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Investigating levies and barriers for the development of offshore multi-use platforms in European regional seas

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The ocean is a crucial driver of economic activities, providing space for sectors such as offshore wind farms, transportation, and aquaculture. To foster economic growth while minimizing environmental impacts, the European Commission has introduced a sustainable blue economy strategy. However, increasing demand for marine space has led to spatial conflicts and environmental concerns. Offshore Multi-Use Platforms (OMUPs) have emerged as a potential solution, integrating multiple marine activities within a shared infrastructure to optimize space utilization and reduce ecological footprints. This study investigates the barriers and levies associated with OMUP development in European regional seas by applying a business analysis approach to five pilot projects across Belgium, Denmark, Germany, Greece, and the Netherlands. The analysis integrates PESTEL (political, economic, social, technological, environmental, and legal factors), SWOT (strengths, weaknesses, opportunities, and threats), and Business Model Canvas (BMC) methodologies. Findings indicate that OMUP development faces significant challenges, including high investment costs, regulatory complexity, and stakeholder coordination difficulties, while also presenting key opportunities such as technological innovation, policy incentives, and synergies between marine sectors. The research highlights the potential of OMUPs to contribute to a sustainable blue economy by promoting efficient marine resource use and reducing spatial conflicts. Overcoming regulatory and financial barriers is crucial for scaling up pilot projects to industrial implementation, and future research should explore policy harmonization and funding mechanisms to facilitate OMUP adoption in Europe.

KEYWORDS

multi-use offshore platform, blue growth, marine spatial planning, sustainable blue economy, business analysis, PESTEL, SWOT, business model canvas

1 Introduction

The ocean is central to economic activity through the various ecosystem services it provides. Because the oceans and seas are one of the main drivers of the European economy and have significant potential for innovation and growth, the European Commission put the Blue Growth Strategy (European Commission, 2017) in place and, more recently, adopted a novel approach for a sustainable blue economy in the European Union (European Commission, 2021). The new strategy sets out a detailed agenda to transition from "Blue Growth" to a sustainable blue economy, more explicitly incorporating sustainability objectives for blue economy sectors. The strategy aims to support sustainable growth in the maritime sectors (e.g., aquaculture, tourism, transport, energy, etc.) and reduce pressure on the marine environment caused by the growing interest in the various blue economy sectors, notably fishing and maritime transport activities. However, the growth of the European Union's blue economy has intensified competition for marine space and resources.

To address these challenges, marine spatial planning (MSP; European MSP Platform, 2018) has been instrumental in facilitating the balanced allocation of marine resources among competing demands. MSP provides a structured approach to organizing marine space, ensuring that economic development aligns with environmental sustainability and social considerations. By promoting coordinated decision-making among stakeholders, MSP enhances the efficiency of marine resource use and reduces potential conflicts between sectors.

Building on the principles of MSP, offshore multi-use platforms (OMUPs) have emerged as innovative solutions to mitigate conflicts and promote synergies between multiple offshore industries such as aquaculture, energy, transport, and tourism. These platforms integrate multiple activities within the same space, offering a strategic approach to optimize marine resource use. OMUPs' potential to support sustainable marine development has been widely recognized. Xylia et al. (2023) highlight that while multifunctionality, particularly the combination of wind–aquaculture and wave–wind energy, has been extensively studied, aspects like modularity and mobility remain underexplored. Their review underscores the need for further research on the institutional frameworks and methodologies that can facilitate the scaling of such solutions. Within this context, OMUPs provide an opportunity to explore synergies among marine sectors while addressing economic, environmental, and spatial challenges.

Several studies have highlighted this. For instance, the H2020 UNITED project emphasized OMUPs' role in resolving spatial conflicts while fostering innovation and sustainable growth (Zaiter et al., 2022). Other studies, such as Abhinav et al.'s (2020) study, argue that these platforms can enhance operational efficiency by leveraging complementarities between different offshore industries.

Within the European Union, the multi-use of marine space has been a focus of research and innovation for several years, reflected in projects like the EU H2020 MARIBE (http://maribe.eu), which explores OMUPs' potential in the offshore economy, supporting sustainable blue growth in marine and maritime sectors. Similarly, the H2020 MUSES project (https://muses-project.com/) aims to assess OMUPs' current and future potential in the Euro-Mediterranean Sea Basin using a mixed-method approach, including desk research, geographic analysis, and stakeholder engagement through semi-structured interviews and workshops (Depellegrin et al., 2019). The H2020 UNITED project (https://www.h2020united.eu/) aims to demonstrate the benefits and challenges of OMUPs through experiences gained in five pilot projects (Ciravegna et al., 2024). More recently, the ULTFARMs project (https://ultfarms.eu/) aims to increase Europe's low trophic aquaculture capacity through innovative processes optimized for challenging offshore conditions.

Various methodologies have been applied to assess the feasibility and potential of such platforms. Among these is the drivers, added value, barriers, and impacts (DABI) approach (Zaucha et al., 2016). This approach aims to provide a framework to provide an overview of the potential to develop or strengthen multi-use activities in the European seas and evaluate the effect of multi-use development. This approach has gained recognition for systematically evaluating multi-use opportunities. For instance, Kyvelou and Ierapetritis (2021) applied this method to assess socially sustainable multi-use opportunities in the Mediterranean, specifically focusing on small-scale fisheries, tourism, and nature conservation related to marine protected areas in Greece. Bocci et al. (2019), by comparison, aimed to identify multi-use combinations with the greatest potential for environmental, socioeconomic, and local benefits across European seas while also outlining key actions to promote multi-use development. Stancheva et al. (2022) further demonstrated the applicability of the DABI approach by supporting multi-use development in Bulgaria's Black Sea region, focusing on tourism and aquaculture integration to enhance spatial efficiency and economic opportunities.

