energy integration with ocean observations, Mar. Technol. Soc. J. 54 (6) (2020) 114–125, https://doi.org/10.4031/MTSJ.54.6.11.

[17] O. Giustolisi, L. Ridolfi, Modularity index for hydraulic system segmentation, Procedia Eng. 89 (2014) 1152–1159, https://doi.org/10.1016/j.proeng.2014.11.240.

[18] C.Y. Baldwin, K.B. Clark, Design Rules, MIT Press, Cambridge, Mass, 2000.

[19] R.N. Langlois, Modularity in technology and organization, J. Econ. Behav. Organ. 49 (1) (2002) 19–37, https://doi.org/10.1016/S0167-2681(02)00056-2.

[20] D. Clemente, P. Rosa-Santos, F. Taveira-Pinto, On the potential synergies and applications of wave energy converters: a review, Renew. Sustain. Energy Rev. 135 (2021), https://doi.org/10.1016/j.rser.2020.110162.

[21] L. Neimann Rasmussen, P. Montgomery, The prevalence of and factors associated with inclusion of non-English language studies in Campbell systematic reviews: a survey and meta-epidemiological study, Syst. Rev. 7 (1) (2018) 129, https://doi.org/10.1186/s13643-018-0786-6.

[22] E. Dawkins, K. André, K. Axelsson, L. Benoist, Å.G. Swartling, Å. Persson, Advancing sustainable consumption at the local government level: a literature review, J. Clean. Prod. 231 (2019) 1450–1462, https://doi.org/10.1016/j.jclepro.2019.05.176.

[23] N.R. Haddaway, P. Woodcock, B. Macura, A. Collins, Making literature reviews more reliable through application of lessons from systematic reviews: making Literature Reviews More Reliable, Conserv. Biol. 29 (6) (2015) 1596–1605, https://doi.org/10.1111/cobi.12541.

[24] E. Dawkins, K. André, K. Axelsson, L. Benoist, Å.G. Swartling, Å. Persson, Advancing sustainable consumption at the local government level: a literature review, J. Clean. Prod. 231 (2019) 1450–1462, https://doi.org/10.1016/j.jclepro.2019.05.176.

[25] M. Ouzzani, H. Hammady, Z. Fedorowicz, A. Elmagarmid, Rayyan—a web and mobile app for systematic reviews, Syst. Rev. 5 (1) (2016) 210, https://doi.org/10.1186/s13643-016-0384-4.

[26] N.R. Haddaway, B. Macura, P. Whaley, A.S. Pullin, ROSES Flow Diagram for Systematic Reviews. Version 1.0, 2017, https://doi.org/10.6084/m9.figshare.5897389.v3.

[27] G. Salton, C. Buckley, Term-weighting approaches in automatic text retrieval, Inf. Process. Manag. 24 (5) (1988) 513–523, https://doi.org/10.1016/0306-4573(88)90021-0.

[28] A. Aizawa, An information-theoretic perspective of tf–idf measures, Inf. Process. Manag. 39 (1) (2003) 45–65, https://doi.org/10.1016/S0306-4573(02)00021-3.

[29] M. Jabłońska-Sabuka, R. Sitarz, A. Kraslawski, Forecasting research trends using population dynamics model with Burgers' type interaction, J. Informetr. 8 (1) (2014) 111–122, https://doi.org/10.1016/j.joi.2013.11.003.

[30] S. Nam, K. Kim, Monitoring newly adopted technologies using keyword based analysis of cited patents, IEEE Access 5 (2017) 23086–23091, https://doi.org/10.1109/ACCESS.2017.2764478.

[31] A. Jalilifard, V.F. Caridá, A.F. Mansano, R.S. Cristo, F.P.C. da Fonseca, Semantic sensitive TF-IDF to determine word relevance in documents, in: S.M. Thampi, E. Gelenbe, M. Atiquzzaman, V. Chaudhary, K.-C. Li (Eds.), Advances in Computing and Network Communications, vol. 736, Springer Singapore, Singapore, 2021, pp. 327–337, https://doi.org/10.1007/978-981-33-6987-0_27.

