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Operationalizing marine multifunctionality in Europe: Policy mixes, activation modes, and governance functions

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ABSTRACT

Marine multifunctionality, understood as the intentional combination of uses in the same marine space, is increasingly promoted in European policy, yet implementation remains uneven. This study asks which combinations of governance instruments have enabled the operationalisation of marine multifunctionality in Europe, and under what conditions. Using systematic review principles, we synthesise peer-reviewed evidence published between 2007 and 2025 across European sea basins. Guided by a policy mix perspective, we classify instruments into four families – legal, economic, spatial planning, and techno-digital – and examine how they are activated in practice, the functions they perform, and how they are sequenced across governance levels. We further interpret how cases align with three modes of multifunctionality: co-use (shared structures), co-location (spatial proximity), and co-existence (compatible operations). The results show that successful cases assemble policy mixes that first establish spatial and legal clarity, for example through marine spatial planning and coexistence provisions; then address risk through safety zones, liability, and compensation; and finally enable implementation through targeted finance, pilot projects, and monitoring or technical solutions. The most advanced configurations cluster in the North Sea, where energy-led mixes dominate, while Mediterranean examples more often centre on fisheries-tourism-conservation pathways. Where progress lags, missing functions, weak alignment between plans and permits, or unstable rules are common. These findings lead to three recommendations: package instruments ex ante where possible; run pilots under provisional conditions; and embed monitoring and cumulative-effects assessment in licences so that learning feeds back into marine spatial plans and related sectoral frameworks.

1. Introduction

Balancing expanding maritime activities with conservation and sustainability is a central challenge in ocean governance. International initiatives such as the Sustainable Development Goals, the United Nations (UN) Decade of Ocean Science, and the Blue Economy agenda have reframed the ocean not only as a space for economic growth but also as a domain requiring integrated management of ecological, social, and economic goals [1,2]. Multifunctionality, considered as the deliberate combination of uses such as energy, aquaculture, fisheries, tourism, and conservation in the same marine space [3], has been promoted in European Union (EU) strategies, including the Integrated Maritime Policy and the Marine Spatial Planning Directive [4], as a way to improve spatial efficiency and sustainability.

Within the EU, multifunctionality (often referred to as multi-use in the literature) has gained prominence as maritime space has become increasingly disputed by expanding traditional marine uses (such as fisheries, aquaculture, shipping, tourism), the emergence of new activities (like marine renewable energy and the use of marine genetic resources) and the need of increased biodiversity protection targets [5]. The 2007 EU Integrated Maritime Policy sought to improve coordination, cooperation and integration of policies and institutions related to the oceans and seas across fragmented sectors [6,7]. Subsequent initiatives, including the Sustainable Blue Economy agenda and the European Green Deal, further reinforced expectations that marine space should deliver multiple economic, ecological, and societal functions simultaneously (European Commission Directorate General for Maritime Affairs and Fisheries & Joint Research Centre, 2025). Marine Spatial Planning (MSP) has become a central mechanism through which these competing objectives are negotiated, creating growing policy

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interest in multi-use, multi-purpose, and multifunctional approaches capable of reducing spatial conflicts and increasing synergies across sectors [8].

Despite this policy direction, coordination between marine activities across Europe remains uneven. While EU policy frameworks increasingly encourage integrated and multifunctional uses of marine space, implementation has proven substantially more difficult in practice. Barriers reported in earlier research include stakeholder mistrust, technological limitations, insufficient financial benefits, and regulatory ambiguity around licensing, liability, safety zones, and compensation [9–14]. Systematically assessing which instruments supporting governance have enabled implementation, and under what conditions, is essential for translating policy ambitions into practice and for informing MSP strategies, sectoral rules, and investment decisions.

This paper asks: Which combinations of governance instruments have enabled marine multifunctionality in Europe, and under what conditions? Here, governance instruments are understood broadly to include regulatory, economic, planning, and techno-digital mechanisms that support the coordination, implementation, and operationalization of multifunctionality. Using principles of systematic reviews, we examine peer-reviewed literature to identify legal, economic, spatial planning, and techno-digital tools employed across European sea basins that promote multifunctionality. We classify governance instruments by their functions – direction-setting, coordination/learning, demand/legitimacy, and risk or cost-reduction – and analyse how sequencing and coherence across governance levels shape outcomes. To interpret the findings, we apply policy mix theory, which highlights how outcomes emerge not from single instruments but from the way multiple tools interact, accumulate, and evolve across governance levels. This perspective helps explain why individual tools rarely suffice and why durable uptake depends on coherent and sequenced mixes.

We use the term multifunctionality (rather than multi-use or multi-purpose), to emphasize the functional relationships among activities and distinguish between co-use (multiple functions on the same structure), co-existence (shared services or value chains), and co-location (spatial proximity with separate structures). This allows clearer analysis of how different instrument types enable distinct multifunctionality pathways.

Our contribution is twofold. First, we provide an evidence-based typology of instruments and their roles in enabling co-use, co-existence, and co-location. Second, we offer policy-relevant insights on sequencing and alignment that can guide future MSP implementation, sectoral licensing, compensation/insurance design, and monitoring requirements.

2. Theory: Policy Mixes

We analyse the emergence and uptake of marine multifunctionality using a policy mix perspective, defined as the combination of instruments, their interactions, and their evolution across governance levels toward a shared objective [15,16]. This perspective shifts attention from individual policy tools to dynamic configurations shaped by multiple actors, institutions, and trade-offs over time [17].

Complex governance problems rarely have a single cause, and no single instrument can remove all barriers to implementation [18]. Barriers include unclear access rights, spatial conflicts, costs and risks for users, data or technology gaps, and limited stakeholder acceptance [17]. Policy mixes address these challenges by combining instruments with complementary roles, setting direction, coordinating actors and space, creating legitimacy or demand, and reducing costs and risks. When aligned and sensibly sequenced, instruments can reinforce one another and increase uptake [19].

Lehmann [16] formalises this logic by showing that multiple governance failures require multiple instruments, and that when a single "optimal" instrument is impractical or costly, a mix of simpler tools can achieve similar outcomes under real-world constraints such as limited information and institutional capacity. The objective is therefore not to maximise the number of instruments, but to assemble fit-for-purpose combinations [18].

Policy mixes comprise instruments, their underlying rationales, and the arrangements through which they interact across sectors, governance levels (EU, national, subnational), geographies, and time. These interactions may generate complementarities or tensions, and instruments can act as complements or substitutes, including across levels or periods. Policy mixes should therefore be analysed as dynamic, multi-level systems rather than static portfolios [17].

Rogge and Reichardt [20] distinguish between functions (what instruments do) and properties (how the mix as a whole performs). Across the literature, four recurring functions are identified: (1) direction-setting or priority definition (e.g. mandates, targets), (2) coordination and learning (e.g. MSP procedures, data-sharing), (3) demand creation and legitimacy (e.g. guidance supporting co-use), and (4) risk and cost reduction (e.g. safety rules, insurance, compensation) [15–17,20].

3. Analytical framework

Building on the policy mix theory outlined above, we devise an analytical framework to operationalize some of the concepts introduced earlier. The framework combines descriptive coding with temporal lenses to analyse how policy mixes supporting marine multifunctionality are assembled and evolve over time.

We define the multifunctionality of marine infrastructure as the deliberate combination of uses such as energy, aquaculture, fisheries, tourism, and conservation in the same marine space [3,21]. We capture this through three modes: co-use (two or more services on the same structure or resource), co-existence (shared value chains or services), and co-location (spatial proximity that reduces costs or environmental pressures). Related terms include multi-use and multi-purpose platforms, often referring to combinations of energy production with aquaculture, tourism, or transport [22]. The concept of multifunctionality goes beyond economic sectors to include environmental, social, and recreational dimensions [23].

Through inductive coding of the literature, we identify four recurring families of instruments used to advance marine multifunctionality: legal, economic, spatial planning, and technical-digital.