Despite these contributions, multiuse platforms remain largely in the pilot phase within the European member states (e.g., Belgium, Denmark, Germany, Greece, and the Netherlands), with significant challenges to scaling up their implementation. Member states are exploring ways to upscale OMUPs from the development phase to the operational phase.

Diverse studies highlight several challenges associated with implementing economic activities in shared locations. Key requirements for successful implementation include cooperative attitudes among different activities and developing synergies among different sectors. Feasibility, particularly financial feasibility, and attracting investment from private and public stakeholders remain significant concerns (Dalton et al., 2019). The lack of established market mechanisms and clear financial incentives further exacerbates these challenges, potentially slowing the uptake of such initiatives (Stuiver et al., 2016). A more recent study showed that important economic barriers such as high upfront capital investment and financial uncertainties may hinder OMUP implementation (van den Burg et al., 2020). Therefore, government and public subsidies are required to reduce uncertainties and encourage private investors to take the risk (Dalton et al., 2019; van den Burg et al., 2020).

While methodologies such as DABI provide valuable insights, a need remains for integrated approaches that specifically assess the levies and barriers influencing the transition of OMUPs from pilot projects to full-scale operational platforms. This study directly addresses this need by employing a novel business analysis approach (BAA) to systematically investigate the economic, regulatory, and operational barriers that hinder OMUP development, as well as the key levies or enabling factors that can facilitate their successful implementation. Through this comprehensive evaluation, the article provides insights into the viability and challenges associated with implementing multi-use platforms, contributing valuable knowledge to further the goals of a sustainable blue economy in the European maritime sectors.

The International Institute of Business Analysis (2022) defines business analysis as a tool for identifying and addressing organizational needs. Various techniques have been employed in marine and OMUP contexts. For instance, Ronchi et al. (2019) applied the strength, weakness, opportunity, and threat (SWOT) matrix to analyze the barriers to implementing the Fishing For Litter scheme in the Adriatic Ionian microregion. Stuiver et al. (2016) used the Political, Economic, Social, Technological, Environmental, and Legal (PESTEL) analysis to assess governance arrangements that may either facilitate or complicate the development of OMUP in the context of reducing pressure on the marine space. In a different context, the oil and gas industry, the PESTEL analysis was used to explore the challenges and potential of sustainable business models for decommissioning offshore platforms (Capobianco et al., 2021). Christodoulou and Cullinane (2019) combined SWOT and PESTEL to investigate the prospects and challenges of developing a port energy management system based on empirical data from two leading North European port authorities. Finally, the H2020 MARIBE project explored OMUP business models using the business model canvas (BMC). The aim was to gain insights into the business model of OMUP, specifically examining how, within an OMUP, companies create, deliver, and capture value.

Despite these applications, previous studies often used these tools independently without integration, particularly in the context of OMUP development. In this study, we advocate for a novel BAA that combines multiple techniques, specifically PESTEL, SWOT, and BMC, aiming to provide a comprehensive and robust understanding of the barriers and levies in the development process. To the best of our knowledge, this integrated analysis is being proposed for the first time. This approach represents our contribution to advancing the methodological framework for OMUP development by synthesizing insights from these three complementary tools into a cohesive and systematic analysis.

2 Background

The UNITED project encompasses five distinct pilots situated in Belgium, Denmark, Germany, Greece, and the Netherlands, strategically distributed across three regional seas: the North Sea, the Mediterranean Sea, and the Baltic Sea (see Figure 1). By addressing current bottlenecks, showcasing business synergies, and enhancing technology readiness levels, the UNITED project contributes to greater efficiency and collaboration within the Blue Economy while proposing optimized business models for future multi-use sites.

FIGURE 1
Geographical distribution of UNITED project pilots across European Union member states and regional seas. Source: copyright UNITED, https://www.h2020united.eu/, reproduced with permission.

3 Materials and methods: application of the business analysis approach

The BAA developed for this study follows a structured three-step process, illustrated in Figure 2. It systematically examines the internal and external factors influencing OMUP development and assesses its business viability. The approach integrates PESTEL, SWOT, and BMC to provide a comprehensive evaluation of the challenges and opportunities associated with OMUPs.

3.1 Business analysis approach (BAA)

The initial step (Mapping the OMUP Context) involved an in-depth investigation of the OMUP context. This step had two main objectives: first, to clarify pilot activities, including assessing their technology readiness level (TRL[1]; as reported by the pilots and that offered insights into their respective development stages) and conduct a detailed examination of the pilots' missions and visions and, second, to explore the rationale behind activity combinations and the expected synergies while mapping strategic road maps to achieve TRL goals and pilot objectives. While this step provided a broad understanding of the socioeconomic, environmental, and legal contexts of OMUPs, it also highlighted specific gaps requiring further analysis. For example, the interaction between internal strengths and weaknesses and the influence of external political, economic, and technological factors has been identified as critical areas requiring further exploration. This information guided the design of subsequent steps, which applied structured tools such as PESTEL, SWOT, and BMC to address these complexities and provide actionable recommendations for developing OMUPs.

The second step (Mapping the Internal and External Factors Influencing the OMUP Activities) combined two methodologies: PESTEL and SWOT analyses. On one hand, the PESTEL analysis strategically mapped the pilots' contexts and external factors having direct and/or indirect impacts on the pilots' activities. The pilots' contexts, unique to their operational environments, are distinguished across various pilots, while external factors represent occurrences beyond the project's scope that yield direct and/or indirect influence on the pilot. The PESTEL analysis aligns with the five pillars of the UNITED project: Technological, Economic, Environmental, Legal, Policy & Governance, and Societal. The PESTEL technique has been used and applied previously in other renewable energy contexts. For instance, Mytilinou et al. (2015) applied PESTEL analysis when comparing various aspects of wind energy development across different European countries, identifying key technological and economic barriers. Similarly, Valencia et al. (2018) utilized PEST analysis to evaluate the global successes and disadvantages in the development of wind energy, offering a comprehensive overview of the external factors influencing this renewable energy sector. By integrating these five pillars, the PESTEL analysis offers a comprehensive framework for understanding external factors influencing the development of OMUPs.

