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Integrating climate adaptation initiatives for coastal resilience: governance lessons from the Catalan coast

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Mediterranean coastal regions face increasingly interconnected climate risks that require adaptation across sectors and governance levels. Despite growing policy commitments and a widening portfolio of adaptation initiatives, implementation often remains fragmented. This study examines the governance conditions under which diverse climate adaptation initiatives can be integrated to support coordinated regional and local resilience. Using the Catalan coast (Spain) as a case study, the analysis draws on nine adaptation initiatives developed through the European IMPETUS project. These initiatives are interpreted through four response types used as analytical lenses—technological, ecological, social-behavioral, and policy-integrated—and analyzed using a governance diagnostic framework based on five governance dimensions: mandates and responsibilities, coordination mechanisms, funding structures, planning and regulatory embedding, and implementation capacity. The IMPETUS Catalonia demonstration provides a common empirical setting for the analysis, drawing on the documentary, technical, implementation, and stakeholder material generated around the nine initiatives.

The findings identify institutional alignment across governance dimensions as an important condition supporting or constraining adaptation integration. Technological initiatives show stronger alignment with established mandates, funding arrangements, and implementation capacity. Ecological and social-behavioral initiatives face greater coordination and long-term embedding challenges. Policy-integrated characteristics are present across all initiatives yet primarily support the implementation of individual initiatives rather than stronger connections among different adaptation approaches. Overall, adaptation objectives are increasingly embedded within planning and decision-making processes while technological, ecological, and social-behavioral initiatives continue to evolve in parallel. The study contributes a governance diagnostic framework for analyzing adaptation integration and shows how institutional alignment helps identify governance conditions that support or constrain integration. The framework offers an approach for diagnosing governance barriers and strengthening more coordinated climate adaptation in Mediterranean coastal regions.

KEYWORDS
adaptation integration, climate adaptation, coastal resilience, environmental governance, Mediterranean coasts

1 Introduction

Mediterranean coastal regions are under increasing pressure from accelerating climate risks combined with dense infrastructure, economic concentration, and high ecological value. Climate change impacts in these areas are rarely isolated events; they interact with existing environmental vulnerabilities and socio-economic dynamics, generating compound risks and cascading impacts. Sea-level rise, marine storms, water scarcity, and irregular precipitation patterns affect coastal ecosystems, urban settlements, infrastructure networks, and water systems simultaneously (IPCC, 2023; Pörtner et al., 2022). Responding to such interconnected pressures requires adaptation strategies that move beyond single-sector interventions and address resilience in a systemic manner.

Despite growing political commitments and expanding technical knowledge, climate adaptation often remains fragmented in practice (Oberlack, 2017; Roggero et al., 2018). Measures are frequently designed and implemented within sectoral boundaries that reflect existing administrative mandates, funding streams, and professional expertise. Coastal protection may be addressed separately from water management; ecosystem restoration may proceed independently of infrastructure upgrades; behavioral change initiatives may operate as temporary projects without long-term institutional anchoring. As a result, adaptation efforts tend to evolve in parallel rather than as components of a coordinated resilience strategy. The core challenge is not the absence of adaptation options, but the difficulty of integrating diverse initiatives across sectors, governance levels, and institutional mandates (Dovers and Hezri, 2010; Epstein et al., 2021; Von Lüpke et al., 2023). Governance arrangements shape how responsibilities are distributed, how coordination occurs, and how initiatives are institutionally supported. They therefore play a central role in determining whether climate commitments are translated into coordinated adaptation or remain fragmented across sectors and levels of government (Armitage et al., 2009; Ghorbani et al., 2023).

Climate adaptation research and practice have generated a growing portfolio of adaptation initiatives spanning technological, ecological, social, and policy approaches. Yet these initiatives are typically developed within separate institutional arrangements, funding structures, and sectoral mandates, making their coordination into coherent adaptation strategies difficult. While previous research has extensively examined the design and effectiveness of individual adaptation measures, comparatively less attention has been devoted to explaining how diverse adaptation initiatives implemented within the same territorial context are coordinated and integrated (Cabana et al., 2023; Hinkel and Bisaro, 2016; Newell et al., 2015). This paper addresses that gap by investigating how governance arrangements support or constrain the coordination and integration of climate adaptation initiatives beyond their technical characteristics.

The Catalan coast in northeastern Spain provides a particularly suitable empirical setting for examining these dynamics (ICGC, 2021; OCCC, 2021). Extending over 600 km along the Mediterranean Sea, it concentrates strategic infrastructure such as Barcelona Airport and Harbor, petrochemical and industrial complexes in Tarragona, intensive tourism areas along the Costa Brava and Costa Daurada, agricultural production zones, and highly urbanized municipalities within dynamic coastal and deltaic systems. This convergence of exposure and socio-economic intensity creates a pronounced climate adaptation hotspot (IPCC, 2023; Kanan and Giupponi, 2024; McFadden, 2010; Petzold and Scheffran, 2024). Sea-level rise threatens low-lying deltas and estuaries through flooding and saline intrusion; increasingly intense marine storms accelerate erosion and biodiversity loss; chronic water scarcity is aggravated by tourism demand and dependence on river transfers, desalination, and reclaimed water; and irregular precipitation patterns intensify flash flooding, often coinciding with coastal inundation in metropolitan areas. These interconnected pressures generate competing land-use priorities and resource demands, requiring governance systems capable of balancing infrastructure protection, ecosystem conservation, water security, and economic development within limited spatial and administrative capacity.

Within this context, the European IMPETUS[1] project has developed a broad portfolio of climate adaptation initiatives across the Catalan coast. These initiatives pursue different adaptation objectives and reflect diverse ways of addressing climate risks and strengthening resilience, from the development of technical solutions and ecosystem-based interventions to stakeholder engagement processes and the integration of adaptation into planning and policy frameworks. Although they operate within the same regional policy and institutional setting, they are embedded in different governance arrangements, including different funding structures, institutional responsibilities, and coordination requirements across sectors and governance levels. These differences raise the broader question of how governance arrangements support or constrain the integration of climate adaptation initiatives, and ultimately how more integrated resilience strategies can emerge (Keiff and Talbot, 2024; Mesdaghi et al., 2022).