Legal instruments define rights, responsibilities, permissions, and liabilities, including licensing frameworks, access rights, safety zones, insurance and liability arrangements, compensation regimes, and sectoral legislation [24,25]. By clarifying responsibilities and liabilities, acceptable risks, and compliance conditions, they provide the legal certainty required for participation in multifunctional settings [26].

Economic instruments shape multifunctionality by altering incentives or reducing potential losses rather than prescribing behaviour. They modify payoffs, redistribute costs, and reduce financial risk through measures such as subsidies, EU or national grants, structural funds, compensation payments, insurance mechanisms, cost-sharing arrangements, market instruments, or tender requirements [27–29].

Spatial planning instruments coordinate activities in space by defining where uses may occur and how they can interact. Examples include MSPs, zoning systems, placing rules, spatial compatibility assessments, biodiversity corridors, and MPA zoning [30]. By reducing conflict and aligning expectations, they signal where multifunctionality is viable or strategically prioritized [31,32].

Techno-digital tools enable multifunctionality by determining what is technically feasible, safe, efficient, and measurable. These include shared platform designs, co-use engineering standards, monitoring technologies (e.g. optical, acoustic, remote sensing, AUVs), environmental data systems, GIS-based decision-support tools, and integrated operational logistics [33,34].

We adopt these four families as our classification scheme and treat instruments as potentially promoting multifunctionality by design (intended) or as a by-product (incidental). To capture the ways in which instruments trigger multifunctionality (i.e. how they enable it rather than their effectiveness), we also code each instance as active, semi-active, or passive. Active instruments explicitly promote multifunctionality through binding requirements, targeted funding, or purpose-built technologies, and mainly provide direction. Semi-active instruments encourage multifunctionality without binding force, for example through guidance or procedural preferences, and primarily support coordination and legitimacy. Passive instruments address residual barriers, such as licensing, insurance, compensation, or liability, thereby reducing costs and risks and indirectly enabling co-use. This classification reflects the functional roles identified by Rogge & Reichardt [20].

Finally, we examine how policy mixes evolve over time through layering and path-dependent change, as new instruments are added to existing arrangements [17,18]. We assess whether sequencing can be identified. Specifically, which functions appear early, and which are added later, and how this shapes outcomes. Prior research suggests that without early direction-setting and coordination, later funding or risk-reduction measures tend to have limited effect, and vice versa [19]. In this sense, outcomes depend less on individual instruments than on how combinations, sequencing, and coherence shape adoption and impacts. We use the concepts of policy packaging (ex ante bundling of instruments) and policy patching (ex post adjustments) to capture these dynamics [35].

4. Methods

Systematic literature reviews is adopted in the conservation and environmental management fields as a reliable method for synthesizing qualitative and quantitative evidence identifying research trends and knowledge gaps [36]. A key advantage of this method is its ability to ensure transparency, reduce bias, and facilitate replicability by following a strict step-by-step process [37].

Systematic reviews begin with a well-defined research question and a pre-specified protocol that sets out methods for every stage of the review. Following guidance from the Collaboration for Environmental Evidence [38], the protocol specifies the search strategy (search strings, date limits, language, geographical scope, databases, and eligibility criteria for title/abstract and full-text screening) and is made available for external appraisal and piloted to test feasibility.

The study applies a stepwise, adjusted, approach to peer-reviewed (white) literature on the implementation of multifunctionality in Europe, to fit the context, timeframe, and resources of the study. This includes drafting a search protocol, discussed the review with researchers not involved in the paper, and piloted the protocol before executing the full search and screening workflow.

The protocol addressed the research question Which combinations of governance instruments have enabled marine multifunctionality in Europe, and under what conditions? The search was limited to articles published in English indexed in the Web of Science Core Collection (WoS) and Scopus. The temporal scope included papers published between 2007, the year of the Integrated Maritime Policy, up until May 2025. The geographical scope encompassed the EU, the United Kingdom (UK), and Norway (Fig. 1).

The following search string was inserted in the data databases mentioned:

TS= ((Multifun OR Multiuse* OR "Multi-use" OR Multipurpose OR "Multi-purpose" OR "co-use" OR coexistence OR "co-existence" OR colocation OR "co-location" OR co*benefit) AND ("economic incentive*" OR license OR "Mari* Spatial Plan*" OR "Integ* Coastal Zone Manag*" OR "environment* impact assessment" OR "pref* access" OR "tax break*" OR subsidies OR*

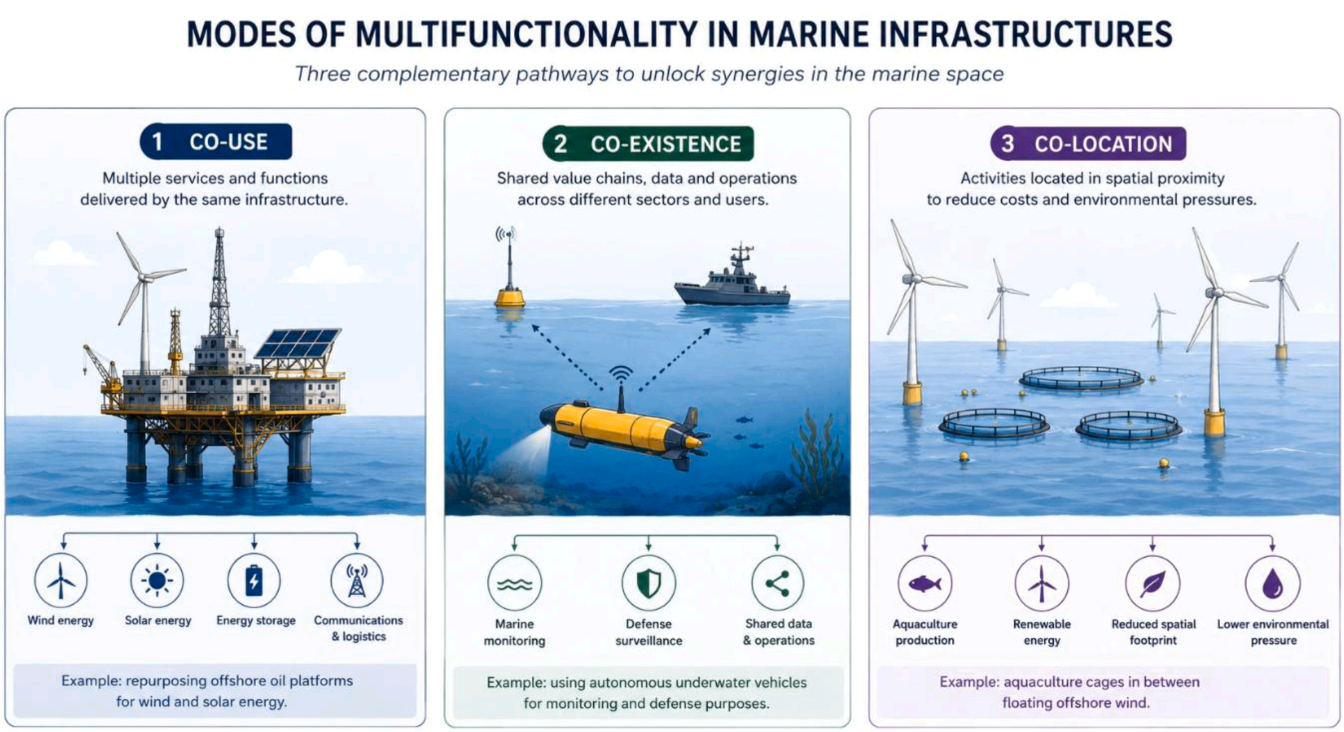

Fig. 1. AI-assisted conceptual illustration of modes of marine multifunctionality. Co-use illustrates the potential repurposing of offshore oil and gas platforms for multiple functions within the same infrastructure, including renewable energy generation, inspired by Shell's Cutter project in the southern North Sea (Reuters, 2006). Co-existence illustrates the use of shared operational systems and technologies, such as crewed and autonomous underwater vehicles, to support monitoring, surveillance, and data collection across multiple sectors and service domains simultaneously, drawing on de Jager (2022). In contrast, co-location illustrates the spatial proximity of otherwise independent activities, such as aquaculture installations situated within offshore wind farm areas, where sectors benefit from shared marine space and reduced spatial or environmental pressures but maintain separate infrastructures (unlike co-use) and operational systems (unlike co-existence), inspired by Simply Blue Group's North Sea Farm 1 project (Casey, 2023). The image is illustrative only; the authors take full responsibility for its content.