On the other hand, the SWOT analysis, complementing the PESTEL analysis, comprehensively identified the pilots' internal strengths and weaknesses while classifying external factors as opportunities or threats. This strategic step enhances awareness of decision-making factors and allows for the anticipation of development by formulating strategies to leverage opportunities and overcome weaknesses. The SWOT method has been effectively employed in previous studies. For example, Stingheru et al. (2018) aimed to provide a comprehensive overview of renewable marine energy resources in Europe by identifying pertinent SWOT factors. Their primary objective was to explore pathways for enhancing the exploitation potential of the marine energy sector. By analyzing internal and external factors, their study provided critical insights essential for strategic planning and informed decision-making in the sector. Similarly, Goffetti et al. (2018) emphasized the necessity of strategic planning in energy transitions, particularly for marine renewable energy technologies. Their study conducted a holistic SWOT analysis across dimensions, including social, economic, legal, technological, and environmental aspects. By disaggregating the SWOT analysis, they aimed to identify specific challenges and opportunities within each dimension, offering a nuanced perspective crucial for optimizing sustainable energy production and marine space management. Furthermore, the combined use of PESTEL and SWOT analyses, as employed by Kansongue et al. (2023), enhances understanding of the development of marine sectors, such as marine renewable energy, marine aquaculture, tourism, and, particularly, the development of OMUP.

The final step (Comprehending the OMUP Business Model) employed the BMC to illustrate how pilots generate, deliver, and capture value. This framework, consisting of nine building blocks, facilitates a shared language for describing, visualizing, assessing, and innovating business models. This study represents the first application of BMC in an OMUP context, showcasing its potential to optimize multi-use business strategies.

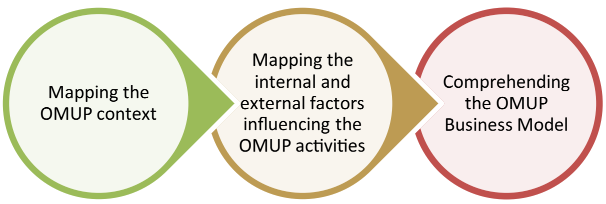

FIGURE 2
Business analysis approach. OMUP, offshore multi-use platform.

3.2 Application of business analysis approach

The application of the BAA followed a structured, multi-phase process to ensure comprehensive and reliable analysis of the pilots.

The preliminary phase involved conducting desk research to gather background information about the different pilots. The information collected included details on the pilots' contexts and

1 TRL is a scale used to assess the maturity of a technology, ranging from TRL 1 (basic principles observed) to TRL 9 (actual system proven in an operational environment).

different stakeholders, as well as the combined activities and pilots' TRL. Preliminary findings were discussed during meetings with different stakeholders involved in the pilots' activities. The stakeholders were asked to validate information and provide additional input based on their expertise and field experience.

In the second phase, additional information was carried out to support the PESTEL, SWOT, and BMC analyses. This was done through interviews with stakeholders directly involved in the pilots' activities. To ensure consistency across pilots, a semi structured questionnaire was developed. This questionnaire focused on identifying internal and external factors affecting the pilots' operations, as well as key elements of their business models. Stakeholders directly involved in the pilots, such as offshore wind farm (OWF) operators and aquaculture farmers, were identified and contacted. In total, 11 stakeholders participated, providing comprehensive information across all sectors studied.

The interview process included a systematic approach: an initial discussion to present preliminary findings, structured interviews to gather in-depth perspectives, and iterative feedback sessions. A double-validation process was implemented to ensure accuracy and completeness. First, responses were verified between the interviewer and interviewee, and second, they were cross-checked with the respective pilot leads.

This rigorous approach—combining desk research, stakeholder consultations, and structured interviews—enhanced the reliability of the collected data. Moreover, the approach allowed a thorough examination of the factors influencing the success of OMUPs and offers actionable insights to inform strategic decision-making and planning.

4 Results

4.1 Pilot contexts

The UNITED pilots span three regional seas in Europe, each demonstrating distinct approaches to OMUP development. While some pilots focus on integrating renewable energy with aquaculture, others explore synergies between tourism and offshore infrastructure. These variations highlight different strategies for optimizing marine space and diversifying economic activities (Table 1).

In the North Sea, the Dutch pilot integrates large-scale offshore solar farms with seaweed cultivation and existing wind energy infrastructure. This initiative aims to maximize space efficiency and develop scalable solutions for multi-use offshore energy production and food supply. Similarly, the Belgian pilot combines offshore wind energy with European flat oyster aquaculture, reef restoration, and seaweed farming. By incorporating ecological restoration alongside food production, this pilot demonstrates how multi-use platforms can enhance biodiversity while optimizing marine space. Operational synergies include shared vessel use for wind farm maintenance and aquaculture activities, improving cost-effectiveness.

TABLE 1 Overview of the five pilot projects analyzed in this study, including their geographical location, key activities, objectives, TRLs, and synergies between the activities.