The paper is guided by the following research question: Under what governance arrangements can diverse climate adaptation initiatives be integrated to support coordinated regional and local resilience? To address this question, the paper first interprets the adaptation initiatives through four response types—technological, ecological, social-behavioral, and policy-integrated— according to their primary adaptation objective and approach. These response types serve as complementary analytical lenses for interpreting the heterogeneous portfolio. Building on this analytical perspective, the paper applies a governance diagnostic framework to systematically examine the governance arrangements supporting or constraining adaptation integration. The empirical analysis draws on documentary, technical, implementation and stakeholder material generated through the IMPETUS Catalan Coast demonstration activities. In doing so, the paper contributes a governance diagnostic framework for analyzing adaptation integration and offers practical insights for strengthening coordinated climate resilience at regional and local levels.

1 Impetus. Turning Climate Commitments into Action. www.climate-impetus.eu.

2 Methods

2.1 Four response types as analytical lenses for climate adaptation

To examine the governance conditions supporting the integration of diverse climate adaptation initiatives, this study interprets the initiatives developed along the Catalan coast through four response types: technological, ecological, social-behavioral, and policy-integrated. The four response types were developed as portfolio-informed analytical lenses and do not constitute an inductively derived or exhaustive typology of climate adaptation. Their starting point was the bounded empirical portfolio of nine initiatives developed within the IMPETUS Catalonia demonstration and the purpose of examining the governance conditions under which these heterogeneous initiatives could become institutionally connected. The response types distinguish broad differences in the initiatives' primary adaptation objectives and approaches and provide a basis for structuring comparison across the portfolio. As detailed below, each response type is conceptually grounded and situated in the relevant adaptation and governance literature. The response types do not represent alternative forms of governance or mutually exclusive categories, nor are they intended as a general classification of climate adaptation responses. They provide complementary analytical lenses through which initiatives with different adaptation objectives and approaches can be examined using a common set of governance dimensions concerning mandates, coordination, funding, planning and regulatory embedding, and implementation capacity (Dovers and Hezri, 2010; Oberlack, 2017).

The technological response type encompasses adaptation initiatives centered on engineered interventions that seek to reduce climate risks by improving the robustness, reliability, or performance of physical and operational systems (Bache, 2020; Koppenjan and Groenewegen, 2005). This type includes a wide range of measures, such as monitoring technologies, early warning systems, predictive models, water management infrastructure, engineered coastal protection, and other technical solutions designed to anticipate, absorb, or reduce climate impacts (Klein et al., 2001; Greiving and Fleischhauer, 2012). These responses are grounded in the assumption that climate risks can be addressed through scientific knowledge, engineering expertise, and technological innovation, emphasizing the design, deployment, and continuous refinement of technical solutions to support adaptation (Bulkeley, 2014; Klein et al., 2001). While technological measures are often associated with physical infrastructure, they also encompass digital systems, analytical tools, and technological processes that enhance the capacity to monitor environmental change and inform adaptation decisions.

The ecological response type comprises adaptation initiatives that reduce climate risks by protecting, restoring, or enhancing ecosystems and the natural processes through which they provide adaptive functions (Blomquist et al., 2010; Patiño et al., 2025). Rather than relying primarily on engineered interventions, they work with ecosystem dynamics to strengthen resilience while simultaneously supporting biodiversity, ecosystem services, and human wellbeing (Anderson and Renaud, 2021; Raymond et al., 2017; Kanan and Giupponi, 2024). Their defining characteristic is their capacity to generate multiple co-benefits across environmental, social, and economic dimensions, including flood regulation, habitat conservation, carbon sequestration, landscape enhancement, and recreational opportunities. Consequently, the ecological response type is increasingly understood as a multifunctional adaptation approach capable of addressing interconnected climate and sustainability challenges while contributing to long-term socio-ecological resilience (Kirsop-Taylor et al., 2022; Sauer et al., 2021).

The social-behavioral response type comprises adaptation initiatives that seek to reduce climate risks by influencing individual and collective behavior, strengthening social learning, and fostering participation in adaptation processes (Aswani et al., 2018; Brink and Wamsler, 2018). They are founded on the premise that climate resilience depends not only on technological innovation or ecosystem management but also on the capacity of individuals, communities, and organizations to understand risks, adapt practices, and engage in collective action. This response type includes initiatives aimed at promoting behavioral change, increasing public awareness of climate risks, supporting participatory decision-making, and encouraging more sustainable patterns of resource use. Their defining characteristic is that adaptation is achieved through changes in knowledge, attitudes, values, and practices, supported by communication, collaboration, trust-building, and social interaction among diverse actors (Sovacool et al., 2021; Urwin and Jordan, 2008).

The policy-integrated response type comprises adaptation initiatives that seek to embed climate adaptation within public policies, planning processes, and governance systems, emphasizing strategic coherence across sectors and levels of government beyond individual adaptation initiatives (Kooiman, 2003; Pahl-Wostl and Knieper, 2023). They are based on the premise that adaptation becomes more effective when climate objectives are incorporated into broader policy agendas and coordinated across sectors such as water management, spatial planning, environmental protection, infrastructure, and economic development. The defining characteristic of this type is the integration of adaptation into decision-making processes through strategic planning, policy coordination, and the alignment of sectoral objectives, enabling adaptation to become a cross-cutting component of governance rather than a stand-alone policy domain (Boyd and Juhola, 2014; Okereke et al., 2009). This involves strengthening policy coherence and strategic integration across governance systems while coordinating adaptation across different institutional arrangements and governance configurations (Rölfer et al., 2024).

These response types provide the analytical lenses through which heterogeneous adaptation initiatives can be interpreted comparatively. Building on institutional diagnostic approaches (Ostrom, 2007; Ostrom and Cox, 2010), the following section introduces the analytical framework used to systematically examine governance arrangements across initiatives through a common set of governance dimensions.

2.2 Analytical approach: a governance diagnostic framework

Climate adaptation initiatives do not operate independently from the governance systems in which they are embedded

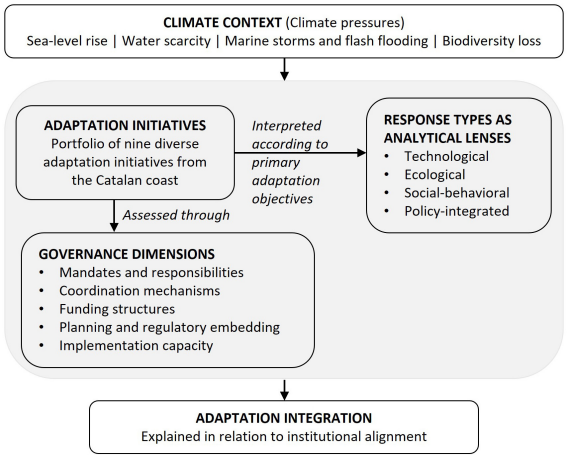


FIGURE 1
Governance diagnostic framework for analyzing adaptation integration. Conceptual representation of the governance diagnostic framework developed in this study. Climate pressures provide the context within which adaptation initiatives are implemented. The governance diagnostic framework examines these initiatives through five governance dimensions while the four response types serve as analytical lenses for interpreting their primary adaptation objective and approach. The framework assesses institutional alignment to identify governance conditions supporting or constraining adaptation integration.

