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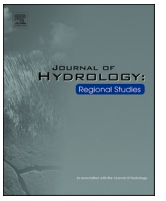

Comparative analysis of adaptation policies and policy instruments for water management in Europe

Tahereh Zobeidi *, Nadejda Komendantova

Cooperation and Transformative Governance Research Group, Advancing Systems Analysis Program, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria

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ABSTRACT

Study region: Ten European countries, including Finland, Austria, Switzerland, Belgium, the Netherlands, Denmark, Estonia, Spain, Latvia, and Lithuania

Study focus: Adaptation policies are deeply structured and shaped by contextual climatic, environmental, social, and governance factors, making them inherently sector-specific. Their effective implementation requires integrated, cross-sectoral approaches, strong governmental engagement, and active citizen engagement. This study conducts a content analysis of adaptation strategies and plans in the water sector across European countries, aiming to identify key themes, policy types, and dominant instruments. Two main documents, the National Adaptation Strategy (NAS) and the National Adaptation Plan (NAP), available on the Climate-ADAPT-2023 platform, have been analyzed.

New hydrological insights for the region: All countries in the study use a mix of adaptation strategies, plans, and policy instruments, each focusing on specific instruments. Information-based instruments such as mapping flood risk are the most widely policy instruments by European countries to address adaptation. Many countries rely on infrastructural and technical instruments, particularly for drinking water supply networks, sewage and stormwater systems, irrigation, and flood risk management. Most countries have employed policies such as promoting responsible water use, enhancing water conservation and recycling, assessing flood risks, and managing flood impacts to promote citizen engagement. By systematically analyzing these policies, the study contributes to clarifying fragmented knowledge, highlighting national priorities, and enabling broader cross-country comparisons.

1. Introduction

According to the IPCC's Sixth Assessment Synthesis Report, more than a century of fossil fuel combustion, along with unsustainable and inequitable patterns of land and energy use, consumption, and production, have been the unequivocal drivers of global warming. Between 2011 and 2020, global surface temperatures rose by about 1.1°C compared to the pre-industrial average (1850–1900) (IPCC, 2023). Climate change impacts on the water cycle, such as shifts in rainfall patterns, have been recorded over the past decades (Kahil et al., 2015; Zobeidi et al., 2022). Increases in water temperature and changes in extreme events, including flooding and drought, are expected to deteriorate water quality and worsen different types of pollution, with potential risks for ecosystems, human health, and

* Corresponding author.
E-mail addresses: zobeidi@iiasa.ac.at (T. Zobeidi), komendan@iiasa.ac.at (N. Komendantova).

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the stability and costs of water systems (Kahil et al., 2015). Moreover, rising sea levels are likely to cause greater salinity in groundwater and estuaries, reducing the availability of freshwater for people and natural habitats in coastal zones (Chettri et al., 2024). Additional effects, such as threats to food security and challenges for water infrastructure like hydropower, flood defences, and irrigation networks, have also been identified (Chettri et al., 2024). In response to climate change, adaptation strategies are being shaped to secure water availability and to limit the severity of climate change impacts on water resources (Quevauviller, 2011; IPCC, 2023).

Governments playing a central role in leading adaptation efforts through the development and implementation of public policies (Henstra, 2016). Public policies are expected either to build adaptive capacities—thus enhancing the ability of various actors, especially in the water sector, to respond to climate change—or to translate these capacities into direct adaptation actions (Adger et al., 2005). These policy measures are intended to shape outcomes for vulnerable populations, critical sectors, and particular geographic areas. Within this framework, adaptation policy is viewed as a coordinated effort to minimize vulnerability and strengthen resilience against the harmful effects of climate change (Henstra, 2016). Adaptation public policy specifically refers to government-led actions aimed at decreasing susceptibility to climate risks and boosting adaptive capacity, with the goal of limiting damage and managing the resulting challenges. Examples of such policies include promoting responsible water use, guaranteeing a reliable water supply, improving water quality and preventing water pollution, and enhancing flood risk management. These examples illustrate how governmental policies can protect vulnerable groups, critical economic sectors, and sensitive regions, while applying a range of instruments to influence the actions of citizens, organizations, and other authorities (Massey et al., 2014). In European countries (EU), the adoption of adaptation policies has been accelerating rapidly (Biesbroek et al., 2010; Ford et al., 2011; Massey et al., 2014). Enhancing adaptation can play an essential role in advancing overarching policy goals, including the 'Europe 2020 — Europe's growth strategy', while also promoting the shift towards an economy that is sustainable, efficient in resource use, environmentally friendly, and low in carbon emissions (European Environment Agency, 2013). The momentum behind climate adaptation policymaking has significantly increased since the European Commission introduced the EU Climate Change Adaptation Strategy in April 2013. European countries are currently at different stages in the formulation and implementation of their National Adaptation Strategies (NAS) and National Adaptation Plans (NAP) (Leitner et al., 2020). As of April 2020, all EU Member States had officially adopted national policies on climate adaptation. In nearly every case, the process began with the development of a NAS, which was then followed by an NAP and/or Sectoral Adaptation Plans (SAPs). According to the European Environment Agency (EEA), a NAS serves as a broad policy framework that outlines the strategic direction a nation intends to pursue in adapting to climate change. On the other hand, an NAP provides a more operational roadmap that details how specific adaptation actions are to be implemented (Pietrapertosa et al., 2018). In addition, EU countries have introduced water-specific initiatives that highlight the central role of water policy within the broader climate adaptation agenda. The European Water Resilience Strategy, launched by the European Commission in 2025, addresses key challenges such as water scarcity, climate stress, and pollution. Its three main objectives are: restoring and securing the water cycle through full implementation of existing directives and expanded measures to retain water and reduce pollutants; developing a water-smart economy that strengthens competitiveness and innovation in the water sector, guided by the Water Efficiency First Recommendation; and ensuring clean and affordable water and sanitation for all, emphasizing human rights and improving services for vulnerable groups while eliminating harmful pollutants. These initiatives demonstrate how water policy is integrated into the EU's broader adaptation and resilience strategies.