[32] G. Chen, L. Xiao, Selecting publication keywords for domain analysis in bibliometrics: a comparison of three methods, J. Informetr. 10 (1) (2016) 212–223, https://doi.org/10.1016/j.joi.2016.01.006.

[33] J. Nothman, H. Qin, R. Yurchak, Stop word lists in free open-source software packages, in: Proceedings of Workshop for NLP Open Source Software (NLP-OSS), Melbourne, Australia, 2018, pp. 7–12, https://doi.org/10.18653/v1/W18-2502.

[34] L. Buitinck, et al., API Design for Machine Learning Software: Experiences from the Scikit-Learn Project, 2013, https://doi.org/10.48550/arXiv.1309.0238.

[35] S. van den Burg, J. Aguilar-Manjarrez, J. Jenness, M. Torrie, Assessment of the geographical potential for co-use of marine space, based on operational boundaries for Blue Growth sectors, Mar. POLICY 100 (2019) 43–57, https://doi.org/10.1016/j.marpol.2018.10.050.

[36] D. Depellegrin, et al., Exploring Multi-Use potentials in the Euro-Mediterranean sea space, Sci. Total Environ. 653 (2019) 612–629, https://doi.org/10.1016/j.scitotenv.2018.10.308.

[37] E. Loukogeorgaki, D. Vagiona, M. Vasileiou, Site selection of hybrid offshore wind and wave energy systems in Greece incorporating environmental impact assessment, Energies 11 (8) (2018), https://doi.org/10.3390/en11082095.

[38] C. Pascual, J. Garcia, R. Garcia, Wind energy ships: global analysis of operability, J. Mar. Sci. Eng. 9 (5) (2021), https://doi.org/10.3390/jmse9050517.

[39] S. van den Burg, M. Schupp, D. Depellegrin, A. Barbanti, S. Kerr, Development of multi-use platforms at sea: barriers to realising Blue Growth, Ocean. Eng. 217 (2020), https://doi.org/10.1016/j.oceaneng.2020.107983.

[40] M. Haji, J. Kluger, T. Sapsis, A. Slocum, A symbiotic approach to the design of offshore wind turbines with other energy harvesting systems, Ocean. Eng. 169 (2018) 673–681, https://doi.org/10.1016/j.oceaneng.2018.07.026.

[41] D. Konispoliatis, et al., REFOS: a renewable energy multi-purpose floating offshore system, Energies 14 (11) (2021), https://doi.org/10.3390/en14113126.

[42] V. Basile, N. Capobianco, R. Vona, The usefulness of sustainable business models: analysis from oil and gas industry, Corp. Soc. Responsib. Environ. Manag. (2020), https://doi.org/10.1002/csr.2153.

[43] S. Grandi, et al., Planning for a safe and sustainable decommissioning of offshore hydrocarbon platforms: complexity and decision support systems. Preliminary considerations, GEAM-Geoing. Ambient. E MINERARIA-GEAM-Geoengin. Environ. Min. 152 (2017) 101–108.

[44] L. Margheritini, et al., Development of an eco-sustainable solution for the second life of decommissioned oil and gas platforms: the mineral accretion technology, Sustainability 12 (9) (2020), https://doi.org/10.3390/su12093742.

[45] E. Meyer-Gutbrod, M. Love, D. Schroeder, J. Claisse, L. Kui, R. Miller, Forecasting the legacy of offshore oil and gas platforms on fish community structure and productivity, Ecol. Appl. 30 (8) (2020), https://doi.org/10.1002/eap.2185.

[46] F. Murray, et al., Data challenges and opportunities for environmental management of North Sea oil and gas decommissioning in an era of blue growth, Mar. POLICY 97 (2018) 130–138, https://doi.org/10.1016/j.marpol.2018.05.021.

[47] M. Pinheiro, et al., From decision-making to Oceans Accounts: a case study, in: OCEANS 2019 - MARSEILLE, 2019.