(Ghorbani et al., 2023; Juhola et al., 2011). Even technically robust or ecologically sound initiatives may remain fragmented if governance arrangements do not support coordination across sectors and levels of government. Understanding the governance conditions supporting or constraining adaptation integration therefore requires an analytical approach capable of systematically examining the institutional arrangements through which adaptation initiatives are governed and connected. To address this challenge, this study develops a governance diagnostic framework (Figure 1). The framework focuses on the governance arrangements that shape how adaptation initiatives are coordinated, financed, institutionalized, and implemented in practice, providing a structured basis for comparing governance arrangements across heterogeneous adaptation initiatives.

Diagnostic institutional analysis has been developed over several decades as a systematic approach for investigating complex governance systems through a common set of analytical variables (Kiser and Ostrom, 1982; Oakerson, 1992). It is based on the premise that governance outcomes emerge from the interaction of multiple institutional attributes whose influence depends on the social-ecological context in which they operate (Ostrom, 2005). Diagnostic frameworks therefore organize empirical inquiry around theoretically defined governance dimensions that provide a common analytical language for describing institutional arrangements, comparing governance configurations across heterogeneous cases, and examining how different governance conditions interact across heterogeneous cases (Ostrom and Cox, 2010; Cole et al., 2019; Epstein et al., 2021).

Building on this methodological tradition, diagnostic frameworks have become increasingly influential in environmental governance research as a means of systematically analyzing governance complexity across diverse social-ecological contexts (Cleaver and Whaley, 2018; Cole et al., 2019; Pahl-Wostl and Knieper, 2023). Their application has been particularly relevant in climate adaptation research, where implementation depends on interactions among multiple institutions, sectors and governance levels (Bosomworth et al., 2017). By providing a consistent analytical framework for examining governance dimensions and their interactions, diagnostic approaches support cumulative comparison across heterogeneous cases while identifying governance conditions associated with different adaptation processes and outcomes.

Figure 1 operationalises this diagnostic logic through a governance diagnostic framework tailored to the analysis of coastal climate adaptation initiatives. The analytical focus is placed on the institutional conditions supporting or constraining adaptation integration within broader governance systems. Adaptation integration refers here to the institutional connection of otherwise distinct adaptation initiatives across sectors, organizations, and governance levels, as opposed to their development as parallel responses within separate governance arrangements. It is examined qualitatively through these governance connections and is not measured as a separate quantitative outcome. Accordingly, the framework assesses governance arrangements and institutional processes, with adaptation initiatives serving as the empirical units through which these governance conditions are examined. The four response types are used solely as complementary analytical lenses for interpreting the primary adaptation objective and approach of each initiative and structuring the comparative analysis. They are not treated as governance models or explanatory variables but provide a common basis for comparing how governance arrangements vary across initiatives pursuing different adaptation objectives.

Drawing on the diagnostic institutional and environmental governance literature discussed above, and on the literature used to conceptualize the four response types, the framework operationalises recurrent institutional attributes relevant to the governance of the adaptation approaches represented in the portfolio. Across these bodies of literature, recurrent attention is given to the distribution of authority, coordination, resources, institutional embedding, and the capacity to translate adaptation into practice. These themes provide five governance dimensions through which the study examines the institutional conditions supporting or constraining connections among heterogeneous adaptation initiatives. The dimensions are not intended as an exhaustive set of governance attributes, but as an operationalisation tailored to the purpose of this study: understanding adaptation integration across the four response types represented in the portfolio.

Specifically, the framework considers: (i) mandates and responsibilities, addressing how authority and responsibilities for adaptation are allocated across institutions and governance actors (Newell et al., 2015; Keiff and Talbot, 2024); (ii) coordination mechanisms, capturing the formal and informal arrangements connecting actors, sectors, and governance levels, including horizontal and vertical forms of institutional coordination (Pahl-Wostl and Knieper, 2023; Von Lüpke et al., 2023); (iii) funding structures, concerning the availability and continuity

of financial resources as part of the institutional conditions supporting adaptation action (Oberlack, 2017; Cabana et al., 2023); (iv) planning and regulatory embedding, tracing how adaptation becomes incorporated into established policy, planning, and regulatory processes (Dovers and Hezri, 2010; Greiving and Fleischhauer, 2012); and (v) implementation capacity, referring to the institutional, administrative, and technical capacities through which adaptation initiatives can be put into practice (Bosomworth et al., 2017; Oberlack, 2017). These five dimensions offer a common structure for comparing governance conditions across initiatives with different adaptation objectives and approaches. Their configuration is interpreted in terms of institutional alignment, defined as the degree of coherence among governance arrangements across the five dimensions. Institutional alignment enables comparison across initiatives and the identification of recurrent governance patterns within and across the four response types.