"national leg" OR "memorandum of understand*" OR "Maritime Spatial Planning Directive" OR "marine protected area*" OR funding OR tender OR procurement) AND ("ocean space" OR "marine environment" OR "marine ecosystem*" OR "mari* space" OR "coastal zone" OR oceanscape OR sea OR blue OR ocean OR marine OR maritime OR coasta*)).*

The initial search resulted in 513 articles, of which 107 were duplicates. After eliminating the duplicates, we undertook a title and abstract screening, excluding papers outside of the scope, reaching a result of 195 relevant papers. Additionally, four articles identified through snowball sampling (cited by the papers captured in the search) were also included. Following a full-text screening of these 199 articles, 150 were excluded due to geographic focus, or lack of relevance for the research question. Ultimately, 49 articles were included in the analysis and subsequent discussion. Fig. 3 illustrates the article selection process, detailing the number of articles at each stage.

Fig. 4 shows the distribution of the articles by year of publication. Grey literature was excluded to ensure comparability in methodological quality across sources, although we acknowledge this may omit emerging practices not yet captured in scholarly publications.

5. Results

The studies span eleven sectors (Fig. 5). Energy-related cases are most common, followed by aquaculture and fisheries; conservation/MPAs appears at a similar level to aquaculture. Tourism is present but less frequent. Shipping, minerals and oil, and data/monitoring occur occasionally, while defence, cultural heritage and biotechnology are rare in the reviewed studies. A regional pattern is evident: in northern Europe (North Sea and neighbouring waters) multifunctionality is predominantly driven by offshore renewable energy, whereas in southern Europe (Mediterranean and parts of the eastern Atlantic) tourism and fisheries are the main entry points. Totals reflect multiple coding where cases involve more than one sector.

The six countries most frequently mentioned in the literature are the UK (21), the Netherlands (10), Germany (9), Spain (9), Denmark (8) and Greece (8). Although the EU has promoted multifunctionality through

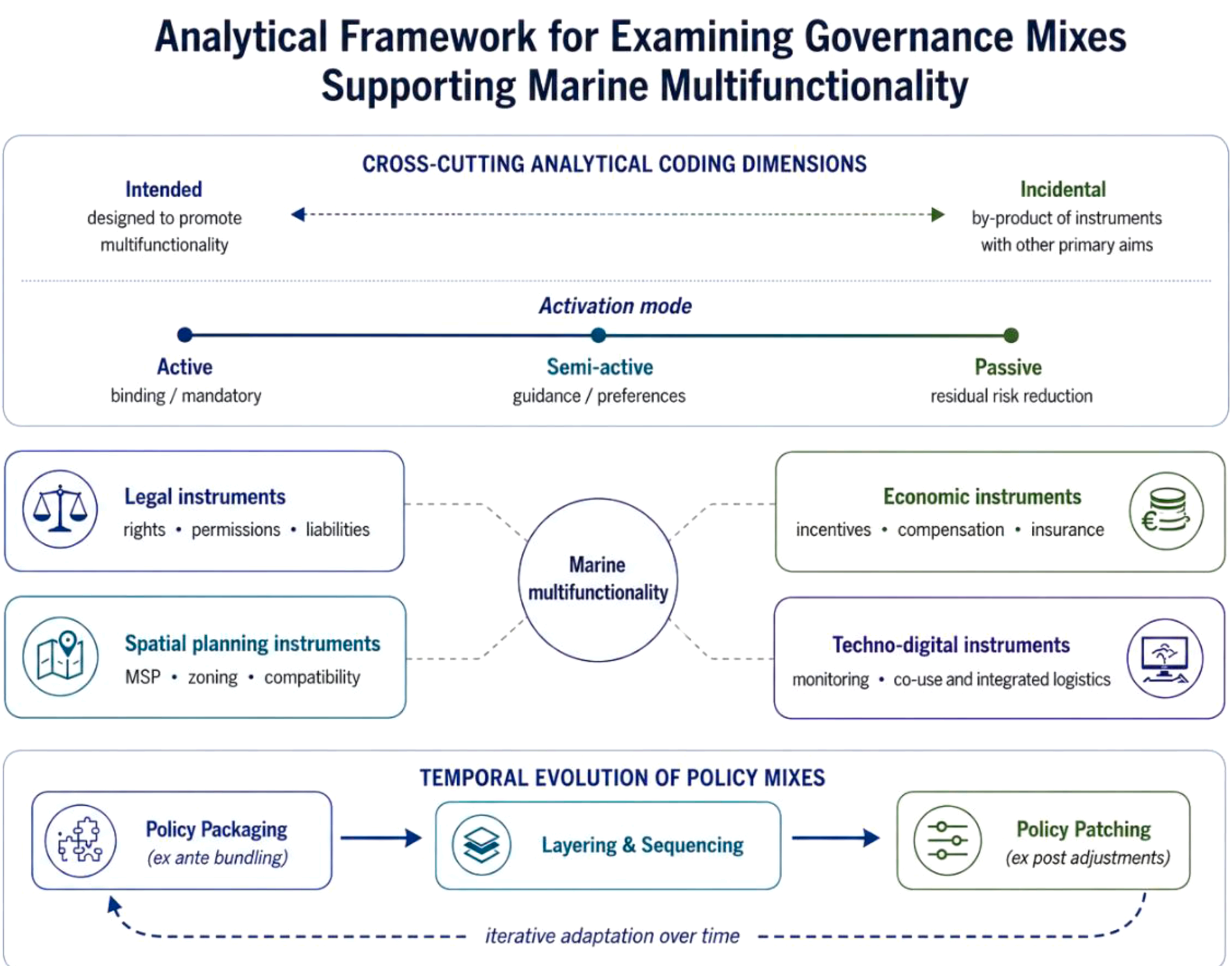

Fig. 2. Analytical framework for examining governance mixes supporting marine multifunctionality. The figure illustrates the analytical structure used to examine how governance mixes supporting marine multifunctionality are assembled, classified, and evolve over time. The upper section captures the temporal evolution of policy mixes through policy packaging (ex-ante bundling of instruments), layering and sequencing, and policy patching (ex-post adjustments), including iterative adaptation over time. The middle section presents the cross-cutting analytical coding dimensions used in the review. Instruments are coded according to whether multifunctionality is promoted intentionally or incidentally, and according to their activation mode as active, semi-active, or passive. The lower section presents the four recurring instrument families identified inductively from the literature: legal, economic, spatial planning, and techno-digital instruments. These dimensions are analyzed in relation to marine multifunctionality and interpreted through a policy mix perspective emphasizing sequencing, layering, and path-dependent evolution of governance arrangements.