[48] I. Antoncecchi, et al., Research HUB for an integrated green energy system reusing SEALINES for H-2 storage and transport, Environ. Eng. Manag. J. 19 (10) (2020) 1647–1656.

[49] N. Capobianco, V. Basile, F. Loia, R. Vona, Toward a sustainable decommissioning of offshore platforms in the oil and gas industry: a pestle analysis, Sustainability 13 (11) (2021), https://doi.org/10.3390/su13116266.

[50] S. Kolian, M. Godec, P. Sammarco, Alternate uses of retired oil and gas platforms in the Gulf of Mexico, Ocean Coast Manag. 167 (2019) 52–59, https://doi.org/10.1016/j.ocecoaman.2018.10.002.

[51] M. Leporini, B. Marchetti, F. Corvaro, F. Polonara, Reconversion of offshore oil and gas platforms into renewable energy sites production: assessment of different scenarios, Renew. Energy 135 (2019) 1121–1132, https://doi.org/10.1016/j.renene.2018.12.073.

[52] K. Satterlee, S. Watson, E. Danenberger, IEEE, New Opportunities for Offshore Oil and Gas Platforms - Efficient, Effective, and Adaptable Facilities for Offshore Research, and Technology Testing, Monitoring, 2018.

[53] D. Sedlar, D. Vulin, G. Krajacic, L. Jukic, Offshore gas production infrastructure reutilisation for blue energy production, Renew. Sustain. Energy Rev. 108 (2019) 159–174, https://doi.org/10.1016/j.rser.2019.03.052.

[54] C. Kaeochuen, A. Mandzir, R. Yusof, K. Kaminishi, W. Aimin, Feasibility study of the methods of hydrogen distribution from ocean thermal energy conversion power plant: an initial proposed OTEC-hydrogen logistics roadmap, in: Proc. 13TH Int. Conf. Innov. Manag. VOLS II, 2016, p. 966.

[55] E. Solomin, K. Gao, Y. Jiang, M. Deng, IEEE, Off-shore PV and wind based energy generation, in: 2019 Int. Conf. Ind. Eng. Appl. Manuf. ICIEAM, 2019.

[56] J. Buongiorno, J. Jurewicz, M. Golay, N. Todreas, The offshore floating nuclear plant concept, Nucl. Technol. 194 (1) (2016) 1–14.

[57] L. Cradden, C. Kalogeri, I. Barrios, G. Galanis, D. Ingram, G. Kallos, Multi-criteria site selection for offshore renewable energy platforms, Renew. Energy 87 (2016) 791–806, https://doi.org/10.1016/j.renene.2015.10.035.

[58] T. Hooper, C. Hattam, M. Austen, Recreational use of offshore wind farms: experiences and opinions of sea anglers in the UK, Mar. POLICY 78 (2017) 55–60, https://doi.org/10.1016/j.marpol.2017.01.013.

[59] N. Steins, J. Veraart, J. Klostermann, M. Poelman, Combining offshore wind farms, nature conservation and seafood: lessons from a Dutch community of practice, Mar. POLICY 126 (2021), https://doi.org/10.1016/j.marpol.2020.104371.

[60] D. Abozaid, M. Abdelaziz, M. Ali, H. Shawky, E. Oterkus, Investment efficiency of floating platforms desalination technology in Egypt, Desalination Water Treat. 183 (2020) 1–6, https://doi.org/10.5004/dwt.2020.25688.

[61] A. Babarit, E. Body, J. Gilloteaux, J. Hetet, IEEE, Energy and Economic Performance of the FARWIND Energy System for Sustainable Fuel Production from the Far-Offshore Wind Energy Resource, 2019.

[62] O.S. Ibrahim, A. Singlitico, R. Proskovics, S. McDonagh, C. Desmond, J.D. Murphy, Dedicated large-scale floating offshore wind to hydrogen: assessing design variables in proposed typologies, Renew. Sustain. Energy Rev. 160 (2022), 112310, https://doi.org/10.1016/j.rser.2022.112310.