2.3 Empirical case, project-generated evidence and analytical procedure

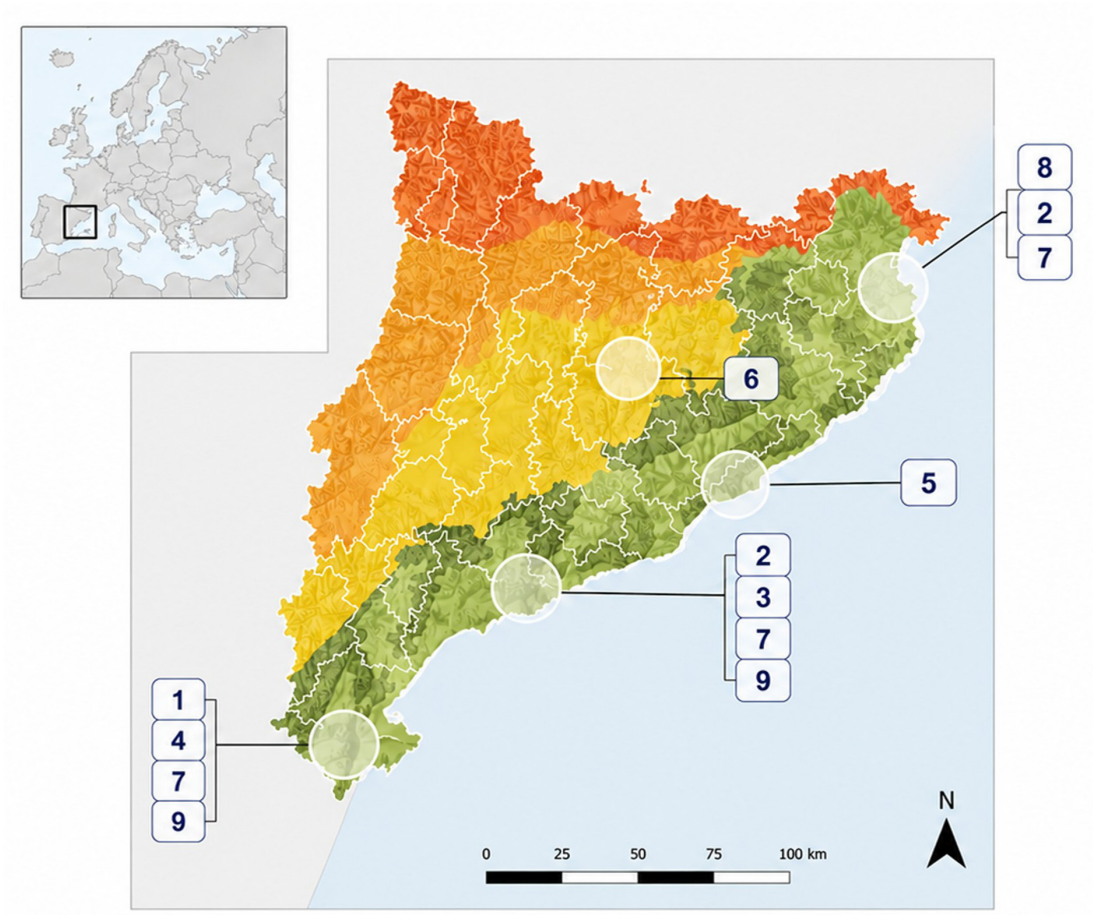
The empirical analysis draws on the complete portfolio of nine adaptation initiatives developed and tested along the Catalan coast within the European IMPETUS project (2021–2025) (Figure 2). No initiatives were excluded, aggregated, or redefined for analytical purposes. Implemented within a shared regional governance, institutional, and temporal context, these initiatives address multiple climate risks—including sea-level rise, marine storms, water scarcity, and biodiversity loss—and encompass technological, ecological, social-behavioral, and policy-integrated approaches across a broad range of coastal settings, including deltaic systems, metropolitan areas, tourism-intensive municipalities, industrial-port zones, and water-scarcity hotspots. The portfolio therefore provides a valuable source of empirical variation in governance arrangements, allowing diagnostic comparison under broadly constant contextual conditions. This empirical setting is particularly well suited to institutional diagnosis, as governance configurations can be examined across initiatives addressing shared adaptation challenges under a common regional policy and institutional context. The analysis focuses on the governance arrangements through which these initiatives are coordinated, financed, institutionalized, and implemented, rather than on evaluating their technical performance or adaptation effectiveness. Interpreted using the four response types as complementary analytical lenses and analyzed across the five governance dimensions of the diagnostic framework, the initiatives provide the empirical basis for comparing governance arrangements across a diverse but institutionally coherent regional adaptation system.

The empirical setting for the study was provided by the IMPETUS Catalonia demonstration activities conducted between 2022 and 2025. Over this period, the project developed and tested nine adaptation initiatives within the same regional governance context, generating an extensive body of evidence around their development, governance and implementation. The material comprised regional climate adaptation strategies, sectoral and municipal planning instruments, project deliverables, technical reports, governance assessments, implementation documentation, and stakeholder material from interviews conducted through different project activities[2]. These sources documented different aspects of the governance context and development of the initiatives and were used complementarily within the structured governance analysis described below. Stakeholder material contributed particularly to the interpretation of governance responsibilities, coordination practices, implementation capacity and informal governance processes, alongside the documentary, technical and implementation evidence. Table S1 in the Supplementary material characterizes the organizational and governance perspectives represented in the stakeholder interview material, illustrating the range of perspectives contributing to this complementary source of evidence. Together, this body of project-generated evidence provided the empirical basis for examining the governance arrangements of all nine initiatives through a common analytical framework.

The empirical analysis followed a structured qualitative governance assessment guided by the governance diagnostic framework presented in Figure 1. Following the diagnostic logic of institutional analysis (Ostrom, 2005), the five governance dimensions provided the theory-informed analytical structure through which the empirical material was examined. The objective was not to derive analytical categories inductively from the empirical material, but to analyse how these literature-grounded governance dimensions were expressed across the nine initiatives. The complete portfolio was examined against the same five dimensions, drawing iteratively on the documentary, technical, implementation, and stakeholder material described above. Relevant project material was revisited as needed to substantiate and compare the initiative-level assessments, with the different sources serving as complementary evidence rather than being analyzed separately. The four response types provided complementary analytical lenses for interpreting similarities and differences across initiatives. The qualitative analysis was undertaken by the first author and subsequently reviewed by the second author to verify the consistent interpretation and application of the governance dimensions across all initiatives and the coherence of the comparative judgements.

For each initiative, the empirical material was examined across the five governance dimensions and considered jointly according to the aspect of governance being analyzed. Documentary and project-based material provided evidence particularly on formal mandates and responsibilities, funding structures, planning and regulatory arrangements, and implementation processes, while stakeholder material complemented this evidence on coordination practices, implementation capacity, and informal governance processes. Evidence for each initiative and dimension was interpreted against the High, Medium, and Low criteria specified in Supplementary Table S2. The final rating reflected

2 The interviews were conducted across different IMPETUS Catalonia activities and did not constitute a stand-alone interview study or follow a single protocol. They form part of the broader project-generated evidence used in this study. Publicly available IMPETUS Catalonia materials and outputs illustrating the scope and nature of these activities can be consulted at www.impetus.eu.