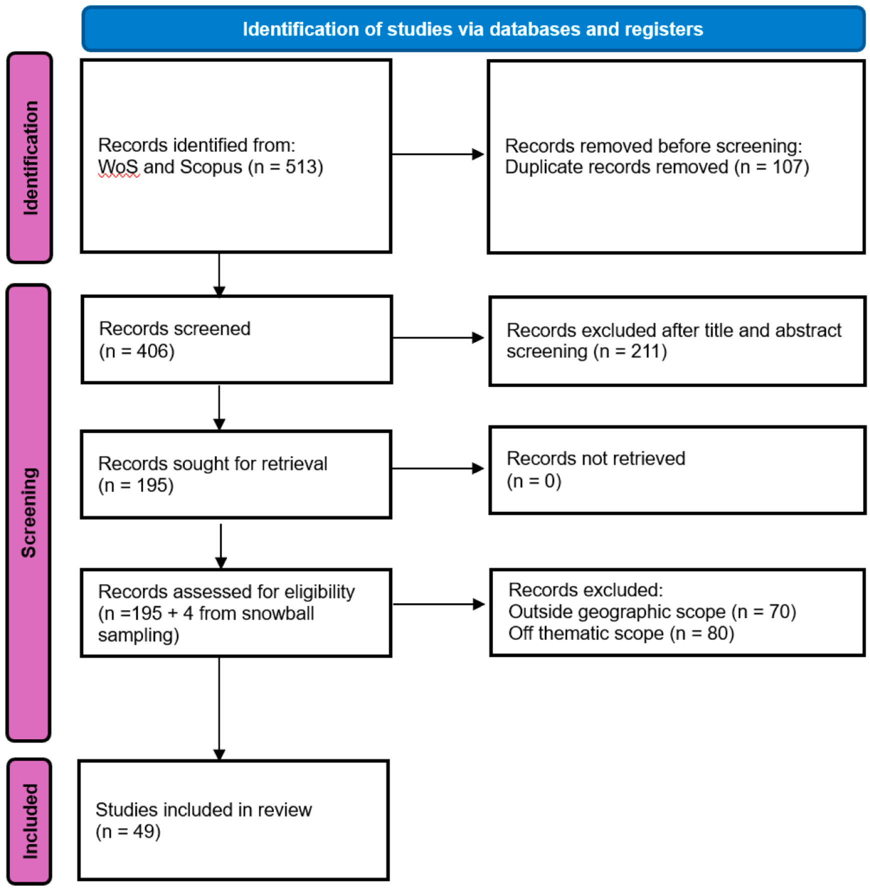

Fig. 3. PRISMA 2020 flow diagram ([39], p. 2021). The figure shows the identification, screening, and inclusion of studies in the systematic review. The search was limited to peer-reviewed articles in English indexed in the Web of Science Core Collection and Scopus between 2007 and May 2025. The geographical scope covered the EU, the United Kingdom, and Norway. Four additional articles were identified through snowball sampling.

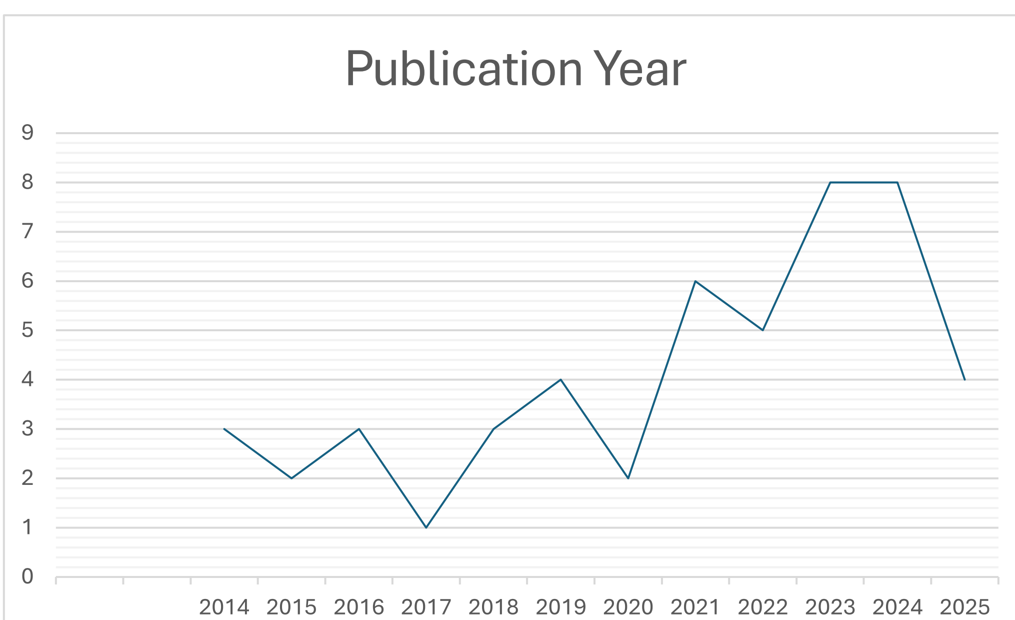

Fig. 4. Publications by year.

various policy instruments, the distribution of documented cases indicates that North Sea countries, particularly the UK, Germany and the Netherlands, have been at the forefront of national-level implementation and experimentation (Fig. 5). However, it might be that such findings are influenced by publication and language biases.

Nearly half of all documented cases are in the North Sea (15) with

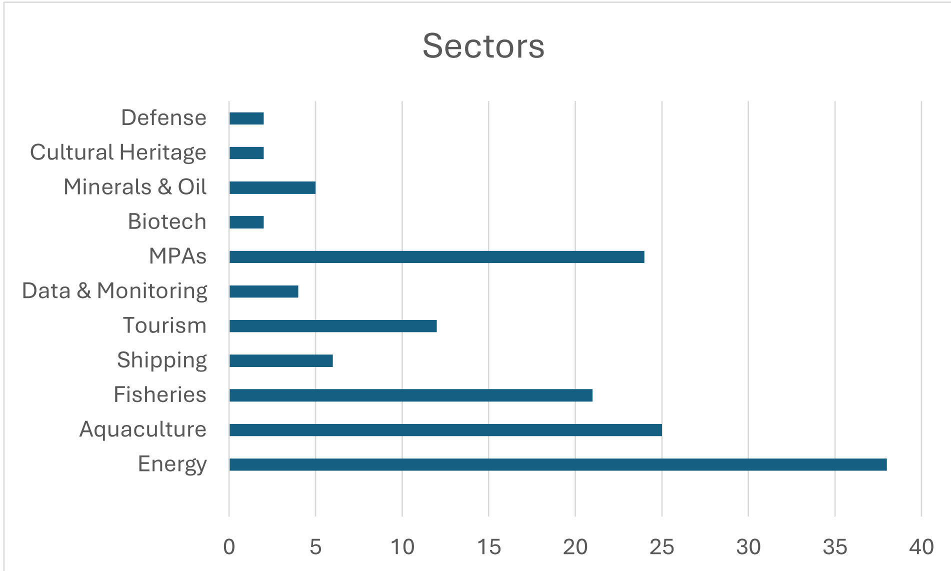

Fig. 5. Frequency of each sector's occurrences in the literature reviewed.

smaller clusters in the Mediterranean Sea (21%), followed by the Eastern Atlantic (15%), the Baltic Sea (12%) and Black Sea (6%). While totals reflect 33 basin-level attributions, some studies cover multiple areas and several did not have a basin-specific focus.

Importantly, as illustrated by Fig. 7, multifunctionality is rarely addressed through a single lens (co-use, co-location, co-existence). Only 16 papers focus on one dimension alone, while 33 papers combine two or more dimensions, including 14 papers that explicitly engage with all three. This pattern indicates that multifunctionality is typically approached as a layered and overlapping configuration rather than a singular mode. It is important to note that these classifications reflect our interpretation of how studies align with the three concepts, as the literature most often relies on broader terms such as "multi-use" or "multi-purpose" without drawing explicit distinctions. Additional details on how individual studies align with each dimension are provided in the supplementary material.

The findings are synthesized along key analytical lenses derived from the framework, including instrument families, and how instruments operate in practice (activation modes and functional roles). Properties and temporal dynamics in policy mix development analyzed across sections.