Although debates continue around the timing and necessity of specific adaptation measures, it remains essential to analyze the range of policy instruments that can support the achievement of emerging goals. Doing so can help build a more coherent analytical framework to evaluate and compare the ways in which EU governments are responding to a rapidly changing climate across diverse contexts and administrative scales (Howlett, 2005). Among these instruments, citizen engagement is increasingly recognized as a cornerstone of transparent governance and an essential component of inclusive policymaking. Actively involving citizens in decision-making processes not only enhances the legitimacy of policies but also contributes to their effectiveness and fairness. According to the Policy Learning Platform (2025), citizen engagement refers to the active involvement of individuals and communities in influencing governance decisions. It is the process through which public authorities involve citizens in discussions to help shape policies related to science, technology, and innovation. This participation occurs in a personal capacity, as opposed to a professional one, such as in the role of a researcher or business representative (Paunov and Planes-Satorra, 2023).

Evidence suggests that such engagement can strengthen community resilience and improve responses to climate-related risks, thereby fostering more effective and just adaptation efforts (Skarzauskiene et al., 2024). Local-level engagement has proven especially impactful, as communities are often more attuned to specific vulnerabilities and the urgency of adaptive action (Hunt and Watkiss, 2011). In response, many countries have adopted co-production and participatory approaches as strategic policy instruments to address climate change. Investigating these instruments, their application across sectors, and their comparative effectiveness can provide valuable insights for accelerating progress toward adaptation goals (Nelson et al., 2007), which this study aims to explore in the context of citizen participation.

National and sub-national adaptation plans and strategies (e.g., NAPs, NASs, and SAPs) provide detailed, context-specific measures tailored to each country's environmental, institutional, and sectoral conditions. However, significant variation in typologies and approaches across countries poses challenges for monitoring and comparing adaptation efforts at the European level. This diversity complicates the development of a coherent, cross-national understanding of climate adaptation. Additionally, the inherent complexity and uncertainty surrounding climate change further strain policy processes and governance systems (Ryan and Bustos, 2019). Addressing these challenges requires the development of a shared, systematic taxonomy to categorize adaptation measures—an essential first step toward capturing and evaluating the adaptation landscape in the EU and fostering cross-country learning (Leitner et al., 2021). Despite its importance, comparative research on adaptation policy remains limited due to difficulties in defining and

operationalizing adaptation as a measurable policy domain (Lesnikowski et al., 2018). While comparative analysis is a well-established method in public policy studies (Kapucu, 2012) and has proven valuable for examining complex and evolving areas such as climate adaptation (Lodge, 2017), its application remains constrained by institutional, legislative, political, and cultural differences among countries. These differences manifest in the timing, structure, scope, and legal status of adaptation strategies, shaping both the methodological design of cross-national studies and the interpretation of findings (Biesbroek et al., 2010). To date, much of the policy analysis has relied on single case studies, which, while insightful, often limit opportunities for comparison and cumulative knowledge building (Vogel and Henstra, 2015).

To respond to these gaps, the present study adopts a context-sensitive comparative framework to ensure robust and meaningful analysis. Although some efforts have been made to compare adaptation policy across jurisdictions, challenges in defining units of analysis and employing suitable methods have hindered deeper understanding of policy variations (Dupuis and Biesbroek, 2013). Notably, Vogel and Henstra (2015) have synthesized insights from public policy and adaptation research to operationalize key dimensions for comparative analysis—policy content and policy process—along with their sub-components. Tangney and Howes (2016) have demonstrated the value of this approach through a comparative study examining how climate science is used in adaptation policymaking in Queensland, Australia, and the UK.

Building on this foundation, the primary purpose of this study is to explore the citizen engagement policies in water management adopted by European countries to achieve the goals outlined in their adaptation plans and future programs. Focusing on the water sector, this study employs comparative analysis to document and explain the adaptation policy instruments used by national governments, while also considering related sectors such as agriculture. This research aims to address the following key questions according to NAS and NAP documents:

1. What are the main themes and priorities of climate change adaptation policies in European countries, particularly in the water sector?
2. How many adaptation policy activities are implemented in each country, and what types are represented?
3. Which types of policy instruments play the most critical role in advancing water-related adaptation policies?

This study contributes to analyze and visualize the adaptation policies in water sector of European countries. By identifying and highlighting the topics that shape these policies, the study will shed light on the key themes and priorities within each country's approach to addressing climate change and reducing vulnerability. This study aims to systematize the fragmented body of knowledge on adaptation policies in the water sector and to deliver up-to-date insights for both researchers and policymakers. The findings are expected to facilitate more comprehensive cross-country comparisons and to inform the ongoing refinement of national adaptation strategies (NASs) and plans (NAPs).

2. Adaptation policy and policy instruments

Adaptation policies refer to the strategic measures implemented by governments to reduce the vulnerability of systems and communities to the impacts of climate change and to enhance their capacity to cope with environmental stressors (Henstra, 2016). In the water sector, for instance, public policies that offer subsidies for investments in efficient irrigation technologies, such as irrigation modernization, are widely recognized as important adaptation options (Kahil et al., 2015). Other measures include investments in climate modeling and forecasting systems to improve water allocation planning under uncertainty, the development of early drought warning systems, the restoration of natural water retention areas, and the implementation of water pricing policies to encourage conservation (Kahil et al., 2015). An expanding body of research underscores the need to reform existing water institutions and policies, advocating for the use of incentive-based approaches to improve the effectiveness of adaptation efforts (Kahil et al., 2015). Achieving the goals of climate change adaptation strategies and plans depends on the careful selection of appropriate policy instruments (Bukowska et al., 2023). Policy instruments are understood as techniques of governance that, in one way or another, involve the utilization of state authority or its conscious limitation. They refer to deliberate, structured efforts by governments to solve policy problems by modifying the actions of the government. In this way, policy instruments can help put climate change adaptation plans into action (Mees et al., 2014). Adaptation policy instruments refer specifically to the tools available to governments that are intentionally designed to deal with the projected, long-term impacts of climate change (Biesbroek and Delaney, 2020). These instruments are the mechanisms through which governments attempt to influence behavior and improve outcomes related to public challenges (Henstra, 2016).