1 **Multifunctional wetlands.** *Below sea-level multifunctional wetland.*

2 **Sand dune restoration.** *Restoration and monitoring to prevent coastal erosion.*

3 **Water Reclamation System (Water reuse).** *Centralized and decentralized hybrid fit-for-use water reclamation system.*

4 **Sediment transport modelling.** *Three-dimensional (3D) water flow and sediment transport modelling using computational fluid dynamics (CFD).*

5 **Microbiological Risk Assessment tool for bathing water quality.** *Quantitative Microbiological Risk Assessment (QMRA) of pathogens in bathing seawater.*

6 **Reducing cyanotoxins in water treatment plants for drinking purposes.** *Monitoring harmful algal blooms (HABs) and testing ultrasonic and solar disinfection.*

7 **Modelling of spatial distribution of species.** *Modelling species distribution change.*

8 **Coastal monitoring system.** *Development of a coastal information system to collect information on flood-prone coastal areas.*

9 **Tourism behavioural change.** *Development of alternative and sustainable tourism strategies.*

FIGURE 2
Study area: the Catalan coast and location of the nine adaptation initiatives.

the governance condition supported by the combined evidence, not the number or relative frequency of sources supporting a particular rating; no numerical weighting or source-specific aggregation was applied. Where evidence was incomplete or divergent, the material most directly informing the governance condition concerned was revisited and interpreted against the

corresponding criteria in Supplementary Table S2 before assigning the final rating. For example, sand dune restoration was rated Low for funding structures because the available evidence identified temporary project funding, corresponding to the Low criterion in Supplementary Table S2. Evidence concerning other aspects of the initiative, such as its strong inter-institutional coordination, informed the corresponding governance dimensions but did not affect the funding rating. Where evidence relevant to the same dimension pointed to different criteria, the sources were revisited jointly against the definitions in Supplementary Table S2, considering their relevance to the governance condition being assessed before assigning the final rating.

The resulting High, Medium, and Low ratings represent structured comparative judgements of governance conditions and do not constitute quantitative scores. The criteria for each governance dimension are provided in Supplementary Table S2 in the Supplementary material, while Table S3 presents representative evidence underpinning the governance assessment and the interpretation of each initiative in terms of its primary response type. Each initiative was interpreted according to the response type that best reflected its primary adaptation objective and approach, while recognizing that individual initiatives may exhibit characteristics of more than one response type. The response types therefore function as comparative analytical lenses and not as mutually exclusive classifications, while the five governance dimensions provide a common structure for comparing governance arrangements and institutional alignment across the nine adaptation initiatives.

3 Results

The portfolio of adaptation initiatives analyzed displays considerable diversity in both the climate risks addressed and the types of interventions implemented (Table 1). The initiatives range from infrastructure and monitoring solutions to ecosystem restoration projects, stakeholder engagement processes, and planning-oriented activities. Although all were developed within the same regional governance context, they operate through different governance arrangements. Some initiatives are embedded in established organizations with well-defined responsibilities and operational capacity, while others involve coordination across multiple actors, project-based funding, or sustained stakeholder engagement. These differences illustrate the diversity of governance configurations within the portfolio despite the shared regional policy and institutional setting.

Table 1 presents the nine adaptation initiatives and their assignment to the response type that best reflects their primary adaptation objective and approach. Because the analysis draws on the complete portfolio of adaptation initiatives developed within the IMPETUS project, the distribution of initiatives across response types is uneven and reflects the empirical composition of the portfolio rather than a balanced comparative design. Table 2 synthesizes recurrent governance patterns identified across initiatives associated with each response type. Systematic variation emerges across the five governance dimensions—mandates and responsibilities, coordination mechanisms, funding structures, planning and regulatory embedding, and implementation capacity. Initiatives associated with the technological response type generally display clearer mandates, stronger implementation capacity, and more stable funding arrangements, whereas initiatives associated with the ecological and social-behavioral response types require more complex coordination and depend more heavily on project-based funding and less formalized institutional arrangements.

Notably, while policy-integrated characteristics were consistently identified across the analyzed initiatives, they did not constitute the primary adaptation objective assigned to any individual initiative in Table 1. Nevertheless, because policy integration forms one of the four analytical lenses of the framework and was repeatedly observed as a secondary characteristic across initiatives (Supplementary Table S3), Table 2 retains a policy-integrated profile synthesizing these recurring characteristics. This pattern is itself an empirical finding and is explored in greater detail below. These patterns provide the basis for the detailed comparative analysis that follows.

3.1 Technological response type

The technological response type includes the hybrid water reclamation system, microbiological risk assessment (QMRA) for bathing water quality, cyanotoxin monitoring in drinking-water reservoirs, coastal monitoring, and species distribution modeling (Table 1). Although these initiatives address different climate risks—including water scarcity, public health, marine storms, and biodiversity loss—they display a relatively consistent governance profile. They are implemented through established organizations responsible for water management, environmental monitoring, and public infrastructure, where mandates and responsibilities are clearly defined and operational capacity is already in place. Across the five governance dimensions, initiatives associated with the technological response type display the highest degree of institutional alignment.

These initiatives also benefit from relatively stable funding arrangements and strong planning and regulatory embedding. Water reclamation and drinking-water monitoring are implemented within existing water management and public health systems, while coastal monitoring and species distribution modeling complement established environmental assessment and planning activities. The presence of specialized technical expertise, established operational procedures, and mature monitoring systems contributes to comparatively strong implementation capacity across these initiatives. At the same time, the comparative analysis indicates that these initiatives remain predominantly embedded within sectoral governance arrangements. Coordination requirements are generally limited because these initiatives operate largely within existing organizational structures and administrative mandates.

Although these initiatives show strong institutional alignment within their respective sectoral arrangements, interaction with ecological restoration, behavioral initiatives, and broader territorial planning remains comparatively limited. Several technological initiatives nevertheless exhibit policy-integrated characteristics through their links to planning frameworks, monitoring systems,

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TABLE 1 Portfolio of climate adaptation initiatives analyzed across the four response types.