6. Instrument Families

Two broad observations emerge. First, multifunctionality is rarely enabled by a single measure; rather, cases typically involve combinations of instruments that address different governance needs. Second, the relative importance of each instrument family varies across sectors and sea basins, reflecting different policy priorities.

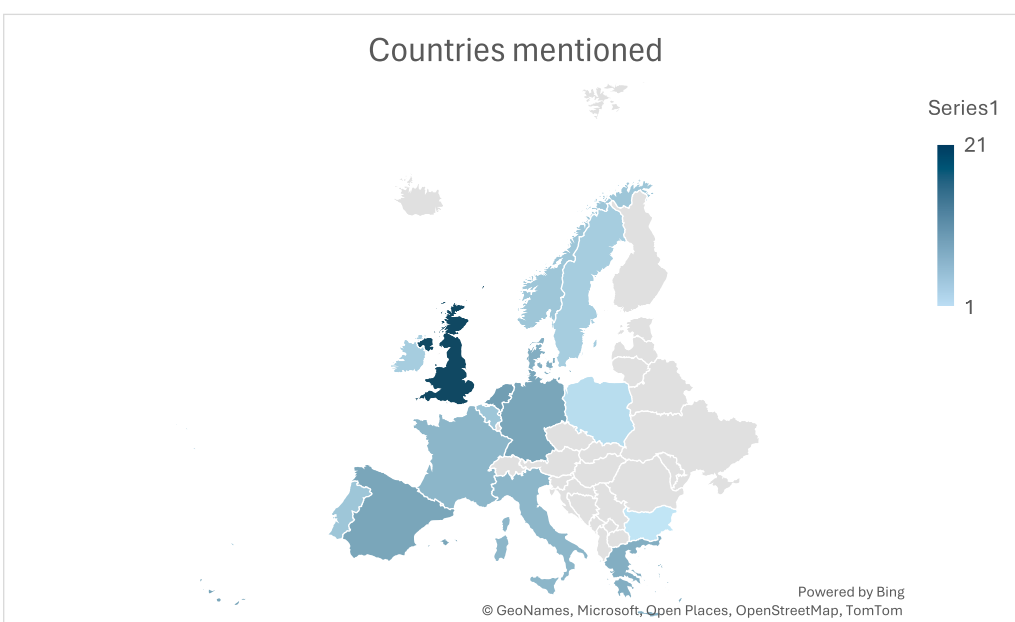

Fig. 6. Frequency of occurrences of each European State in the literature reviewed. The UK includes Great Britain, Scotland Northern Ireland and Wales.

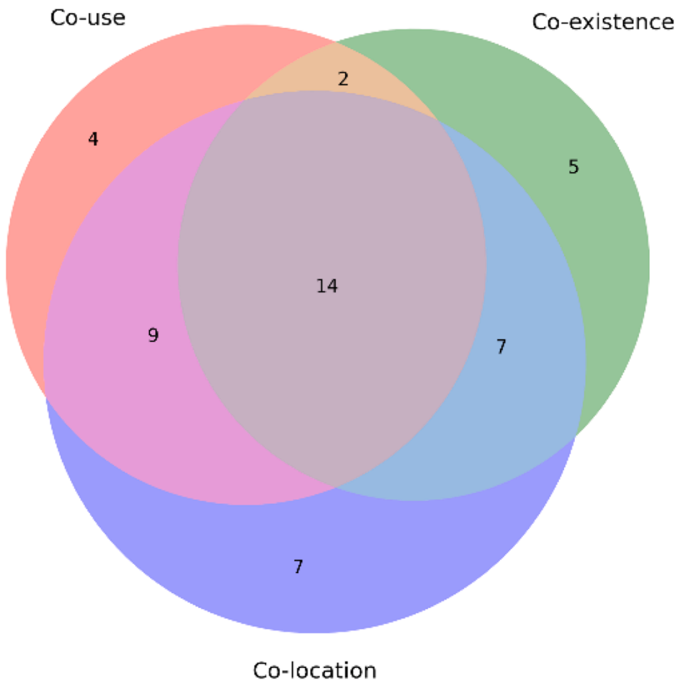

Fig. 7. Overlap between co-use, co-existence, and co-location concepts across the reviewed papers. Counts reflect the authors' coding of the literature (see Supplementary Materials). The figure was generated using AI-assisted visualisation tools; the underlying data and analysis were produced by the authors.

6.1. Legal Instruments

Legal instruments support multifunctionality by defining which activities are permitted and the rights, responsibilities, liabilities, and risk-management measures applicable. Clear assignment of monitoring responsibilities, liability for damages, and rights of use (tenure) is essential for any form of co-location, co-existence, and in fewer cases, co-use, because these arrangements often requires coordinated operations, compatible practices, and clearer liability arrangements than mere spatial sharing [10,40].

At the international level, the UNESCO Convention on Underwater Cultural Heritage has facilitated co-location of cultural-heritage protection, tourism, and conservation [9,41]. At the domestic level, several frameworks incorporate multifunctionality into sectoral laws. Belgium's MSP-related decrees go the furthest by allowing aquaculture within offshore wind concessions, enabling co-location when conditions are met [42]. Germany's MSP integrates principles for sectoral co-existence within its licensing system [43,44], while the UK Marine Policy Statement promotes integration across sectors, also supporting co-existence [9,10]. Portugal's Law 17/2014 and Decree-Law 38/2015 similarly enable multifunctionality without explicitly naming it [9]. Bulgaria's amendment to the Maritime Spaces, Inland Waterways and Ports Act promotes the combination of different marine activities and provides a legal basis for integrated uses involving sectors such as tourism, fisheries, and underwater cultural heritage [41], thus aligning with co-location or co-existence depending on the combination.

Regional patterns are evident. In the North Sea, renewable-energy legislation is the primary pathway for multifunctionality, particularly through provisions that enable co-location of fisheries or aquaculture within offshore wind areas, and in some cases co-existence through coordinated access arrangements [9,45]. In the Mediterranean, fisheries-tourism regulations (e.g., pescatourism in Greece and Spain) enable co-existence by allowing fishers to diversify vessel use [46,47].

Legal instruments also address operational frictions that determine whether multifunctionality is viable. Safety-zone rules, gear permissions, licensing arrangements, and tenure conditions define acceptable co-location between fisheries and offshore wind [14,24]. Some jurisdictions allow limited recreational access within offshore wind farms, reflecting controlled co-existence [48].

Pilot initiatives show that temporary legal flexibility helps generate evidence necessary for scaling multifunctionality, as seen in Belgium [49]. North Sea cases remain the most advanced, largely due to legal frameworks around offshore wind that facilitate structured co-location and co-existence, while Southern European examples often involve fisheries-tourism-conservation interactions expressed primarily through co-existence or co-location [47,48,50].

6.2. Economic Instruments

Economic instruments shape multifunctionality by influencing financial viability, risk distribution, and incentives for actors to adopt combined uses. They support all three modalities, with specific roles depending on the combination of activities.

Subsidies and financial programmes frequently underpin multifunctionality pilots. In Greece, subsidies enabled an aquaculture-diving tourism model, illustrating co-existence [51]. Fisheries Local Action Groups funded diversification and eco-tourism initiatives that rely on co-existence between fisheries and tourism [50]. In the Netherlands, innovation programmes supported trials of passive-gear fisheries operating within offshore wind areas, an example of co-location [52].