Policy instruments have been classified in various ways across different frameworks. In Finland's national adaptation strategy (Ministry of Agriculture and Forestry of Finland, 2005), adaptation measures are categorized into five key groups: administration and planning, such as the development of water services plans; research and information, exemplified by official guidelines aimed at minimizing flood damage; economic and technical measures, such as deploying temporary flood protection systems; and the normative framework, which covers adjustments in regulations and permit processes. Another widely recognized classification comes from Hood (1983), who identifies four main types of resources that governments can utilize: information (referred to as nodality), regulation (authority), financial tools (treasure), and institutional influence (organisation) (Bukowska et al., 2023). Similarly, Niang-Diop and Bosch (2005) have proposed a classification that also outlines four distinct groups: legislative, regulatory, and judicial instruments; economic tools, including financial and market-based measures; institutional mechanisms; and education and information-based approaches. In the present study, policy instruments are categorized into four overarching groups, building on these existing typologies while tailoring them to our research context. Table 1 outlines the categories of policy instruments employed in this study and

provides their corresponding definitions.

3. Methodology

3.1. Research method (Samples and documents)

Fig. 1 shows the research framework and process. In our study, we established a comprehensive framework focusing on the geographical scope of European countries, with a specific emphasis on the water sector.

A systematic data collection process was used to identify relevant national policies from official documents. Our data collection was meticulous, utilizing essential sources such as the National Adaptation Strategy (NAS) and the National Adaptation Plan (NAP). However, typically, both types of documents—NASs and NAPs—are cross-sectoral and integrative, encompassing a wide range of measures, policies, and initiatives designed to tackle various climate-related risks and associated socio-environmental challenges. However, despite their shared objectives, these documents differ considerably in structure, terminology, scope, and the way they address vulnerabilities, define sectoral responsibilities, set targets, and assign roles to governance levels and actors responsible for execution (Leitner et al., 2020). Additionally, we incorporated insights from Climate-ADAPT and OECD. This diverse range of sources enabled us to capture a holistic view of adaptation policies. The analytical framework employed included a detailed coding process that facilitated the identification of key quotations and thematic categorization. The content analysis phases involved rigorous cross-country comparisons, and a sector-specific analysis centered on the water sector. Our output includes comprehensive conclusions and recommendations aimed at enhancing adaptation of governance. This structured approach not only strengthens our findings but also contributes to the ongoing discourse on climate change adaptation across different national contexts.

This study conducted a content analysis of climate change adaptation strategies and plans in the water sector from selected European countries. Countries were selected based on two criteria: their profiles listed on the European Climate Adaptation Platform (Climate-ADAPT) at the time of our review in 2023, and the availability of at least one adaptation document — either a National Adaptation Plan (NAP) or a National Adaptation Strategy (NAS) — in English. Based on these criteria, ten countries were included in the analysis: Finland, Austria, Switzerland, Belgium, the Netherlands, Denmark, Estonia, Spain, Latvia, and Lithuania.

Additionally, we incorporated findings from various studies such as OECD Studies on Water and Climate Change Adaptation Policies (OECD, 2013) to enrich the dataset. Countries were excluded if they did not report any NAP or NAS, if these documents were reported in their national languages, or if the information in their files was insufficient (Iceland). Fig. 2 depicts the Map of countries with national adaptation policies, while Table 2 provides a list of adaptation documents (NAP/NAS) that were available and used for content analysis. The methodology employed ensured a comprehensive examination of adaptation policies across the selected countries. A total of 20 documents were selected for the analysis of adaptation policies.

3.2. Data analysis

This study employed a mixed-method research design, combining document analysis with directed qualitative content analysis (DQICA) to identify national adaptation strategies and plans. Policy documents were primarily sourced from local council archives and thoroughly reviewed. Relevant excerpts related to adaptation were identified through close reading and extracted as quotations. The coding process was conducted using ATLAS.ti software. In total, 262 quotations and 193 codes related to water issues were extracted

Table 1
Classification and Definitions of Policy Instruments.

Policy Instrument	Definition / Purpose	Examples	Sources
Information-based instruments	There are tools designed to inform, educate, and guide stakeholders, enabling them to make decisions that align with adaptation goals.	Public awareness campaigns, educational initiatives, training sessions, and communication processes like workshops, surveys, websites, articles, labels, and certifications; and decision-support tools, such as flood risk maps and climate adaptation guidelines for local authorities	Henstra, (2016); Mendonça et al., (2021)
Law (Legislative) and regulatory instruments	These are authoritative tools that governments use to mandate or prohibit specific actions. Encompassing laws, standards, and regulations, these instruments define permissible behaviors and set legal requirements. They are typically supported by compliance mechanisms and penalties, ensuring accountability and effectiveness.	Land-use zoning laws, emission control standards	Bouwma et al., (2015)
Economic and financial instruments	These instruments leverage financial incentives and disincentives to promote adaptive behavior. By providing price signals that integrate both positive impacts and negative externalities.	Water pricing schemes, pollution taxes, subsidies for green infrastructure, and tradable permits	Mendonça et al., (2021); Biesbroek and Delaney, (2020); Avgousti et al., (2023)
Infrastructural and technological instruments	These refer to direct investments in physical systems or technological innovations that enhance adaptive capacity.	Infrastructure such as sea walls, drainage systems, and irrigation networks, as well as the integration of smart technologies in resource management	Mimura et al., (2014)

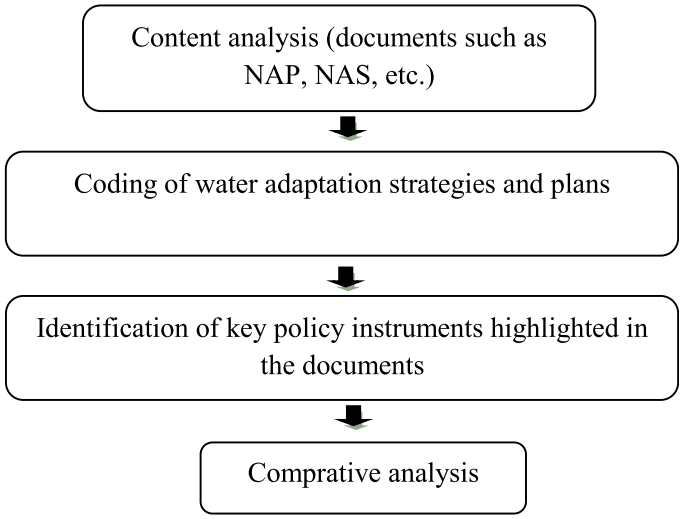

Fig. 1. The research framework: extracting, analyzing and comparing adaptation strategies and plans in the water sector.