Pilot	Activities	Objective	TRL	OMUPs' synergies
DK	OFW and tourism	Expand existing tourism activities and create new attractions through shared sea space, joint on- and offshore infrastructure, and operational activities.	TRL 9	Shared use of vessels for maintaining the OWF and conducting tourism activity tours, leading to cost savings and financial benefits for all parties involved.
NL	OFWs, offshore solar farms, and aquaculture (seaweed)	• Support the development of large-scale offshore solar farms and address important bottlenecks that impede such implementation. • Develop large-scale offshore seaweed farms integrated with existing wind parks and develop new OWFs offering integrated wind/aquaculture activities.	TRL 6 and 7	Cost reductions, wave dampening effect, solar-powered monitoring systems for aquaculture health using sensors that can transfer measurements to onshore monitoring stations, and improved wind grid infrastructure from solar power generation, enhancing economic performance.
BE	Aquaculture (oysters, seaweed) and OFWs	• Evaluate OWFs as suitable locations for restoring native flat oyster reefs alongside cultivating flat oysters and seaweed for human consumption. • Compare the growth of sugar kelp cultivated offshore and nearshore.	TRL 5 and 6 (OWF TRL 9)	Cost savings through shared service vessels for wind turbine maintenance, restoration, and aquaculture. Utilization of the same port facilities and offshore infrastructure.
DE	OFW and aquaculture	• Develop, operate, and evaluate offshore demonstration aquaculture farm with blue mussels (*Mytilus edulis*) and macroalgae (*Saccharina latissima*) at the offshore research platform FINO3. • Investigate multi-use possibilities in the North Sea between offshore wind energy generation and aquaculture.	TRL 7 (TRL 9 for individual components)	Shared transportation (ships, helicopters) for routine monitoring and maintenance trips—which would also reduce the environmental impact of transportation. Combined monitoring and maintenance trips improve logistical efficiency. Shared offshore infrastructure optimizes operational costs.
EL	Aquaculture and diving tours	The mission of the Greek pilot was to explore how to combine aquaculture and tourism activities. Specifically, the pilot investigated the potential of including an aquaculture farm in scuba diving tours, thereby turning the aquaculture farm into a touristic asset, providing economic opportunities, and alleviating local opposition to aquaculture.	TRL 7/8	Synergies include shared customer segments (domestic and international tourists), cost savings through overlapping expenses (advertising and boats), and using tourism to raise awareness about sustainable aquaculture practices.

TRL, technology readiness level; OMUP, offshore multi-use platform; DK, Denmark; NL, the Netherlands; BE, Belgium; DE, Germany; EL, Greece; OWF, offshore wind farm.

The German pilot, located at the FINO3 research platform, also integrates offshore wind energy infrastructure with a demonstration aquaculture farm of blue mussels and macroalgae. The pilot is testing the feasibility of co-locating blue mussel and macroalgae farming within wind park areas. This pilot explores logistical challenges, such as coordinating aquaculture operations with wind farm maintenance and ensuring the resilience of aquaculture structures in high-energy offshore environments. Synergies from this multi-use solution include logistical efficiencies, automated monitoring systems that benefit both aquaculture and wind energy operations, and enhanced social acceptance of offshore activities.

Moving beyond energy-aquaculture integration, the Danish pilot near Copenhagen focuses on combining offshore wind energy with tourism. By leveraging its location near key cultural and historical landmarks, this pilot introduces educational tours, virtual visits, and recreational activities such as diving and fishing. This initiative demonstrates the potential of tourism to create public engagement, increase acceptance of offshore wind farms, and generate additional revenue to support infrastructure maintenance. The synergies in this pilot include using tourism revenues to support the ongoing maintenance of wind turbines, ensuring both economic and environmental sustainability.

In the Mediterranean, the Greek pilot at Cape Sounio integrates aquaculture with tourism in a marine protected area. Visitors engage in scuba diving tours that provide insights into aquaculture practices while promoting environmental awareness. Synergies include using tourism as a platform for educating visitors about sustainable aquaculture practices, thereby enhancing local acceptance and support for marine conservation efforts. In addition, the pilot incorporates a third digital activity: monitoring fish behavior through cameras installed at the aquaculture cages to track stress indicators during the scuba diving expeditions. Environmental parameters at the aquaculture site are monitored using multi-probe sensors. However, for the purposes of this study, only the primary activities of aquaculture and tourism were analyzed.

Collectively, these pilots highlight diverse approaches to OMUP development, demonstrating how different industries can be integrated to enhance efficiency, sustainability, and stakeholder engagement in offshore environments.

4.2 External drivers influencing OMUP development

OMUP development is influenced by a range of factors across the political, economic, social, technological, environmental, and legal sectors. Each of these factors plays a crucial role in shaping the success and feasibility of such initiatives.

At the *political level*, the success of OMUPs heavily relies on the support and commitment of both national governments and European institutions. Political support is essential for creating favorable policy frameworks, financial incentives, and strategic plans aimed at promoting renewable energy and sustainable marine activities. For example, at the EU level, policies such as the European Green Deal (European Commission, 2019) and the European Union's Sustainable Blue Economy (European Commission, 2021) support marine renewable energy and multi-se platforms. The European Green Deal emphasizes renewable energy sources, including offshore wind, to achieve climate neutrality by 2050. Meanwhile, the Sustainable Blue Economy fosters innovation and investment in sustainable marine and maritime sectors. However, the degree of support and the regulatory environment vary significantly across EU member states, affecting the implementation and progress of OMUP projects. For instance, the German pilot benefits from strong political support at both the EU and national levels. The 2021 German MSP aligned with the European Union's Marine Strategy Framework Directive (MSFD) and Renewable Energy Directive, allocates 15% of the exclusive economic zone to offshore wind energy and explicitly supports aquaculture expansion and multi-use initiatives. However, gaps remain in regulatory and financial incentives, as no dedicated subsidies or streamlined permitting frameworks exist for multi-use projects, presenting challenges to OMUP development. Similarly, the Dutch pilot has benefited from stable political commitment and progressive policies, such as the 2015 Dutch Offshore Wind Energy Act and the Dutch 2021 MSP, which emphasize co-location of activities like aquaculture and renewable energy. While renewable energy subsidies have facilitated offshore wind development, specific financial mechanisms for integrated projects like floating solar and aquaculture are still lacking. High costs and regulatory compliance issues, particularly during the COVID-19 pandemic, have further complicated implementation.