Studies show that co-locating wind, wave, and aquaculture operations can create cost and productivity synergies. Shared logistics, vessel use, and maintenance reduce operational costs for aquaculture and wave devices within offshore wind areas, while complementary resource patterns, such as different seasonal peaks in wind and wave energy, can enhance overall system productivity [52,53]. The study by Buck and Langan [42] similarly indicate that mussel or seaweed cultivation within offshore wind areas can be financially feasible in the Dutch context, largely because co-location allows aquaculture to benefit from existing offshore infrastructure, the sheltered conditions provided by turbine arrays, and shared installation and maintenance logistics. Przedrzymirska et al., [50] describe pescatourism arrangements in which fishers use the same vessel for both fishing and tourism activities, such as guided trips or cultural experiences, demonstrating co-existence through shared operations and diversified income streams. Studies analyzing planning practices further show that permitting certain forms of co-location (e.g., passive gear within offshore wind farms) can reduce total system costs by improving spatial efficiency [54]. Ecological changes in and around offshore wind farms, such as local increases in brown crab or gadoids, can enhance revenue potential for passive fisheries where regulatory access exists [12,54]. Market mechanisms such as ecolabels in MPAs demonstrate how economic incentives can reinforce conservation goals while sustaining livelihoods [55].

Compensation and insurance remain decisive economic factors for multifunctionality. Compensation schemes can offset losses for fishers displaced by offshore developments, reducing financial risk and making participation in multifunctional arrangements more acceptable. By contrast, insurance coverage for activities inside offshore wind arrays, such as aquaculture or passive fishing, remains limited, often offered only on a case-by-case basis or with exclusions for key risks. This uncertainty raises costs and deters potential co-users [14]. In parallel, emerging proposals for ecosystem-service payments, for example, recognising the nutrient-removal benefits of seaweed or shellfish cultivation, illustrate how targeted economic incentives could strengthen the business case for ecological multifunctionality [56]. Trust, procedural fairness, and local acceptance influence whether actors participate in multifunctional initiatives, especially those requiring co-use or closer forms of co-existence [11,13].

6.3. Spatial Planning Instruments

Spatial planning instruments enable multifunctionality by governing where activities occur, how they interact in space, and which combinations are spatially feasible.

In the North Sea, national MSPs establish spatial priorities and coexistence principles that guide multifunctional development. The Dutch "area passports" under the North Sea Agreement provide spatially explicit information on existing uses, environmental conditions, and feasible combinations such as seaweed or mussel cultivation within offshore wind areas [14,57]. Similarly, the North Sea Farm Foundation's Multi-Use Procedure offers stepwise spatial guidance for trialing multi-use configurations [48]. In Scotland's Pentland Firth and Orkney Waters, coexistence aims and monitoring duties are integrated into tidal-energy consents, supporting planned co-existence [58]. Germany's new Exclusive Economic Zone Plan allows overlapping designations for wind energy, conservation, defence and shipping, enabling co-location where priorities do not conflict, while recognising remaining uncertainties around cumulative effects [43].

Area-based conservation instruments also support multifunctionality. In France, site management plans in Parc Naturel Marin d'Iroise and Marennes–Oléron enable co-existence among environmental protection, fisheries, and tourism [9]. Other studies examine how offshore wind farms can be sited relative to MPAs to achieve co-location with conservation benefits while managing associated constraints [10,48]. Evidence shows that offshore wind farms can function as de facto refugia, where reduced fishing pressure allows benthic habitats and certain fish and invertebrate populations to recover [12,59].

At the same time, there are some challenges related to turbine foundations that may facilitate the spread of non-indigenous species, and conservation objectives can restrict or prevent co-location when impacts cannot be aligned with protection requirements. Sweden's approval of offshore wind development within a Natura 2000 site as part of the Kriegers Flak expansion illustrates that co-location with conservation designations can be authorised under specific conditions. However, it is noteworthy to highlight that most other applications in the country have been denied, with several still pending (see discussion in [60]), indicating a cautious and highly case-specific approach [24]. In the Borssele offshore wind area, seaweed cultivation trials represent another example of co-location, with aquaculture systems placed within the wind-farm footprint. Buck & Langan [42] report ecological co-benefits such as nutrient removal and local habitat enhancement and note that certain design options, such as shared mooring or partial structural integration, could shift such arrangements closer to co-use.

Recent spatial analyses using ecosystem-service mapping show that multifunctionality potential varies substantially within basins, highlighting trade-offs between ecological hotspots and sectoral priorities that influence all three modalities (co-location, co-existence, and co-use) [61,62]. Conflict-management studies in Denmark, England, and the Netherlands further indicate that many trade-offs are still resolved during project licensing rather than at the MSP level, reflecting gaps between strategic planning and operational decision-making [63].

6.4. Technical-digital Instruments

Technical and digital instruments enable multifunctionality by providing infrastructures, technologies, and monitoring systems that support co-use, co-location, and co-existence. The literature documents both purpose-built designs, engineered from the outset to accommodate multiple activities, and repurposed offshore structures adapted for new uses.

Purpose-built innovations include the aquaculture–tourism combination in Western Rhodes, Greece, where modified fishing gear, adapted feeding schedules, and revised operational routines allowed aquaculture sites to host recreational diving while maintaining production activities, an example of technologically facilitated co-existence [51]. In Scotland, the MeyGen tidal project integrated tidal-current turbines with extensive environmental monitoring – using marine-mammal acoustic sensors, fish-movement tracking, and benthic cameras – to enable energy generation to operate alongside strict ecological monitoring requirements through real-time data and adaptive management [9,58]. Similarly, Sweden's Hexicon platform concept demonstrates how multi-energy floating structures, combining wind and wave technologies, could in future configurations accommodate aquaculture systems, creating potential pathways toward co-use where different activities share offshore infrastructure [52].

Repurposing existing offshore structures represents a second technological pathway. Falconer et al., [11] document early trials assessing the suitability of decommissioned oil and gas platforms for shellfish or seaweed cultivation. These cases exemplify sequential or spatial co-location: although the industrial activity has ceased, the structure provides a stable base for new aquaculture operations without requiring new construction.

Feasibility studies identify technically viable options for co-locating long-line mussel and seaweed systems within offshore wind farms in the North Sea. Buck & Langan [42] show that such systems can operate effectively within turbine arrays, though their deployment depends on addressing practical constraints such as mooring stability in high-energy environments, offshore logistics for installation and harvesting, and alignment with wind-farm concession periods and maintenance schedules. Further technical risks, including mooring failure, collision hazards, turbine-induced vibration, and sediment transport dynamics, require agreed engineering standards and operational protocols before wider deployment is feasible [64].

GIS-based conflict and synergy mapping can support early identification of suitable areas for co-location by visualising spatial overlaps among uses and environmental features [65]. Scenario-evaluation and spatial optimisation tools can support strategic planning by identifying space availability for offshore wind deployment under different assumptions about coexistence with fisheries or conservation areas [66]. Cumulative-impact modelling tools also play a role. Tamis et al., [67] show how comparing single-use and multi-use configurations can quantify ecological impact risk and reveal where integrated designs may reduce cumulative pressures on the marine environment. Multi-criteria decision-analysis tools further support planning by ranking offshore wind priority areas through combined socio-ecological and technical criteria [68].

Low-cost optical and acoustic sensors, remote-sensing platforms, and continuous environmental monitoring systems provide the ecological data needed to track interactions between uses [69]. Research in Iberian systems reinforces this need: Cunha et al., [70] show that adding activities such as aquaculture or renewable energy to areas already used for fisheries or conservation can alter trophic interactions, species distributions, and ecosystem functions. These findings demonstrate that co-location requires integrated assessment of how multiple pressures overlap in space and time, rather than evaluating each activity in isolation.

7. How governance instruments operate in practice

We examine how instruments operate in practice to advance marine multifunctionality. This captures both the mode of activation of instruments and the functional roles they perform in addressing governance challenges

7.1. Modes of activation

Building on the classification described in the Methods (active, semi-active, and passive), this subsection examines how instruments differ in the explicitness and intentionality with which they promote multifunctionality. Table 1 synthesizes the activation modes identified across

Table 1
Activation modes per instrument family.