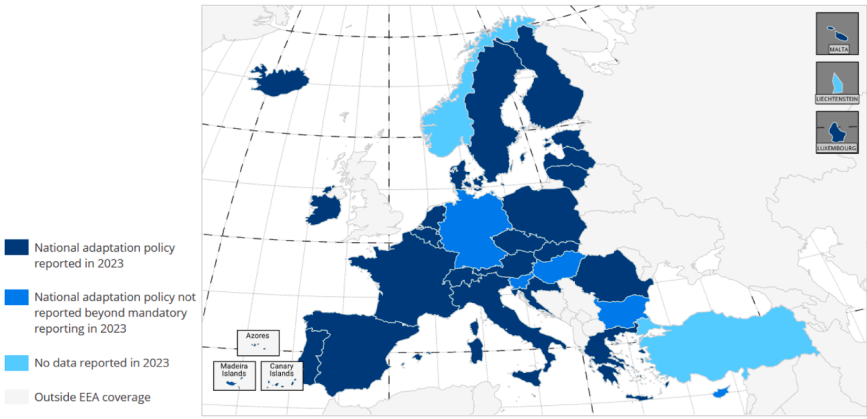

Fig. 2. Map of European countries with national adaptation policies, Source: https://climate-adapt.eea.europa.eu/en/countries-regions/countries.

from 20 documents.

4. Results

4.1. Overview of adaptation policies

Fig. 3 presents a word cloud generated from quotations of adaptation policies related to water across all these documents. Table 3 summarizes the adaptation policies identified in the reviewed materials.

4.2. Country-specific analyses

4.2.1. Austria

The analysis of Austria's water adaptation policies, based on the Austrian Adaptation Strategy and the Austrian Action Plan documents, reveals a forward-looking approach to water resource management. These policies aim to ensure the sustainable availability of water resources, which are considered essential for both human life and ecosystems.

Given Austria's overall abundance of water resources, widespread water scarcity is not anticipated in the near future. However, certain regions may face challenges related to both the quality and availability of water (Austrian Ministry of Agriculture, 2017b). In response, policies have been designed to enhance water security in these vulnerable areas through planning and technological interventions. The documents emphasize several priorities, including improving water-related databases and reducing knowledge defects, ensuring water security, considering both low water flow and temperature levels in water management, and integrating industrial technologies into planning processes. Moreover, flood risk management and the proactive handling of extreme hydrological

Table 2
List of available/unavailable documents and used (2023).

Countries	NAP	NAS	NAP in English	NAS in English	Used documents
Germany	×	×	-	-	
Hungary	×	×	-	-	
Slovenia	×	×	-	-	
Bulgaria	×	×	-	-	
Norway	×	✓	-	×	
Cyprus	×	×	-	-	
Finland	✓	✓	✓	✓	Finland's National Strategy for Adaptation to Climate Change 2005 (Ministry of Agriculture and Forestry of Finland, 2005) Finland's National Climate Change Adaptation Plan 2022 (Ministry of Agriculture and Forestry of Finland, 20142022)
Austria	✓	✓	✓	✓	The Austrian strategy for adaptation to climate change (PART 1: (Austrian Ministry of Agriculture, 2017a), PART2: (Austrian Ministry of Agriculture, 2017b)
Italy	✓	✓	×	×	
Switzerland	✓	✓	×	✓	Adaptation to climate change in Switzerland Federal Office for the Environment (FOEN), 2012
Iceland	✓	✓	Not available (being developed)	✓	
Belgium	✓	✓	✓	✓	Belgian National Adaptation Strategy (National Climate Commission- Belgium NAS, 2010b) Belgian National Adaptation Plan (National Climate Commission- Belgium NAP, 2010a)
Netherland	✓	✓	✓	✓	Adapting with ambition - National climate adaptation strategy 2016 (NAS) (Government of the Netherlands, 2016) Implementation Programme 2018 – 2019 (Government of the Netherlands, 2018)
Denmark	✓	✓	✓	✓	Danish strategy for adaptation to a changing climate (Danish Ministry of Climate and Energy and Utilities, 2008) Action plan for a climate-proof Denmark (Danish Ministry of Climate and Energy, 2012)
Estonia	✓	✓	Not available	✓	Climate Change Adaptation Development Plan until 2030 (Republic of Estonia, Ministry of the Environment, 2017)
Greece	×	×			
France	✓	✓	×	×	
Spain	✓	✓	×	✓	National Climate Change Adaptation Plan 2021−2030 (Ministry for the Ecological Transition and the Demographic Challenge, 2020)
Portugal	✓	✓	×	×	
Poland	✓	✓	Not available	×	
Norway	✓	✓	Not available	×	
Liechtenstein	✓	✓	Not available	×	
Romania	✓	✓	×	×	
Croatia	✓	✓	×	×	
Czech	✓	✓	×	×	
Slovakia	✓	✓	×	×	
Latvia	✓	✓	✓	Not available	Latvian National Plan for Adaptation to Climate Change until 2030 (Ministry of Environmental Protection and Regional Development of Latvia, 2019)
Lithuania	✓	✓	✓	✓	National Climate Change Management Policy Strategy (Seimas of the Republic of Lithuania, 2012) National energy and climate plan (Republic of Lithuania, Ministry of Energy, 2022)
Laxembourg	✓	✓	×	×	
Malta	✓	✓	Not available	Not available	
Sweden	✓	✓	×	×	

events are also prominent. Among the policy instruments, those based on awareness-raising and regulatory measures are the most emphasized, whereas economic instruments receive comparatively less attention. Ensuring a reliable future water supply to increasing qualitative and quantitative security of the water supply in areas threatened by water scarcity by means of planning and technological measures considered as both Infrastructural and technical Instruments. One notable policy—promoting the responsible use of water resources—is directly linked to citizen engagement. This approach encourages individuals to adopt water-efficient behaviors, take part in local initiatives, and follow public campaigns aimed at reducing water waste. The success of such a policy relies heavily on public education and active participation at both household and community levels.