Initiative	Description	Primary adaptation objective and approach	Impetus climate risk	Primary response type*	Secondary response types
Multifunctional wetlands	Below sea-level multifunctional wetland.	To demonstrate the feasibility of the technology in wetlands, as decentralized water treatment systems able to reduce nutrients and pollutants from agricultural fields.	Sea level rise	Ecological	Technological Policy-integrated
Sand dune restoration	Sand dune restoration and monitoring to prevent coastal erosion.	To reduce the exposure of the hinterland and thereby enhance the protection of people and infrastructure from sea level rise.	Marine Storms	Ecological	Policy-integrated
Water Reclamation System (Water reuse)	Centralized and decentralized hybrid fit-for-use water reclamation system.	To increase water availability for non-drinking purposes. To prove the economic, social and environmental benefits of greywater reuse.	Water scarcity	Technological	Policy-integrated
Sediment transport modeling	Three-dimensional (3D) water flow and sediment transport model using computational fluid dynamics (CFD).	To reproduce the water flow and sediment dynamics within the Ebro river and the irrigation channels, as a tool to propose efficient management and adaptation measures.	Marine Storms	Ecological	Policy-integrated
Microbiological Risk Assessment (QMRA) tool for bathing water quality	Quantitative Microbiological Risk Assessment (QMRA) to determine the risk due to the presence of pathogens in bathing seawater.	To develop and implement tools for risk prediction, monitoring and management of water-borne disease in Barcelona demo-site.	Health diseases	Technological	Policy-integrated
Reducing cyanotoxins in water treatment plants for drinking purposes	Implementing advanced monitoring tools in water reservoirs to predict harmful algal blooms (HABs). Implementing/evaluating ultrasonic and solar disinfection techniques for cyanotoxins removal.	To increase the resilience of water plants to water-borne pathogens.	Health diseases	Technological	Policy-integrated
Modeling of Spatial distribution of species	Modeling techniques and analytical frameworks for assessing species distribution change.	To improve the understanding of climate change impacts on species distribution; to provide information for conservation practitioners to use within the context of their planning at national and local scales.	Biodiversity Loss	Technological	Policy-integrated
Coastal monitoring system	Development of a coastal information system by collecting information about the areas most vulnerable to flood risk in the Catalan coast.	To assess the economic impacts of extreme storms in infrastructures.	Marine Storms	Technological	Policy-integrated

(Continued)

TABLE 1 (Continued)

Initiative	Description	Primary adaptation objective and approach	Impetus climate risk	Primary response type*	Secondary response types
Tourism behavioral change	Development of alternative and sustainable tourism strategies.	To make tourism less affected by and more resilient to climate change.	Water scarcity	Social-behavioral	Policy-integrated

*Each initiative was assigned to the response type that best reflected its primary adaptation objective and approach. The response type assignment provides the basis for identifying recurrent governance patterns across initiatives with similar adaptation objectives and approaches. Secondary response type characteristics indicate complementary features associated with other response types but were not used to determine the primary analytical classification.

and decision-support processes. These findings indicate that strong institutional alignment within sectoral governance arrangements does not in itself generate connections with other adaptation approaches; such integration also requires mechanisms connecting knowledge, planning, and action across sectors and governance levels.

3.2 Ecological response type

The ecological response type comprises multifunctional wetlands, sand dune restoration, and sediment transport modeling (Table 1). Although these initiatives address different climate risks—from sea-level rise and marine storms to water quality and sediment dynamics—they exhibit a common pattern of governance arrangements centered on the involvement of multiple organizations operating across different territorial scales. River basin authorities, coastal managers, environmental agencies, municipalities, landowners, and research organizations all play complementary roles, making implementation more organisationally distributed than in the technological response type.

Across the three initiatives, responsibilities are shared among organizations with different sectoral mandates and planning priorities. Wetland restoration combines water treatment, agricultural runoff management, and ecosystem conservation. Dune restoration brings together coastal protection, biodiversity conservation, and municipal land management. Sediment transport modeling connects river basin management with coastal adaptation and agricultural water management. These cross-sector linkages increase coordination requirements and require negotiation among actors with different planning responsibilities and management objectives. The comparative analysis also indicates that governance support is less consistent than for initiatives associated with the technological response type. Funding frequently relies on project-based or environmental programmes rather than dedicated infrastructure investment, while planning and regulatory embedding varies across initiatives and territorial contexts. Taken together, these characteristics indicate a comparatively lower degree of institutional alignment across the five governance dimensions.

Across these initiatives, implementation capacity is closely associated with sustained collaboration across organizations and territorial scales. Several initiatives also exhibit policy-integrated characteristics through their links to planning processes and cross-sector coordination. However, these connections primarily concern the institutional embedding of individual initiatives and do not necessarily connect ecological responses with other adaptation approaches. The ecological cases therefore illustrate how cross-sector coordination and planning embedding can support individual initiatives while adaptation integration across the broader portfolio remains limited.

3.3 Social-behavioral response type

The social-behavioral response type is represented by the tourism behavioral change initiative, which promotes more sustainable tourism practices to reduce vulnerability to water scarcity and strengthen climate resilience (Table 1). Unlike initiatives associated with the technological and ecological response types, its adaptation approach centers on behavioral change, stakeholder engagement, and collaboration among municipalities, tourism actors, research organizations, and local communities. Its governance arrangements therefore place greater emphasis on sustained participation, communication, and the involvement of diverse actors than on established technical or operational structures.

The comparative assessment indicates that responsibilities are distributed across multiple organizations without clearly defined statutory mandates. Activities are primarily supported through temporary projects and external funding, while coordination relies on collaboration among public authorities, civil society organizations, research institutions, and private actors. This collaborative character broadens participation but also depends heavily on voluntary engagement and project continuity. Planning and regulatory embedding remains limited, with the initiative only partially incorporated into formal adaptation and territorial planning processes. These characteristics indicate comparatively weak institutional alignment across the five governance dimensions.

The initiative exhibits policy-integrated characteristics through its links to broader planning and coordination processes. However, its comparatively low institutional alignment reflects limited formal embedding, temporary funding arrangements, and continued reliance on stakeholder engagement. These findings indicate that connecting social-behavioral adaptation with wider governance and planning frameworks remains a key governance challenge for adaptation integration.

TABLE 2 Comparative governance patterns across the four response types*.

Response type	Mandates and responsibilities	Coordination mechanisms	Funding structures	Planning and regulatory embedding	Implementation capacity	Governance diagnostic profile
Technological	**High** (clear sectoral mandates)	**High** (well-established sectoral coordination mechanisms)	**High** (stable infrastructure-based funding)	**High** (embedded in sectoral plans and regulatory frameworks)	**High** (established operational agencies and technical expertise)	High institutional alignment within established sectoral governance arrangements, with comparatively limited cross-sector integration..
Ecological	**Medium** (shared and overlapping responsibilities)	**High** (multi-actor coordination across organizations and governance levels)	**Medium–Low** (mainly project-based funding)	**Medium** (partial planning and regulatory embedding)	**Medium** (distributed institutional and technical capacity)	Moderate institutional alignment requiring sustained coordination across organizations and governance levels.
Social-behavioral	**Low** (diffuse responsibilities)	**Medium** (collaborative but largely project-based coordination)	**Low** (temporary project funding)	**Low** (limited formal planning and regulatory embedding)	**Medium–Low** (dependent on stakeholder participation and engagement)	Low institutional alignment, with implementation capacity closely associated with continued stakeholder engagement and project continuity.
Policy-integrated**	**Medium** (shared responsibilities across sectors)	**High** (institutional coordination across sectors and governance levels)	**Medium** (dependent on intersectoral alignment)	**High** (embedded in strategic planning frameworks)	**Medium** (dependent on institutional commitment and cross-sector implementation)	Moderate institutional alignment characterized by strong strategic coherence but more variable institutional and operational capacity.