Instrument family	Active	Semi-active	Passive
Legal	Binding coexistence provisions; explicit legal permission for combined uses (e.g. aquaculture within offshore wind farm concessions); mandated monitoring or access rules.	Non-binding coexistence clauses in marine policy statements; guidance on compatible uses.	Clarification of liability, tenure, safety zones, insurance conditions, compensation schemes.
Spatial Planning	MSP zones explicitly prioritising or reserving space for multi-use; area passports specifying intended combinations.	MSP principles encouraging co-location; overlap allowances subject to conditions; management plans in MPAs.	Spatial conflict-resolution rules; buffer zones; adaptive zoning that removes prohibitions rather than promoting integration.
Economic	Targeted funding for multi-use pilots; subsidies conditional on combined uses; innovation programmes for multi-use platforms.	Funding schemes that allow (but do not require) multifunctionality; diversification support.	Compensation for displaced users; risk-sharing mechanisms; ecosystem-service payments that offset losses.
Techno-digital	Purpose-built multi-use platforms; co-designed infrastructure enabling shared functions.	Monitoring systems and decision-support tools facilitating coordination and learning.	Repurposing existing structures; baseline monitoring required for compliance rather than integration.

the four instrument families and illustrates how multifunctionality may be promoted through active, semi-active, or passive arrangements.

Across the reviewed cases, semi-active and passive activation modes predominated, while fully active promotion of multifunctionality was comparatively rare and concentrated in specific sectors and regions. Passive instruments were particularly common in early or more cautious contexts. These included measures such as clarification of licensing conditions, safety-zone rules, compensation arrangements, and liability provisions, which removed barriers to co-use or co-location without actively requiring or incentivizing integration.

7.2. *Text Box 1. North Sea offshore wind–aquaculture co-location*

In the Dutch and Belgian North Sea, multifunctionality has evolved through layered governance mixes combining marine spatial planning, pilot funding, coexistence guidance, monitoring requirements, and adaptive licensing arrangements. Offshore wind zones initially provided the spatial anchor through MSP processes and designated energy areas. Subsequent pilot projects for seaweed cultivation, mussel farming, and fisheries access were supported through innovation funding schemes and techno-digital feasibility studies. Over time, additional governance instruments were introduced to address emerging barriers, including insurance uncertainty, liability allocation, safety procedures, and operational compatibility. Rather than resulting from a single integrated policy, multifunctionality emerged incrementally through sequencing, policy packaging, and later policy patching mixing instruments with active, semi-active and passive intentionality. These cases represent some of the more mature multifunctionality configurations identified in the literature because they combine spatial planning, economic support, legal clarification, and technological adaptation within relatively stable governance arrangements

7.3. *Text Box 2: Aquaculture–tourism co-existence in Greece*

In Western Rhodes, Greece, multifunctionality emerged through the co-existence of aquaculture and marine tourism activities. Fish farms adapted operational practices, including feeding schedules, diving protocols, and modified equipment arrangements, to accommodate recreational diving while maintaining production activities. Unlike North Sea offshore wind cases, governance support relied less on formalized legal or spatial-planning instruments and more on local coordination, operational adaptation, and diversification incentives. Multifunctionality therefore emerged more incrementally through semi-active governance arrangements that encouraged compatibility without imposing binding multifunctionality requirements. The case illustrates how multifunctionality may develop through shared services and operational systems rather than through shared infrastructure or tightly integrated policy frameworks. It also highlights the importance of legitimacy-building and local acceptance in sustaining multifunctional marine activities.

Semi-active instruments were widely used to encourage multifunctionality while retaining flexibility. Examples included MSP principles, guidance documents, coexistence procedures, and management plans that expressed preferences for compatible uses without imposing binding obligations. These instruments supported coordination and learning and were often employed where uncertainty or stakeholder contestation remained high.

Fully active instruments, such as binding coexistence provisions, targeted funding for multi-use pilots, or purpose-built technological designs, were less frequently reported. Where they did occur, they were largely associated with energy-led contexts in the North Sea, where stable regulatory frameworks and policy priorities enabled more explicit promotion of combined uses. This predominance of passive and semi-active tools helps explain why multifunctionality typically advances incrementally rather than through immediate, mandated integration. As illustrated in Table 1, these active configurations were most frequently associated with combinations of legal, economic, and techno-digital instruments rather than with single governance tools operating in isolation.

7.4. *Functional roles of governance instruments*

Within and across these activation modes, instruments perform distinct functional roles in practice. These functional roles frequently overlapped with the activation patterns summarized in Table 1. In particular, passive instruments were commonly associated with risk- and cost-reduction functions, while semi-active instruments more often supported coordination and legitimacy-building. Furthermore, across the analysed cases, four recurring functions emerge.

First, some instruments primarily performed a direction-setting function, signalling that multifunctionality was desirable or permissible and reducing uncertainty about future policy expectations. Spatial planning instruments, coexistence principles, and explicit legal allowances for combined uses were most often associated with this role. Their presence was particularly evident in North Sea cases, where MSPs and sectoral energy frameworks provided early signals that co-location or co-existence within offshore wind areas was an accepted policy objective.

Second, a set of instruments served a coordination function, organising how activities fit together in space and governance processes. These included zoning rules, area passports, coexistence procedures, and planning guidance that translated high-level objectives into spatially explicit and procedurally manageable arrangements. Where such instruments were absent or weak, conflicts were more frequently deferred to project-level licensing, increasing transaction costs, delays, and uncertainty for prospective users.

Third, instruments contributed to legitimacy and demand creation, not typically through standalone mandates but by normalising multifunctionality through repeated procedures, pilots, and guidance. Economic diversification schemes (such as pescatourism), participatory planning processes, and transparent monitoring requirements helped build acceptance among incumbent users, particularly fisheries and local communities, and reduced resistance to novel combinations of activities.

Finally, a distinct group of instruments performed a risk- and cost-reduction function, addressing the practical barriers that often deter participation even where multifunctionality is encouraged in principle. Safety-zone rules, liability allocations, compensation schemes, and, where available, insurance arrangements were decisive in determining whether actors could engage without disproportionate financial or operational exposure. Across the literature, the absence of such instruments was a recurring reason why multifunctionality stalled despite supportive plans or strategic commitments

These patterns indicate that multifunctionality typically advances through policy layering and sequencing, with passive and semi-active instruments often preceding more active forms of promotion. Moreover, where instruments are bundled early, they resemble policy packaging; more commonly, multifunctionality emerges through policy patching as new instruments are added to existing frameworks.

8. Discussion

This review shows that marine multifunctionality advances when policy mixes jointly perform four complementary governance functions: setting direction and legitimacy, coordinating activities in space, mobilising resources and sharing risks, and enabling operations through technical and monitoring capacities. Across the literature, multifunctionality tends to stall when one or more of these functions is absent or poorly aligned.

Regulatory instruments legitimise and de-risk access by defining permissible uses, responsibilities, and safety provisions. Planning and conservation instruments coordinate activities by clarifying where multifunctionality is feasible and under which spatial conditions. Economic instruments mobilise resources, offset losses, and distribute financial risk, while technical and digital instruments materialise co-use or co-location and provide monitoring capacities for adaptive management. When viewed as policy mixes, three cross-cutting patterns emerge.

First, sequencing matters. Across the reviewed cases, strong multifunctional systems were characterized by the early introduction of planning and conservation instruments, which clarified spatial priorities and the conditions under which activities may interact. Regulatory instruments then specify how multifunctionality may occur through access rules, safety requirements, and monitoring obligations. Economic and techno-digital instruments usually follow, once spatial and legal foundations are in place, because financial commitments and technical designs depend on clear rights, responsibilities, and performance standards [4,9,14,42,43].

Evidence from offshore wind–aquaculture interactions illustrates this dependency. Basirati et al. [71] show that technical risks (e.g., mooring stability, sediment dynamics, or collision hazards) cannot be addressed through engineering alone, but require regulatory clarity on safety expectations and monitoring responsibilities. Techno-digital solutions therefore become operational only once legal and planning frameworks are established.