4.2.2. Belgium

Belgium encompasses several areas identified by the European White Paper on Adaptation as highly vulnerable to climate change, including coastal regions, flood-prone river basins, and urban centers. The presence of all these at-risk zones underscores the urgent need for a targeted national adaptation strategy. Increased and more intense precipitation in Belgium can cause severe flooding, particularly in coastal and river flood-prone areas, often accompanied by salinity issues (National Climate Commission- Belgium NAS,

Fig. 3. Word cloud based on quotations from all countries.

Table 3
Water Adaptation Policies and Associated Policy Instruments.

	Water management policies	Information-based instruments	Law and regulation instruments	Economic instruments	Infrastructural and technical Instruments
	Austria (10)				
1	Analysing existing data and promoting the collection of additional data on water resources	*			
2	Enhancing coordination and information regarding water consumption and demand	*			
3	Ensuring a reliable future water supply		*		*
4	Promoting responsible usage of water resources	*			*
5	Giving greater attention to low water levels in water resource management	*	*		
6	Achieving and maintaining the good ecological and chemical status of water bodies, including groundwater	*			
7	Implementing proactive water management planning for groundwater resources		*		
8	Adaptive flood management Measures		*		
9	Taking water temperature into account in water management initiatives	*	*		
10	Installing industrial water management instruments				*
	Belgium (33)				
11	Protection and remediation of groundwater reserves (balanced management of reserve), account taken of the impact of water scarcity and drought (e.g. salinization)	*	*		
12	Banning new flood-sensitive developments	*	*		
13	Controlling flooding zones		*		
14	Counter regression of hydraulic regime for bodies of surface water				*
15	Countering sedimentation in watercourses				*
16	Development and application of groundwater level and region-specific				*
17	Development of low water strategies				*
18	Ensure safety-based drainage capacity				*
19	Expansion and optimization of the distribution network				*
20	Implementation of ground water abstraction charge in Flanders				*
21	Mapping flood risk	*			
22	Improving surface and groundwater quality		*		
23	Improving knowledge of flood management	*			
24	Improving the management of rivers		*		
25	Incentivizing grant policy and price structure			*	
26	Integrating management of banks		*		
27	Legislation and licensing of surface water extraction		*		
28	Implementation of new legislative changes to deal with flooding and other natural hazards		*		
29	Optimizing use of alternative water sources	*			
30	Optimizing sustainable water consumption			*	
31	Preventive measures including insurance		*		
32	Protect, restore, and establish flood zones				*
33	Protection from non-tidal and transitional waters		*		
34	Protection of coastal		*		
35	Protection or safeguarding of water conservation areas		*		
36	Reassessment of water and wastewater management systems		*		
37	Recovering rainwater				*
38	Reducing and decelerating the runoff of water on slopes			*	
39	Reducing of diffuse pollution to water			*	
40	Structural repair				*
41	Sustainable use of ground and surface water resources			*	
42	Sustaining the availability of affordable drinking water			*	
43	Water retention				*
	Denmark (13)				
44	Balancing the cost of water for efficient and clean water supply			*	
45	Wastewater treatment and resource recovery				*
46	Mapping flood risk	*			
47	Managing and reducing water loss				*
48	Mapping and identification of risk areas	*			
49	Minimizing Non-Revenue Water				*

(*continued on next page*)

Table 3 (*continued*)

	Water management policies	Information-based instruments	Law and regulation instruments	Economic instruments	Infrastructural and technical Instruments
50	Moving water extraction				*
51	Implementing new bathing water regulations		*		
52	Planned reorganization of water extraction		*		
53	Reassessment of permits for water extraction		*		
54	Taking into account future groundwater levels	*			
55	Monitoring water flow and quality of watercourses and wetlands	*			
56	Sustainable groundwater management	*			
	Estonia (17)				
57	Risk analysis of extreme events by cities (local plans take into account)	*			
58	Amending monitoring plans	*			
59	Assessing water quality of freshwater bodies	*			
60	Improving the quality of surface water bodies				*
61	Eliminating non-functional dams		*		
62	High-resolution modeling for forecasting the impacts of climate change	*			
63	Enhancement of regulation, monitoring, and control		*		
64	Increasing preparedness for floods	*			
65	Maintenance of dams		*		
66	Mapping and identification of risk areas (including mapping flood risk)	*			
67	Modeling transfer and stratification regimes	*			
68	Modernization of rainwater systems				*
69	Monitoring mapped climate risks	*			
70	Monitoring external and internal substance loads	*			
71	Implementing necessary risk management measures		*		
72	Preservation of water regimes	*			
73	Regular upgrading of the monitoring system for surface waters	*			
	Finland (43)				
74	Acquisition and development of temporary flood control structures				*
75	Revision of regulation permits		*		
76	Construction and development of irrigation systems				*
77	Construction of properties farther away from flood-prone areas				*
78	Construction of reserve water intake plants				*
79	Enhancing cooperation between authorities		*		
80	Distribution of water of lower quality		*		
81	Emergency preparedness planning for municipalities		*		
82	Ensuring smooth preventive and rescue operations during flooding	*	*	*	
83	Expansion of water supply and sewerage networks				*
84	Implementation of flood forecasting and monitoring	*			
85	Implementation of flood insurance policies			*	
86	Implementation of building regulations for flood resilience		*		
87	Improving water safety measures				*
88	Enhancing information dissemination in flood and drought situations and their hazards	*			
89	Increasing the discharge capacity of dams				*
90	Issuing instructions to reduce flood damage by authorities		*		
91	Interconnecting water supply plant networks				*
92	Providing investment subsidies for fixed irrigators			*	
93	Investment in projects that improve preparation for floods			*	
94	Integration into the network of a water services company				*
95	Land use planning to mitigate flood risks				*
96	Maintenance of water structures				*
97	Municipal and regional flood planning				
98	Operational flood prevention measures				
99	Planning of trenching and stormwater services				*
100	Planning of water services infrastructure				*
101	Priority on protecting settlements and vital societal functions				*
102	Protection of properties against floods				*
103	Purchasing water from other water services companies			*	
104	Reforming the compensation system for flood damages			*	

(*continued on next page*)

Table 3 (*continued*)