Regulatory frameworks are equally critical in shaping the development of OMUPs. These include laws, regulations, and guidelines governing marine space use, environmental protection, and the integration of various marine activities. Fragmented, unclear, or overly strict frameworks pose significant challenges for project developers. Obtaining permits for OMUPs can be a complex and lengthy process, often involving multiple regulatory bodies and stringent environmental impact assessments (EIAs). For instance, in Belgium, the strict EIA requirements and complex regulatory landscape at both the national and EU levels cause delays and increased costs, making navigating these processes challenging. Fragmentation of policies and uncertainty over legal frameworks further exacerbate the issues of regulatory bottlenecks in the initial stages of OMUP implementation (Dalton et al., 2019).

Political stability and long-term commitment are also essential for OMUPs' success. Political instability or frequent changes in government policies can create an uncertain environment for investors and developers. Long-term political commitment ensures that policies and support mechanisms remain consistent, providing a predictable environment for investors and developers. Countries with stable political environments and long-term commitments to renewable energy and marine spatial planning tend to be more successful in developing OMUPs. The Danish pilot illustrates the benefits of long-term political support, promoting local engagement and sustainable development. Moreover, international collaboration and policy harmonization are becoming increasingly important, particularly in shared marine areas. Harmonizing policies across borders can help reduce regulatory fragmentation and create a cohesive environment for OMUP development. The

European Union plays a crucial role through initiatives such as the Atlantic Strategy (European Commission, 2020b) and the North Sea Energy Cooperation (NSEC, 2024). The Atlantic Strategy focuses on fostering cooperation in marine research and innovation, particularly in renewable energy and sustainable marine activities, while the NSEC facilitates collaboration between North Sea countries to achieve joint targets for offshore wind energy and multi-use platforms. For example, the NSEC encourages the alignment of grid connections and promotes innovation in integrating wind and aquaculture activities. Additionally, the European Union's Renewable Energy Directive (European Commission, 2018) and MSFD (European Commission, 2008) set overarching frameworks that guide member states in achieving environmental and renewable energy goals. These collaborations address shared challenges like policy fragmentation and encourage best practices that enhance the feasibility and efficiency of OMUP projects of specific policies and frameworks, making the text more robust and concrete.

The *economic* drivers of OMUP include both the potential for market expansion and the challenges related to financial feasibility. The integration of renewable energy, such as OWFs, with other marine activities, opens new economic opportunities, including the expansion of energy markets and the promotion of eco-tourism. This multi-sector approach creates synergies that enhance OMUPs' economic value. For instance, the Danish pilot not only leverages the growing market for renewable energy but also taps into the tourism sector, creating new revenue streams and boosting local economies. However, economic challenges, such as the high capital costs associated with OWFs and the complex financial mechanisms for multi-use projects, present barriers. Securing funding for OMUPs is often difficult, as the development of integrated projects typically involves higher risks and uncertainties. Dalton et al. (2019) further highlight that the economic viability of OMUPs depends on robust techno-economic assessments, which remain underdeveloped for most emerging multi-use concepts. In Germany, for instance, despite strong political backing, the lack of specific financial incentives for multi-use projects hampers the ability to attract investors. Furthermore, financial incentives, such as subsidies for multi-use platforms or tax relief for private investors could help mitigate the high initial capital investment costs and mobilize investors (van den Burg et al., 2017).

Economic stability is crucial for long-term project viability, as volatile markets and uncertain economic conditions can deter investment. For instance, while the Greek pilot benefits from national policies supporting renewable energy and sustainable development, broader economic challenges still impact OMUPs' feasibility and attractiveness. The COVID-19 pandemic further exacerbated these economic challenges by disrupting supply chains, increasing operational costs, and causing market volatility. In the Netherlands, compliance issues and increased costs due to the pandemic have posed additional challenges to OMUP developers, emphasizing the need for robust risk management strategies. Previous studies showed that market volatility and economic uncertainty are key factors in reducing the attractiveness of OMUPs for private investment (van den Burg et al., 2017).

Social factors, such as public acceptance and support, stakeholder engagement, and community benefits, play an essential role in the success of OMUPs. Public acceptance significantly influences OMUP's success. Engaging local communities and stakeholders early builds trust and acceptance. Transparent communication about the benefits and potential impacts of OMUP projects is essential. For example, the Danish pilot fostered strong public support through proactive engagement and clear communication about job creation and economic opportunities.

Stakeholder engagement is equally important. OMUP projects often involve multiple stakeholders, including government agencies, environmental organizations, local businesses, and the public. Effective engagement ensures their interests and concerns are considered, fostering collaboration (Billing et al., 2022). For example, the German pilot emphasizes the importance of involving various stakeholders in the planning and implementation process, addressing their concerns, and incorporating their feedback to enhance acceptance and project success.

Community benefits, such as job creation, economic development, and improved local infrastructure, increase public support. In the Greek pilot, the potential for coastal job creation and economic revitalization has been a major driver of stakeholder and public support.

Workforce availability is another key factor. Skilled and trained workers are necessary for implementing and operating OMUPs. Training and education programs can help build local capacity, ensuring sufficient skilled expertise. For instance, in the Netherlands, the pilot has included initiatives to train local workers, support employment, and enhance social impact.