Procedural practices in the North Sea further support this interpretation. The Dutch “area passport” system provides site-specific information on environmental conditions, existing uses, and feasible combinations before co-users are invited [57]. Similarly, stepwise procedures translate MSP priorities into access rules prior to piloting [48]. Where such translation is absent, reliance on case-by-case licensing increases transaction costs and delays implementation [63]. Multiple studies show that unresolved trade-offs are often deferred to project-level licensing rather than addressed strategically at plan level [43,48,63], indicating incomplete alignment rather than a preferred governance approach.

Taken together, the literature suggests that multifunctionality becomes implementable, and financially and technically viable, only once spatial and legal conditions are clarified. While sequencing is not strictly linear, early direction-setting and coordination appear to be enabling conditions for later economic and technical interventions.

Second, complementarity rather than redundancy links instrument families. In the more mature North Sea cases, MSP procedures and coexistence provisions provide direction and legitimacy, while compensation schemes and safety-zone rules clarify residual risks. Targeted funding supports early trials, and monitoring systems reduce uncertainty for regulators and operators [10,14,48,65,69]. Insurance arrangements, however, remain limited and uneven across jurisdictions.

Evidence also shows that data alone is insufficient. Where trust in regulators is low, procedures themselves are contested, underscoring the importance of transparent engagement and clear allocation of responsibilities and liabilities [13,72]. Where tenure arrangements, liability rules, or insurance coverage remain unclear, developers often resist multifunctionality despite supportive MSPs [10,14,40]. Even where ecological or spatial synergies exist, multifunctionality remains unviable without workable business models and cost-sharing mechanisms [70,71]. Strengthening the weakest function – whether direction, coordination, risk reduction, or financial and technical capacity – can yield the greatest gains.

Third, policy mixes are path-dependent and basin-specific. In the North Sea, multifunctionality has largely evolved around offshore renewable energy, which provided early direction-setting and coordination. As a result, many documented cases focus on energy-fisheries-nature interactions supported by MSP procedures and sectoral wind regulations [45,48]. In contrast, Southern European basins more frequently exhibit fisheries–tourism–conservation pathways, shaped by local development instruments and coastal management traditions rather than energy frameworks [41,47,50,73,74]. These different entry points anchor policy mixes in distinct sectors, requiring subsequent layers (e.g., compensation rules, monitoring expectations, or technical designs) to align with those anchors [64,72,75].

Although some European hotspots cover all key functions, alignment across governance levels remains uneven. National MSPs may signal support for multifunctionality while sectoral licensing and insurance practices still treat co-users as exceptions, leading to bespoke negotiations [9,40]. This vertical misalignment helps explain why many trade-offs are resolved at project level rather than strategically through MSPs, increasing costs and undermining credibility for investors and incumbent users [43,63].

Activation modes further clarify how these functions are realised in practice. Instruments providing direction are most often actively deployed through binding provisions. Coordination and learning typically rely on semi-active instruments such as guidance and procedures, while risk- and cost-reduction functions are largely addressed through passive instruments, including compensation schemes, safety-zone templates, and insurance arrangements. These modes are interdependent: ecological or economic opportunities created by co-location only translate into practice once access, liability, and insurance conditions are clarified. Co-location thus creates potential value, but activation determines whether that value can be realised.

Three practical implications follow. First, sequencing and modes of assembly matter [17]. Policy mixes may be deliberately packaged ex ante or incrementally patched over time. In practice, this suggests establishing clear policy direction and provisional risk-mitigation measures, running scoped pilots to generate evidence, and codifying risk-reduction measures before scaling [76,77]. Second, coherence requires continuous attention. Ensuring that MSP objectives translate into permits, contracts, and data obligations across governance levels remains essential, often requiring cross-agency coordination and shared data infrastructures [24,44,78]. Third, cumulative-effect monitoring should be embedded as a core obligation rather than treated as an add-on. Linking monitoring requirements to licences and ensuring that results feed back into MSP revisions are crucial for adaptive capacity and long-term credibility [12,41,59,79].

Finally, our review confirms that multifunctionality is rarely treated as a single or clearly bounded category in the literature. Most studies rely on broad terms such as "multi-use" or "multi-purpose" without distinguishing systematically between co-use, co-existence, and co-location. Our categorisation therefore reflects interpretive judgement. Even so, a consistent pattern emerges: most studies combine modalities, with co-location frequently serving as an entry point that is later complemented by co-use or co-existence. This overlap reflects an empirical reality in which spatial proximity often precedes more integrated governance, economic, and technical arrangements. Multifunctionality thus emerges as a layered and evolving configuration rather than a singular mode, reinforcing the policy-mix perspective that implementation depends on bundled and interacting instruments rather than isolated tools.

9. Conclusions

This study examined the conditions and combinations of governance instruments that enable marine multifunctionality in Europe, drawing on peer-reviewed evidence across offshore renewables, fisheries, aquaculture, tourism, conservation, and underwater cultural heritage. Through a systematic literature review, we classified governance instruments into four families (legal, economic, spatial planning, and techno-digital) and analysed how they operate in practice through their activation modes and functional roles. We further examined how instruments are sequenced and combined over time, and how the literature aligns with three modes of multifunctionality: co-use (shared structures), co-location (spatial proximity), and co-existence (compatible operations).

The findings show that multifunctionality advances when policy mixes jointly provide four complementary governance functions: clear direction, spatial coordination, legitimacy or demand creation, and risk and cost-reduction. Across the reviewed cases, successful configurations typically follow a sequence in which planning and legal instruments establish spatial and regulatory clarity; risk-management rules (such as safety zones, liability, and compensation) are then added; and economic, pilot-based, and techno-digital measures subsequently enable implementation and learning. Where progress is limited, one or more of these functions is missing, rules are weakly aligned or unstable, and plan-level intentions are not consistently translated into licensing and operational practice. Across sea basins, co-location most often appears as the initial entry point, frequently complemented over time by co-use or co-existence, indicating that multifunctionality therefore develops incrementally as a layered configuration rather than as a discrete, one-off arrangement.

A policy-mix perspective helps explain why both policy packaging (aligning planning, licensing, and compensation ex ante) and policy patching (using flexible instruments, adjustable or incremental as gaps emerge) are critical. Packaging strengthens coherence and predictability, while patching allows governance arrangements to remain workable as pressures, technologies, and evidence evolve. In practice, policy mixes are only as effective as their weakest element: unclear tenure, absent insurance, or insufficient monitoring can constrain implementation even where other instruments are in place.

Three implications follow for policymakers. First, multifunctionality benefits from early direction-setting and provisional risk-mitigation measures, followed by tightly scoped pilots that generate evidence before risk-reduction rules are standardised and scaled. Second, coherence requires sustained attention to how MSP objectives are carried through into permits, concession agreements, and data obligations across EU, national, and local levels. Third, monitoring and cumulative-effects assessment should be embedded as core requirements rather than treated as add-ons, so that co-use, co-location, and co-existence, particularly in or near protected areas, support rather than undermine conservation objectives.

This study has limitations. The evidence base reflects peer-reviewed literature available up to the search dates and therefore excludes fast-moving developments often documented in grey literature. The review is also Euro-centric, with strong representation of the North Sea, and predominance of english-speaking literature, meaning that observed patterns in sequencing and instrument interaction may not translate directly to other governance contexts.

Future research could extend this analysis by: (i) incorporating high-quality grey literature to capture operational innovation between publication cycles; (ii) comparing European experience with other regions where multifunctionality evolves under different legal and administrative systems; and (iii) examining how tenders and procurement processes embed requirements and incentives for multifunctionality, including how governance instruments are combined within these mechanisms.

CRediT authorship contribution statement

Karina Barquet: Writing – review & editing, Writing – original draft, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Luciana Fernandes Coelho:** Writing – original draft, Investigation, Data curation.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2026.107202.

Data availability

No data was used for the research described in the article.

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