	Water management policies	Information-based instruments	Law and regulation instruments	Economic instruments	Infrastructural and technical Instruments
105	Regulating land use and building to manage floods		*		
106	Restrictions on water use during flood events		*		
107	Water conservation and recycling initiatives				*
108	Development of stormwater management manuals	*			
109	Studying the impacts of rain-induced floods	*			
110	Subsidies for investments improving flood preparedness			*	
111	Surveying risk sites and preparing general risk plans	*			
112	Surveying the needs for managing floods	*			
113	Establishing quality requirements for water				*
114	Incorporating rain-induced floods into zoning and urban planning	*			*
115	Using lower-quality water resources				*
116	Utilizing reserve systems at water supply plants				*
	Latvia (14)				
117	Amending monitoring plans	*			
118	Assessing the capacity of collecting rainwater	*			
119	Enhancing rainwater systems in cities				*
120	Assessing water quality of freshwater bodies	*			
121	Improving surface and groundwater quality		*		
122	Taking water temperature into account in water management initiatives	*	*		
123	Developing guidelines for integrating changes in rainwater runoff	*			
124	Implementing an early warning system	*			
125	High-resolution modeling for forecasting climate change impacts	*			
126	Promoting accessibility to drinking water			*	*
127	Restoring land amelioration systems				*
128	Restoring natural sections crossing watercourses				*
129	Studying the dismantling of mechanical obstacles in rivers	*			
130	Encouraging the use of rainwater	*			
	Lithuania (17)				
131	Assessing the impact of climate change and enhancing climate change resilience	*			
132	Developing risk management instruments			*	*
133	Developing irrigation plans				*
134	Improving surface and groundwater quality				*
135	Implementing, assessing and ensuring the functionality of the flood risk management system	*			*
136	Implementing green infrastructure measures				*
137	Identifying remedial measures	*			
138	Implementing rainwater treatment projects			*	
139	Implementing and regularly improving water management and protection projects	*			*
140	Enhancing the resilience of wastewater treatment infrastructure to reduce risks				*
141	Improving regulation, monitoring, and control measures		*		
142	Enhancing the efficiency of water-efficient technologies				*
143	Increasing investment in irrigation infrastructure			*	
144	Modernizing runoff rainwater treatment infrastructure				*
145	Modernizing and improving surface wastewater systems				*
146	Preventing water pollution	*	*		
147	Regularly upgrading the monitoring system for surface waters and groundwater		*		
	Netherland (10)				
148	Assuring water quality				*
149	Ensuring availability of fresh water				*
150	Developing stress test expertise	*			
151	Raising general societal awareness about water issues	*			
152	Increasing water levels in nature areas				*
153	Initiating climate pilot projects			*	
154	Incorporating water considerations into spatial planning	*			
155	Managing subsidence and water table levels in relation to spatial functions			*	*
156	Addressing potential flooding within the spatial structure	*			*
157	Enhancing water safety measures				*
	Spain (10)				

(*continued on next page*)

Table 3 (*continued*)

	Water management policies	Information-based instruments	Law and regulation instruments	Economic instruments	Infrastructural and technical Instruments
158	Expanding and updating knowledge on the potential impacts of climate change	*			
159	Expanding knowledge about water resource management	*			
160	Improving water resource management and planning	*	*		
161	Enhancing planning in agriculture	*			
162	Improving irrigation practices	*			*
163	Implementing initiatives regarding insurance for natural disasters, including floods			*	
164	Implementing integrated water cycle management		*		
165	Promoting the process of knowledge generation	*			
166	Implementing statutory requirements for water plans and the inventory of water resources		*		
167	Promote the acquisition and strengthening of capacities for adaptation.	*			
	Switzerland (27)				
168	Considering changes in discharge patterns and turbine performance	*			
169	Creating drinking water supply networks				*
170	Creating incentives/funding mechanisms for watershed management			*	
171	Developing water storage				*
172	Ensuring space for revitalization, flood control, and healthier ecology				*
173	Examining legal bases for changing natural conditions		*		
174	Implementing new cooling technologies				*
175	Structural measures along navigable channels				*
176	Improving transboundary water management cooperation	*	*		
177	Improving irrigation practices	*			*
178	Upgrading sewage networks and detention basins				*
179	Developing institutional framework for watershed management		*		
180	Addressing international demands	*			
181	Mitigating substance leaching	*			*
182	Developing local farming practices for soil erosion prevention	*			
183	Managing reservoirs	*			*
184	Safeguarding riverine zones				*
185	Ensuring safety of large-scale dams				*
186	Addressing regional drinking water bottlenecks				*
187	Regionalizing drinking water supply		*		*
188	Regionalizing wastewater treatment		*		*
189	Revising existing provisions for residual flow		*		
190	Reviewing lake regulations		*		
191	Revising legal provisions for low water, discharges, and lake regulations		*		
192	Run-of-river power plants				*
193	Meeting ecological requirements for water resources	*			
194	Utilizing shipbuilding technology				*

2010b). To address these risks, Belgium focuses on flood risk mapping to identify vulnerable areas and guide management efforts. The country also invests in improving knowledge of flood management through research and data collection. Measures include the alteration or removal of constructions in flood-sensitive areas, control of flood zones, implementation of new legislative frameworks to address flooding and natural hazards, and actions to protect, restore, and establish flood zones. The use of maps as an information-based instrument has played a crucial role in water management strategies.

Belgium uses economic instruments to influence behavior and promote sustainable practices through financial mechanisms. These include the implementation of a groundwater abstraction charge in Flanders, incentivizing grant policies and pricing structures, and promoting the optimized use of alternative water sources. Additional economic tools involve encouraging sustainable water consumption and ensuring the availability of affordable drinking water. Insurance-based preventive measures are also part of this strategy to reduce vulnerability and manage risk effectively.

On the legal side, Belgium has implemented several regulatory measures to strengthen water governance. These legal instruments include legislation and licensing for surface water extraction and the introduction of new laws to address flooding and other natural hazards. Restrictions on new developments in flood-sensitive areas, as well as the alteration or removal of existing constructions in such zones, serve as legal tools to prevent further vulnerability. Together, these instruments support a more resilient and adaptive water management system in the face of evolving environmental pressures.