Technological readiness and innovation also serve as crucial enablers of OMUP development. The successful integration of multiple marine activities, such as OWFs and aquaculture, requires the development of advanced technologies that can ensure efficient and sustainable operations. Technology readiness, often measured by the TRL, is a crucial aspect of OMUP projects. Technologies must be sufficiently developed and tested to ensure reliability and efficiency (Nassar et al., 2020). For instance, in the Belgian pilot, advanced technologies integrating offshore wind energy and aquaculture require further development to reach higher TRLs, which is essential for the project's success and operational efficiency. Innovation is another key driver, as OMUPs offer opportunities to combine various activities in ways that have not been explored before. The German pilot highlights OMUPs' innovation potential through the synergies between different activities, driving technological advancements that benefit all involved sectors. Moreover, technological integration involves ensuring compatibility between the various systems used in OMUPs. This coordination is crucial for optimizing space usage and improving the overall productivity of the platform. Technological developments must also address the logistical challenges of infrastructure support, such as port facilities and transportation networks, which are necessary to support deploying and operating OMUPs.

Environmental factors, such as environmental impact assessments (EIAs), sustainability practices, regulations, and ecosystem compatibility, are central to the success of OMUP projects. EIAs are a regulatory requirement in many regions, ensuring that projects do not harm marine ecosystems and are designed to minimize environmental impact. However, the process can be time-consuming and costly, as seen in Belgium, where strict EIA requirements present challenges. Sustainability practices also contribute significantly to the long-term viability of OMUPs. By prioritizing eco-friendly energy solutions, such as renewable energy, and promoting practices like eco-tourism, these projects enhance their environmental credentials. The Danish pilot is an example of this, where integrating renewable energy and eco-tourism not only supports sustainability but also boosts the pilot's environmental credibility. In addition to sustainability, environmental regulations play a critical role in shaping OMUP development. These laws and guidelines ensure that OMUP projects meet high environmental standards and protect marine ecosystems. However, these regulations can also present significant hurdles, as seen in Germany, where the complexity of both national- and EU-level frameworks makes compliance a challenging and essential part of project development. Developers must carefully navigate these regulatory requirements to ensure the project's success.

Another crucial aspect of OMUP projects is ecosystem compatibility, which ensures that integrated activities do not disrupt, but instead support, the surrounding marine environment. The Dutch pilot project exemplifies how careful planning and monitoring can foster a harmonious relationship between the platform's activities and the local ecosystem. Through this approach, the project not only helps maintain biodiversity and ecological balance but also demonstrates how OMUPs can offer sustainable solutions for marine ecosystem preservation.

Finally, *legal factors* that encompass regulatory frameworks, property rights, legal compliance, and liability issues all play a critical role in the development of OMUP projects. These frameworks include laws, regulations, and guidelines that govern the use of marine spaces, as well as the activities conducted within them. Complying with these frameworks is essential to obtain the necessary permits and approvals for OMUP projects. For example, the German pilot faces significant challenges due to the complexity of regulatory environments at both the national and EU levels. Successfully navigating these requirements ensures adherence to legal standards and helps avoid potential legal disputes or delays.

Property rights represent another critical legal factor. Clarifying and securing property rights for the use of marine spaces can be complex, as such areas are often subject to multiple overlapping jurisdictions and regulations. Feedback from the Greek pilot highlighted significant hurdles related to property rights and marine space allocation, where stakeholders expressed concerns over unclear entitlements and responsibilities. Similarly, challenges related to property rights were echoed in three other pilots, particularly where aquaculture and energy activities overlapped. These findings underscore the need for clear property rights frameworks to minimize conflicts, provide clarity on stakeholder responsibilities, and facilitate smoother project implementation.

Legal compliance involves adhering to all relevant laws and regulations throughout the life cycle of the OMUP project. These include environmental laws, health and safety regulations, and labor laws, among others. Ensuring compliance helps prevent legal challenges and penalties that could hinder progress. For example, the Danish pilot has carefully addressed legal compliance issues, particularly in relation to environmental and safety regulations, to ensure the project's smooth execution and operation.

Liability issues are another significant legal concern for OMUP projects. Determining liability for potential accidents, environmental damage, or other unforeseen events is critical for managing risks and protecting the interests of all stakeholders. In the Netherlands, liability issues related to insurance and potential environmental impacts have been a major consideration. Establishing clear liability frameworks and securing appropriate insurance coverage are essential for mitigating risks and enhancing the project's resilience to legal challenges.

4.3 Internal challenges and opportunities

The analysis revealed various external and internal factors influencing OMUP development, with a focus on identifying common strengths, weaknesses, opportunities, and threats across pilots (Table 2).

Common strengths across pilots include growing market potential for renewable energy and providing a robust economic foundation for OMUP projects. Socially, high public support and the potential for job creation underscore the positive reception and social benefits anticipated from these initiatives. Technologically, the pilots benefit from advanced integration capabilities and significant potential for innovation, indicating a strong readiness to adopt cutting-edge solutions. Environmentally, the emphasis on sustainable practices and adherence to

TABLE 2 SWOT matrix.

Factors	Strengths	Weaknesses	Opportunities	Threats
Economic	Growing market potential for renewable energy	High development costs and capital investment	Potential for economic revitalization and market growth	Economic instability and funding gaps
Social	High public support and job creation potential	Complex stakeholder engagement and public concerns	Increased public awareness and support for projects	Public resistance due to high costs and community concerns
Technological	Advanced integration and innovation potential	High technological costs and infrastructure challenges	Advancements in renewable energy technologies	Readiness challenges
Environmental	Focus on sustainable practices and comprehensive regulations	Stringent EIA requirements and environmental impact concerns	Adoption of sustainable practices and positive environmental impact	High EIA requirements and environmental impact concerns

SWOT, strengths, weaknesses, opportunities, threats; EIA, environmental impact assessment.

comprehensive environmental regulations demonstrates the commitment to minimizing ecological impacts and ensuring long-term sustainability.