[63] J. Izquierdo-Perez, B. Brentan, J. Izquierdo, N. Clausen, A. Pegalajar-Jurado, N. Ebsen, Layout optimization process to minimize the cost of energy of an offshore floating hybrid wind-wave farm, Processes 8 (2) (2020), https://doi.org/10.3390/pr8020139.

[64] D. Pantusa, A. Francone, G. Tomasicchio, Floating offshore renewable energy farms. A life-cycle cost analysis at brindisi, Italy, Energies 13 (22) (2020), https://doi.org/10.3390/en13226150.

[65] C. Perez-Collazo, D. Greaves, G. Iglesias, A novel hybrid wind-wave energy converter for jacket-frame substructures, Energies 11 (3) (2018), https://doi.org/10.3390/en11030637.

[66] S. Roussanaly, et al., Offshore power generation with carbon capture and storage to decarbonise mainland electricity and offshore oil and gas installations: a techno-economic analysis, Appl. Energy 233 (2019) 478–494, https://doi.org/10.1016/j.apenergy.2018.10.020.

[67] C.E. Clark, A. Miller, B. DuPont, An analytical cost model for co-located floating wind-wave energy arrays, Renew. Energy 132 (2019) 885–897, https://doi.org/10.1016/j.renene.2018.08.043.

[68] S. Oliveira-Pinto, P. Rosa-Santos, F. Taveira-Pinto, Assessment of the potential of combining wave and solar energy resources to power supply worldwide offshore oil and gas platforms, Energy Convers. Manag. 223 (2020) 113299, https://doi.org/10.1016/j.enconman.2020.113299.

[69] I. Qasim, L. Gao, D. Peng, B. Liu, Catamaran or semi-submersible for floating platform selection of a better design, in: W. Tang (Ed.), International Conference on Energy Engineering and Environmental Protection (EEEP2017), vol. 121, 2018, https://doi.org/10.1088/1755-1315/121/5/052041.

[70] C. Weiss, et al., Co-location opportunities for renewable energies and aquaculture facilities in the Canary Archipelago, Ocean Coast Manag. 166 (2018) 62–71, https://doi.org/10.1016/j.ocecoaman.2018.05.006.

[71] S. Huebner, Tackling climate change, air pollution, and ecosystem destruction: how US-Japanese ocean industrialization and the metabolist movement's global legacy shaped environmental thought (circa 1950s present), Environ. Hist. 25 (1) (2020) 35–61, https://doi.org/10.1093/envhis/emz080.

[72] F. Lagasco, et al., New engineering approach for the development and demonstration of a multi-purpose platform for the blue growth economy, in: Proceedings of the Asme 38th International Conference on Ocean, Offshore and Arctic Engineering, vol. 6, 2019, p. 2019.

[73] C. Ruzzo, et al., Scaling strategies for multi-purpose floating structures physical modeling: state of art and new perspectives, Appl. Ocean Res. 108 (2021) 102487, https://doi.org/10.1016/j.apor.2020.102487.

[74] J. Tamis, R. Jongbloed, G. Piet, R. Jak, Developing an environmental impact assessment for floating island applications, Front. Mar. Sci. 8 (2021), https://doi.org/10.3389/fmars.2021.664055.

[75] J.C. Pereira-Kohatsu, L. Quijano-Sánchez, F. Liberatore, M. Camacho-Collados, Detecting and monitoring hate speech in twitter, Sensors 19 (21) (2019), https://doi.org/10.3390/s19214654.

[76] M.N. Nikiforos, Y. Voutos, A. Drougani, P. Mylonas, K.L. Kermanidis, The modern Greek language on the social web: a survey of data sets and mining applications, Data 6 (5) (2021), https://doi.org/10.3390/data6050052. Art. no. 5.

[77] H. Nguyen, C. Wang, Z. Tay, V. Luong, Wave energy converter and large floating platform integration: a review, Ocean. Eng. 213 (2020), https://doi.org/10.1016/j.oceaneng.2020.107768.

[78] S. van den Burg, et al., Participatory design of multi-use platforms at sea, Sustainability 8 (2) (2016), https://doi.org/10.3390/su8020127.