Belgium also places strong emphasis on technical and infrastructural instruments as part of its comprehensive water management strategy. These include the development and application of groundwater level strategies tailored to specific regions, expansion and optimization of the water distribution network, and improvement of river management systems. The integration of bank management and active water level control further supports efficient flow regulation and flood mitigation. Technical efforts also involve ensuring safety-based drainage capacity, structural repair of vulnerable infrastructure, countering sedimentation in watercourses, and reducing runoff on slopes. By investing in such tools, Belgium enhances its capacity to manage water resources sustainably, adapt to hydrological extremes, and maintain the functionality of vital systems under the stress of climate change.

Several of Belgium's water management policies inherently allow for or benefit from citizen participation. For example, flood risk mapping and improving knowledge of flood management can be enhanced through public engagement and local observations, supporting more accurate and community-relevant data collection. Optimizing sustainable water consumption and recovering rainwater are also areas where households play a direct role, making behavior change essential for achieving broader water-saving goals. Moreover, preventive measures including insurance involve individual decision-making, encouraging people to take responsibility for managing their own flood risk.

4.2.3. Denmark

Denmark's adaptation policies address water management and climate impacts through various strategies: Information-based instruments include mapping flood risk, mapping and identifying risk areas, and monitoring water flow and quality in watercourses and wetlands. The country also focuses on considering future groundwater levels to inform long-term planning. These measures can involve citizen engagement, as local communities may contribute to identifying risk areas, participate in data collection for monitoring water quality and flow, and provide local knowledge to support flood risk mapping. Engaging citizens in these processes not only enhances data accuracy but also fosters public awareness, shared responsibility, and support for long-term adaptation planning.

Laws and regulations instruments involve implementing new bathing water regulations, planning the reorganization of water extraction, and reassessing permits for water extraction. These regulations help ensure safe water quality and manage water resources effectively. Economic instruments are used to balance the cost of water for efficient and clean water supply and manage and reduce water loss. This country also works on minimizing non-revenue water, which involves addressing water that is produced but not billed to customers. Infrastructural and physical instruments include wastewater treatment and resource recovery, as well as moving water extraction to optimize resource use. Denmark also invests improving systems to manage and reduce water loss. Denmark pays considerable attention to information-based, law and regulatory, and physical and infrastructural instruments, while placing less emphasis on economic instruments.

4.2.4. Estonia

Estonia focuses on mapping and identifying risk areas, including flood risk, and monitoring climate risks and substance loads to inform adaptation measures. The regular upgrading of the monitoring system for surface waters is also part of their approach to maintaining accurate and up-to-date information. In Estonia, laws and regulations are essential for improving regulation, monitoring, and control in water management. They focus on improving the quality of surface water bodies, eliminating non-functional dams, and ensuring the maintenance of existing dams. Legal measures are put in place to support necessary risk management actions and ensure compliance with standards for water management. Economic instruments are used to support preparedness for floods, often through awareness-raising initiatives, which can help allocate resources effectively and encourage proactive measures. Infrastructural and physical instruments include modernizing rainwater systems, enhancing surface water quality, and managing physical infrastructure like dams. Estonia also invests in the preservation of water regimes and the implementation of necessary risk management measures to ensure that infrastructure supports climate adaptation efforts.

4.2.5. Finland

In Finland, water management involves a range of policy types and instruments, with a primary focus on infrastructural and physical instruments. Key policies include the acquisition and development of temporary flood control structures, the construction and development of irrigation systems, the relocation of properties away from flood-prone areas, and the development of reserve water intake plants. These initiatives rely heavily on infrastructural and physical tools to address water management challenges effectively. Finland also focuses on the expansion of water supply and sewerage networks, improving water safety measures, increasing the discharge capacity of dams, interconnecting water supply plant networks, and integrating systems into the network of a water services company. Land use planning to mitigate flood risks, maintenance of water structures, planning of trenching and stormwater services, and comprehensive planning of water services infrastructure further support this strategy. Additionally, there is priority on protecting settlements and vital societal functions, property-level flood protection, water conservation and recycling initiatives, and incorporating rain-induced floods into zoning and urban planning. Measures also include using lower-quality water resources, and utilizing reserve systems at water supply plants. All of these clearly fall under infrastructural and physical instruments.

Finland places a strong emphasis on laws and regulatory instruments in managing water resources, especially concerning flood management policies. These policies include regulating land use and construction to reduce flood risks, imposing restrictions on water use during flood events, and issuing official guidance to minimize flood damage. While these actions are part of broader water management strategies, they are primarily focused on the legal and regulatory framework. Additionally, Finland emphasizes revising regulatory permits, enhancing cooperation among authorities, and organizing the distribution of lower-quality water when necessary. Emergency preparedness planning for municipalities and the implementation of building regulations to enhance flood resilience

highlight the country's legal and institutional commitment to proactive water management.

The following policies are centered around citizen engagement in water management: emergency preparedness planning for municipalities, ensuring smooth preventive and rescue operations during flooding, water conservation and recycling initiatives, surveying risk sites and preparing general risk plans, surveying the needs for managing floods, Studying the impacts of rain-induced floods, and imposing restrictions on water use during flood events.

4.2.6. Latvia

Latvia is strongly focused on information-based instruments for the policies, such as amending monitoring plans, assessing and enhancing the capacity for collecting rainwater, and evaluating the water quality of freshwater bodies. The country also considers water temperature in water management initiatives and develops guidelines for integrating changes in rainwater runoff. Additional policies include implementing an early warning system, high-resolution modeling for forecasting climate change impacts, and studying the dismantling of mechanical obstacles in rivers. These strategies highlight Latvia's emphasis on using information and data-driven approaches to improve water management and climate resilience.

Economic instruments in Latvia include promoting accessibility to drinking water through financial incentives or subsidies and encouraging the use of rainwater. These instruments aim to support sustainable water management practices and improve access to essential resources.

Infrastructural and physical instruments are also a significant focus. Latvia invests in enhancing rainwater systems in urban areas, restoring land amelioration systems, and rehabilitating natural sections crossing watercourses policies.

Several citizen engagement policies in Latvia include enhancing rainwater systems in cities, restoring land amelioration systems, and encouraging the use of rainwater. These initiatives rely on active community participation, public awareness, and collaboration, making them valuable for fostering citizen engagement in sustainable water management and climate adaptation efforts.