*Comparative governance patterns were synthesized from the initiative-level qualitative governance assessments of the nine adaptation initiatives and interpreted throuhg the four response types. Supplementary Table S3 provides the initiative-level evidence underpinning the comparative governance profiles.

**Although no initiative was assigned primarily to the policy-integrated response type (Table 1), policy-integrated characteristics were consistently identified across all nine initiatives (Supplementary Table S3). The High–Medium–Low assessments shown here therefore do not derive from a distinct group of initiatives, but from the comparative synthesis of how these recurring policy-integrated characteristics were expressed across the five governance dimensions within the initiative-level assessments.

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3.4 Policy-integrated response type

The policy-integrated response type differs from the other response types in an important respect. While policy-integrated characteristics were identified across all analyzed initiatives (Table 1), they did not emerge as the dominant adaptation objective of any individual initiative. This pattern does not indicate the emergence of a distinct portfolio of policy-integrated initiatives; instead, it suggests that adaptation is increasinglybeing incorporated into planning processes, policy frameworks, and institutional coordination mechanisms across different adaptation domains. Policy integration therefore appears less as a stand-alone adaptation approach than as a transversal governance function supporting coordination, planning, and strategic alignment across diverse forms of adaptation action.

Across the portfolio, policy-integrated characteristics were reflected in efforts to embed adaptation objectives within planning processes, strengthen coordination across sectors and governance levels, and align adaptation actions with broader policy priorities. These characteristics were generally well embedded within strategic planning instruments and involved broad institutional participation, although responsibilities remained distributed across multiple organizations and funding arrangements varied across sectors and territorial contexts. The resulting governance profile showed mixed institutional alignment across the five dimensions, with stronger alignment in planning and coordination than in funding and implementation capacity.

The widespread presence of policy-integrated characteristics nevertheless did not translate into a distinct set of policy-integrated initiatives or stronger connections among technological, ecological, and social-behavioral approaches. This suggests that policy integration often operated within individual initiatives rather than between them, highlighting an important distinction between integrating adaptation into governance processes and integrating adaptation initiatives with one another.

3.5 Comparative patterns across response types

Comparison across the four response types reveals distinct governance configurations across the five dimensions of the analytical framework (Table 2). Technological initiatives exhibit comparatively high institutional alignment within established sectoral governance arrangements, characterized by clear mandates, stable funding, strong planning and regulatory embedding, and high implementation capacity. Ecological initiatives involve more distributed responsibilities and greater coordination across organizations and territorial scales, while the social-behavioral initiative relies more strongly on stakeholder participation, project-based funding, and less formalized institutional arrangements. Policy-integrated characteristics occupy a different position, appearing across the portfolio through links between individual initiatives and planning, policy, and coordination processes. However, their widespread presence does not translate into stronger connections among technological, ecological, and social-behavioral approaches. The comparative analysis therefore highlights a distinction between the institutional alignment supporting individual adaptation initiatives and the governance connections required to integrate different adaptation approaches across sectors, organizations, and governance levels.

4 Discussion

This study examined under what governance arrangements diverse climate adaptation initiatives can be integrated to support coordinated regional and local resilience. Across the nine initiatives, adaptation integration was associated with different configurations of institutional alignment across the five governance dimensions examined—mandates and responsibilities, coordination mechanisms, funding structures, planning and regulatory embedding, and implementation capacity. Institutional alignment refers here to the degree of coherence among governance arrangements across these dimensions, rather than to any single institutional attribute. The contribution of the governance diagnostic framework is therefore not to identify an optimal portfolio of adaptation initiatives, but to provide a structured basis for examining how these governance configurations relate to the institutional connections among heterogeneous adaptation initiatives within a common regional context.

The comparison across response types illustrates how these governance conditions differ across adaptation approaches. Technological initiatives generally exhibited stronger institutional alignment, reflecting their connection with established administrative mandates, funding arrangements, technical expertise, planning frameworks, and operational capacity. Ecological initiatives involved more distributed responsibilities and greater coordination across organizations, sectors, and territorial scales, while the social-behavioral initiative depended more strongly on stakeholder engagement, project-based funding, and less formalized institutional arrangements. These patterns highlight how different adaptation approaches are associated with distinct configurations of governance conditions and implementation capacity within the same regional context.

A particularly noteworthy finding concerns the policy-integrated response type. Unlike the technological, ecological, and social-behavioral response types, policy-integrated characteristics did not emerge as the primary classification of any individual initiative but were consistently observed across initiatives associated with the other response types. This suggests that policy integration operates less as a stand-alone adaptation approach than as a transversal governance function that supports coordination, alignment, and institutional embedding across diverse adaptation efforts. The widespread presence of policy-integrated characteristics indicates that adaptation is increasingly being incorporated into planning processes, policy agendas, and institutional decision-making. In other words, many initiatives sought to strengthen their own degree of policy integration by embedding adaptation objectives within planning frameworks, improving coordination, and aligning implementation with broader policy priorities. However, these policy-integrated

characteristics were largely directed toward supporting individual initiatives rather than connecting different adaptation approaches. Technological, ecological, and social-behavioral initiatives frequently incorporated elements of policy integration, but these efforts were rarely designed to create stronger linkages among initiatives operating in different domains. As a result, policy integration often occurred within initiatives rather than between them.

This finding points to an important distinction between integrating adaptation into policies and integrating adaptation initiatives with one another. While adaptation objectives may be embedded within plans, strategies, and institutional processes, this does not necessarily generate stronger connections among technological, ecological, and social-behavioral approaches. Adaptation integration therefore involves an additional governance challenge: developing institutional connections across sectors, organizations, and governance levels that allow otherwise distinct adaptation initiatives to form part of a more coordinated response. More broadly, the findings suggest that the five governance dimensions operate as an interconnected system rather than as independent enabling conditions. Stable funding cannot compensate for fragmented responsibilities, strong planning frameworks cannot substitute for limited implementation capacity, and clear mandates alone do not produce integration in the absence of effective coordination. Institutional alignment therefore concerns the extent to which governance conditions reinforce one another and provide an institutional basis for sustaining adaptation initiatives and connecting them with wider governance processes. This distinction also clarifies the substantive role of adaptation integration in relation to implementation and effectiveness. The capacity to implement individual initiatives does not in itself imply the governance capacity to integrate complementary adaptation responses. Integration is therefore understood here as an enabling governance condition for coordinated adaptation: stronger institutional connections may support implementation and the coordination of complementary responses, but they do not necessarily translate into more effective adaptation or improved resilience outcomes. The relationship between integration and adaptation effectiveness is not empirically tested in this study.