In contrast, *common weaknesses* highlight areas where improvements are needed for successful development. High development costs and the need for substantial capital investment pose economic challenges, potentially hindering project feasibility. Socially, the complexity of stakeholder engagement and public concerns over environmental and economic impacts are recurring issues. Technologically, high costs and infrastructure limitations persist, requiring ongoing investment and development. Environmentally, stringent EIA requirements and concerns over environmental impact present additional hurdles that need to be navigated carefully.

Despite these weaknesses, *opportunities* remain abundant. Economic revitalization through market growth in the renewable energy sector offers significant potential for expanding OMUPs. Socially, increased public awareness and support for renewable energy projects provide a favorable environment for OMUP development. Technologically, advancements in renewable energy technologies and the integration of innovative solutions offer avenues for further enhancement and efficiency. Environmentally, adopting sustainable practices and the potential positive ecological impacts underscore the broader benefits of OMUPs.

However, *threats persist*, which could jeopardize the success of OMUPs. Economic instability and funding gaps for renewable energy projects pose significant risks. Socially, public resistance due to high costs and community concerns over environmental and economic impacts may hinder progress. Technologically, challenges related to ongoing advancements and readiness must be addressed to maintain development momentum. Environmentally, high EIA requirements and concerns about ecological impacts remain critical issues that must be carefully managed to ensure successful project implementation.

4.4 Business model to have an operational OMUP

We compare the four main building blocks of the BMC—cost structure, revenue stream, targeted segment, and value proposition—because they represent the most common areas of differences across pilots. These comparisons provide valuable insights into the strategic priorities and unique approaches that contribute to the success and development of OMUP projects.

The *cost structure* of pilots is characterized by high expenditures necessary for developing and maintaining OMUPs. All pilots incur substantial costs due to high initial capital investments and ongoing operational expenses. These include significant outlays for advanced technological integration, regulatory compliance, stakeholder engagement processes, and comprehensive environmental impact assessments. For instance, the German pilot faces high costs for regulatory compliance and technological integration, while the Dutch pilot allocates significant resources to technological infrastructure and stakeholder engagement. Similarly, the Belgian pilot's expenses are driven by technological applications and environmental assessments. The Danish pilot incurs continuous costs associated with technological development, and the Greek pilot must overcome broader economic instability and invest in infrastructure.

The *revenue streams* across all pilots reflect their strategies for generating income and sustaining operations, primarily through the sale of renewable energy and government support. The German, Dutch, Danish, and Belgian pilots generate significant revenue from renewable energy sales and benefit from government subsidies and grants supporting green initiatives and renewable energy projects. Moreover, the different pilots further diversify their income through potential partnerships and innovation-driven investments. For instance, the Danish pilot benefits from the tourism activities in place to generate additional revenues, while the Belgian and Dutch pilots benefit from the sale of aquaculture products. By contrast, the Greek pilot's revenue stream is solely focused on the tourism activities.

The *targeted market segments* for each pilot reflect their specific focus and customer base. The German pilot targets a diverse market, including industrial consumers and residential sectors seeking sustainable energy solutions. The Dutch pilot caters to industrial sectors, governmental bodies, and environmentally conscious consumers. The Belgian pilot targets both industrial and residential markets, emphasizing innovative renewable energy applications. Danish pilot target segments include industrial users, governmental agencies, and a broad base of environmentally aware consumers, while the Greek pilot targets a wide range of sectors, including industrial, governmental, and residential markets, with its tourism-centered approach.

The *value propositions* of the pilots emphasize unique benefits and competitive advantages, primarily focusing on technological innovation, sustainability, and renewable energy solutions. The German and Danish pilots prioritize reliable, high-quality renewable energy and advanced technological solutions, underscoring their commitment to sustainable practices. The Dutch and Belgian pilots both emphasize sustainability and innovative technological applications, with the Dutch pilot also focusing on community engagement and integrating diverse renewable energy technologies.

5 Discussion and conclusion

This study provides a comprehensive examination of the creation and application of OMUPs. Using PESTEL, SWOT, and BMC analyses, the research assessed the main levies and barriers in the business models of OMUPs, focusing on pilot sites in five EU member states: Belgium, Denmark, Germany, Greece, and the Netherlands. The results illustrate both the difficulty of setting up OMUPs and their potential to make a substantial contribution to sustainable maritime development and the blue economy.

Cost structure across all pilots emerges as one of the most notable issues identified in this research. Significant up-front capital investments and continuous operational costs associated with regulatory compliance, technological integration, and EIAs. These financial constraints pose significant obstacles to scaling OMUPs beyond the pilot stage. However, opportunities for cost-sharing and operational synergies arise when several maritime activities—such as aquaculture, tourism, and renewable energy generation—are integrated into a single platform (Depellegrin et al., 2019). Compared to single-use activities, such platforms can optimize marine resource use and diversify income streams, offering more sustainable and efficient business models. Dalton et al. (2019) further highlight that the economic viability of OMUPs depends on robust techno-economic assessments, which remain underdeveloped for most emerging multi-use concepts. Their study introduced a ranking methodology for investment opportunities in blue-growth sectors, demonstrating that smaller-scale platforms with lower capital expenditure tend to yield higher returns. This suggests that OMUP development could benefit from prioritizing cost-efficient configurations that balance investment risk with economic feasibility. In addition, Bocci et al. (2019) emphasized that multi-use platforms foster cross-sector collaboration, reduce spatial conflicts, and enhance economic resilience by leveraging complementary activities.