This is particularly relevant for coastal resilience, where interconnected climate risks require governance capacity extending beyond the implementation of individual initiatives. In the Catalan case, strong institutional alignment was often concentrated within established sectoral arrangements, while connections among technological, ecological, and social-behavioral approaches remained more limited. Institutional alignment can therefore be understood as a governance condition contributing to adaptive capacity where it supports the implementation and institutional embedding of individual initiatives as well as their connection across sectors, organizations, and territorial scales. From this perspective, strengthening coastal resilience involves both sustaining individual adaptation responses and developing the governance capacity to connect complementary approaches where climate risks and adaptation needs intersect.

These patterns also have important implications for adaptation investment. Resources are frequently mobilized through the institutional arrangements surrounding individual adaptation initiatives, while the governance mechanisms required to connect complementary initiatives across sectors and governance domains may receive less explicit attention. The findings show that funding structures are closely intertwined with other governance dimensions: more stable funding arrangements were observed alongside established mandates and organizational capacity, whereas initiatives requiring coordination across multiple organizations more often relied on temporary or project-based funding. Funding should therefore be understood not as an isolated driver of adaptation, but as part of the broader institutional configuration through which adaptation initiatives are sustained, coordinated, and connected.

From an environmental economics perspective, this has implications for how adaptation investment is understood and prioritized. The governance conditions surrounding investment influence the institutional capacity to sustain individual measures and coordinate them with complementary adaptation efforts. Investment decisions therefore concern not only the allocation of resources to particular adaptation measures, but also the institutional arrangements needed to connect those measures across sectors and governance levels. This shifts attention from the volume of adaptation investment alone toward the governance conditions under which financial resources can contribute to more coordinated adaptation strategies and, ultimately, to coastal resilience.

The implications of the study follow directly from its focus on adaptation integration as a governance challenge. Understanding how heterogeneous adaptation initiatives become institutionally connected is an important step toward assessing adaptation from a broader governance perspective, beyond the performance of individual measures considered separately. Where climate risks cut across sectors and governance levels, this perspective helps identify whether different adaptation responses form part of a coordinated strategy and the governance conditions that support or constrain their integration. A next step is to examine empirically how governance conditions and patterns of integration relate to adaptation effectiveness and resilience outcomes, using complementary outcome-specific and longitudinal evidence.

The contribution of this study extends beyond the Catalan coast by providing a governance diagnostic for examining adaptation integration across heterogeneous initiatives. As climate risks increasingly cut across sectors and territorial scales, expanding the portfolio of adaptation measures alone may leave important institutional connections unresolved. The framework provides a structured basis for identifying where mandates, coordination, funding, planning and regulatory embedding, and implementation capacity support or constrain these connections. Its broader analytical value lies in providing a context-sensitive basis for diagnosing governance configurations and identifying where institutional action could strengthen coordination across adaptation efforts. In this way, the framework contributes to understanding how governance capacity can support more integrated regional and local responses to interconnected climate risks.

5 Conclusion

This study examined how diverse climate adaptation initiatives can be integrated to support coordinated regional and local resilience along the Catalan coast. The findings highlight the relevance of institutional alignment across governance arrangements for understanding adaptation integration beyond the characteristics of individual initiatives. By comparing adaptation initiatives interpreted through four response types, the study shows how mandates, coordination mechanisms, funding structures, planning and regulatory embedding, and implementation capacity combine into different configurations of institutional alignment. Climate adaptation should therefore be understood not simply as the deployment of individual initiatives but as the capacity of governance systems to sustain and connect them over time. Strong governance conditions surrounding individual initiatives do not necessarily translate into broader adaptation integration when connections across sectors, organizations, and governance levels remain limited.

Strengthening coastal resilience consequently calls for attention both to the governance capacity surrounding individual adaptation measures and to the capacity to integrate complementary responses to interconnected climate risks. The findings further suggest that policy integration and adaptation integration should not be treated as equivalent processes. While policy-integrated characteristics were consistently present across all initiatives, they primarily supported the institutional embedding of individual initiatives rather than creating stronger linkages among technological, ecological, and social-behavioral approaches. As a result, adaptation objectives were often incorporated into planning and decision-making processes without necessarily generating greater integration across adaptation domains. The governance diagnostic framework developed here provides a practical analytical approach for identifying where governance arrangements support or constrain adaptation integration within a common institutional context.

The study also highlights the institutional dimension of adaptation investment. Funding emerged not as an independent driver but as part of a broader configuration of governance conditions through which adaptation initiatives are sustained, coordinated, and translated into practice. From this perspective, adaptation investment involves not only allocating resources to adaptation measures themselves, but also strengthening the governance conditions that enable complementary initiatives to be sustained and connected within broader strategies for coastal resilience. This illustrates the value of examining adaptation integration as a first step toward addressing broader questions of adaptation effectiveness and resilience from a governance perspective. Understanding the institutional conditions under which adaptation efforts become connected provides a basis for subsequent research examining whether, and under what conditions, more integrated adaptation contributes to climate-risk reduction and resilience outcomes.

Beyond the Catalan coast, the framework offers a potentially applicable basis for examining adaptation governance in Mediterranean coastal regions facing comparable combinations of climate risk, institutional fragmentation, and competing territorial priorities. Its value lies not in prescribing specific adaptation measures or governance models, but in providing a systematic way to identify context-specific governance bottlenecks and support the prioritization of institutional actions that strengthen adaptation integration. Future research should apply and refine this framework across different governance contexts and combine governance diagnosis with outcome-specific and longitudinal evidence to examine how institutional configurations relate to adaptation effectiveness and resilience over time.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://climate-impetus.eu/get-involved/#resources.

Author contributions

JD-P: Writing – original draft. QP: Writing – review & editing. SC: Writing – review & editing. XM: Writing – review & editing.

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Conflict of interest

The author(s) declared that this work 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) declared that Generative AI was used in the creation of this manuscript. Generative AI tools were used in a limited capacity during the preparation of this manuscript to support the design of figures and to assist with English language proofreading and editing. All scientific content, analysis, interpretations, and conclusions were developed and verified by the author(s), who take full responsibility for the integrity and originality of the work.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frevc.2026.1906550/full#supplementary-material

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