However, even with these advantages, attracting long-term investment remains a critical challenge. Aligning OMUP development with *corporate social responsibility* (CSR) initiatives presents a promising strategy. Companies seeking to reduce their carbon footprint and enhance their sustainability credentials could integrate OMUPs into their CSR strategies, supporting renewable energy projects and sustainable aquaculture while showcasing their commitment to environmental stewardship. In addition, leveraging the *voluntary carbon market* offers another pathway to attract investors (Streck, 2021). OMUPs that produce renewable energy, such as offshore wind and solar, could leverage carbon markets to attract investment, as demonstrated in offshore wind development, where market strategies evolved from subsidies to risk-sharing alliances and commercialization to enhance financial viability (Dedecca et al., 2016).

Political support is also crucial to the development of OMUPs, as evidenced by the varied progress of the pilot projects. Strong regulatory frameworks and government incentives in countries like Germany and Denmark have significantly advanced these platforms. In contrast, pilot projects in regions with inconsistent political support, such as Greece, face greater uncertainty and barriers to progress. This emphasizes the importance of stable, long-term political commitments to support renewable energy projects and streamline regulatory approval processes. Policymakers can support OMUPs' growth by offering more consistent and transparent regulations, providing financial incentives, and encouraging public–private partnerships (PPPs) to reduce investment risks. For instance, the EU's Offshore Renewable Energy Strategy promotes the development of offshore wind energy and emphasizes the integration of multi-use solutions, including offshore wind and aquaculture (European Commission, 2020a). Similarly, the Sustainable Blue Economy supports the sustainable development of marine and maritime sectors, providing a policy framework to drive innovation in multi-use platforms (European Commission, 2021). To facilitate OMUP expansion, EU member states should harmonize regulatory frameworks for offshore space, particularly in shared marine areas (Abhinav et al., 2020). This includes aligning MSP efforts to ensure that overlapping jurisdictions, such as between fisheries, aquaculture, and offshore energy, are streamlined. This way, MSP can enhance the development of OMUPs (Stancheva et al., 2022). Furthermore, financial incentives, such as subsidies for multi-use platforms or tax relief for private investors could help mitigate the high initial capital investment costs and mobilize investors (van den Burg et al., 2017). Encouraging PPPs can also foster collaboration and share risks, as seen in Denmark's approach to integrating offshore wind with tourism and energy sectors. Additionally, the European Maritime, Fisheries and Aquaculture Fund could be used to support aquaculture-based multi-use initiatives across EU waters, providing direct financial aid to the pilots.

Technological innovation is another key factor for successfully scaling up OMUPs. Although pilot projects have demonstrated their ability to integrate cutting-edge technologies such as offshore wind and solar power, further research and development are required to reduce operational costs and improve efficiency. For example, improving grid connectivity for offshore platforms, advancing floating wind technologies, or developing better storage solutions for renewables could significantly improve the long-term viability of OMUPs. As noted by Nassar et al. (2020), one of the critical challenges is ensuring that offshore platforms are powered by 100% renewable energy sources, which requires significant advancements in energy storage and grid infrastructure to maintain power reliability in remote locations. Moreover, the potential of marine biomass as an energy source could help reduce battery storage requirements and improve energy supply stability, further enhancing the sustainability of OMUPs. Public- and private-sector investment in research and technological innovation will be essential to ensure that these platforms can operate at scale while maintaining financial sustainability.

Social acceptance and community engagement also emerged as critical elements. OMUPs often involve diverse stakeholders, including local communities, environmental organizations, and government agencies. Addressing public concerns about environmental impacts and ensuring equitable economic benefits are vital for building trust and gaining support and can provide OMUPs with a social license to operate (Billing et al., 2022). Smythe et al. (2025) report a mismatch between the discourse on multi-use and co-location, on one hand, and actual user experiences, on the other. Chen et al. (2020) found similar patterns in the case of Liuqiu Island, where concerns about environmental impacts and conflicts with existing industries influenced public acceptance. Their findings highlight the need for integrating local perspectives into project planning to improve stakeholder support and long-term viability. Early stakeholder engagement, transparent communication about risks and benefits, and mechanisms to share economic gains generated by OMUPs with local communities can help foster broader acceptance. Additionally, OMUPs can contribute to job creation and local economic development, particularly in coastal regions, further enhancing their social value proposition.

Finally, this study has shown that OMUPs hold great promises for optimizing the use of marine space while supporting the wider objectives of the blue economy and sustainable development. By integrating renewable energy production with other marine activities, OMUPs create multifunctional platforms capable of delivering both economic and environmental benefits. Nevertheless, there are a number of major obstacles to scaling up OMUPs, including high costs, regulatory complexity, technological challenges, and ineffective engagement (Schupp et al., 2021).

To ensure the long-term viability of these platforms, innovative financial models must be explored, such as blended finance structures, impact investing, and PPPs. In addition to these, strategies like CSR initiatives, and voluntary carbon markets can provide supplementary funding and enhance the attractiveness of OMUPs to private investors. Political support remains essential, with policymakers playing a central role in creating stable regulations and providing financial incentives. Continued investment in technological innovation and research is essential to reduce costs and improve the operational efficiency of OMUP. Finally, fostering strong community engagement and ensuring local stakeholders benefit from the economic opportunities generated by OMUPs will be key to their sustained success as they evolve.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

YZ: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. ML: Data curation, Formal analysis, Methodology, Validation, Writing – original draft, Writing – review & editing. JM: Writing – review & editing. RD: Methodology, Project administration, Resources, Writing – review & editing. HC: Writing – review & editing. SB: Writing – review & editing. AA: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that Generative AI was used in the creation of this manuscript. Generative AI was used to rephrase and summarize sentences derived from the original deliverables of the H2020 UNITED project to ensure clarity and conciseness in the manuscript. All outputs generated by AI were carefully reviewed and edited by the author(s) to maintain accuracy and alignment with the research findings.

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