4.2.7. Lithuania

Lithuania focuses on a variety of policy approaches to manage water resources and address climate change impacts. Information-based instruments play a crucial role, with policies focused on assessing climate change impacts, enhancing climate resilience, and developing risk management tools. Regular upgrades to the monitoring system for surface waters and groundwater help ensure effective management. The country also emphasizes the importance of implementing and improving water body management initiatives and flood risk management systems, which rely on different policy instruments.

In addition, Lithuania works on improving regulation, monitoring, and control measures to ensure effective water management and protection. Preventing water pollution is a key regulatory focus to maintain water quality. Economic instruments are employed to enhance the efficiency of water-efficient technologies, increase investment in irrigation infrastructure, and support rainwater treatment projects.

Lithuania's policies, including developing irrigation plans, developing risk management instruments, improving surface and groundwater quality, implementing, and ensuring the functionality of flood risk management systems, implementing green infrastructure measures, implementing water body improvement initiatives, implementing and regularly improving water management and protection projects, enhancing the resilience of wastewater treatment infrastructure to reduce risks, enhancing the efficiency of water-efficient technologies, modernizing runoff rainwater treatment infrastructure and surface wastewater systems, and reconstructing wastewater infrastructure, rely heavily on infrastructural and physical instruments.

These policies reflect a comprehensive approach by integrating information-based strategies, regulatory measures, economic incentives, and infrastructural improvements to manage water resources and adapt to climate challenges effectively.

4.2.8. Netherland

The country also focuses on incorporating water considerations into spatial planning to ensure that land use and development take water management into account. Laws and regulations are crucial for implementing flood safety policies and addressing potential flooding within the spatial structure. These regulations help manage risks and ensure that infrastructure and planning strategies are aligned with flood protection needs.

Economic instruments support adaptation through various measures, including initiating climate pilot projects. These projects are often funded through financial mechanisms to test and implement innovative solutions for climate adaptation.

Infrastructural and physical instruments are applied to assure water quality, ensure the availability of fresh water, and improve water safety measures. The Netherlands also works on increasing water levels in nature areas and managing subsidence and water table levels in relation to spatial functions. This includes enhancing infrastructure to support water management and flood prevention. Overall, these policies reflect a comprehensive approach, integrating information-based strategies, regulatory frameworks, economic incentives, and infrastructural improvements to address water management and climate adaptation challenges in the Netherlands.

4.2.9. Spain

Spain's water adaptation policies involve a combination of information-based, law and regulatory, economic, and infrastructural instruments to achieve their goals. In Spain, there has been a stronger emphasis on knowledge-based policies, although water-related policies are less frequently mentioned in these documents; however, they mostly rely on knowledge and focus on agriculture and irrigation. Policies such as expanding and updating knowledge about the potential impacts of climate change and water resource management, improving irrigation practices, enhancing planning in agriculture, and promoting the process of knowledge generation to better understand climate-related challenges and solutions primarily rely on information-based instruments.

Laws and regulations are central to policies such as improving water resource management and planning, implementing integrated water cycle management, establishing statutory requirements for water plans, and maintaining an inventory of water resources. These regulations ensure comprehensive and enforceable water management policies.

Economic instruments are applied through initiatives like insurance for natural disasters, including floods, which help manage financial risks and promote preparedness for extreme weather events.

Infrastructural and physical instruments are integral to improving irrigation practices and implementing integrated water cycle management. These measures focus on enhancing the efficiency and effectiveness of water use and management systems, which are essential for adapting to climate impacts.

The policies of expanding and updating knowledge on the potential impacts of climate change and water resource management, along with promoting the process of knowledge generation, rely on active participation, awareness-building, and collaboration, making them suitable for citizen involvement in water management and climate adaptation efforts.

4.2.10. Switzerland

Switzerland's adaptation policies encompass a range of strategies to address climate impacts and manage water resources. Policies such as considering changes in discharge patterns and turbine performance, developing expertise in improving transboundary water management cooperation, improving irrigation practices, mitigating substance leaching, and implementing local farming practices for soil erosion prevention focus more on information-based instruments. The country also addresses international demands and works on optimizing transport capacities. Improving transboundary water management cooperation, improving irrigation practices, and watershed management require different instruments to achieve their goals. Policies such as examining legal bases for changing natural conditions, revising existing provisions for residual flow, and updating legal provisions for low water discharges and lake regulations, as well as the institutional framework for watershed management, focus more on law and regulation instruments. The policy of creating incentives and funding mechanisms for watershed management and addressing regional drinking water bottlenecks aligns with economic instruments.

Infrastructural and physical instruments are used to achieve the goals of policies such as developing drinking water supply networks, improving water storage, ensuring space for revitalization, flood control, and healthier ecology, implementing new cooling technologies, mitigating substance leaching, managing reservoirs, optimizing transport capacities, addressing regional drinking water bottlenecks, regionalizing drinking water supply, regionalizing wastewater treatment, upgrading sewage networks and detention basins, implementing structural measures along navigable channels, safeguarding riverine zones, ensuring the safety of large-scale dams, and maintaining residual flow. Policies that strongly involve citizen engagement include local farming practices aimed at preventing soil erosion.

5. Discussion

The aim of this study is to explore the main themes and priorities of climate change adaptation strategies and plans in European countries, as reflected in the NAS and NAP documents, with a particular focus on the water sector. Additionally, the study seeks to compare and identify which types of policy instruments play the most critical role in advancing water-related adaptation efforts across different national contexts.

Comparative analysis of the content analysis results in European countries showed notable differences in water-related management adaptation priorities, while information-based instruments are the most widely used policy instruments by European countries to address adaptation. The widespread reliance on information-based instruments highlights the role of governments in addressing information gaps by generating knowledge that supports adaptation decision-making. There are several types of information-based instruments. These include communication tools for raising awareness and capacity building as well as guidance documents for local governments, businesses or individuals. Information on risks often takes the form of early warning systems for hazards or flood risk maps. For instance, in Austria, where water use relies almost entirely on groundwater, careful planning remains particularly important. Maintaining both the quantity and quality of groundwater reserves continues to be a central goal (Austrian Ministry of Agriculture, 2017a). Austria's adaptation measures in the water sector rely mainly on information-based approaches, followed by legal and regulatory instruments. According to the results, these measures include analyzing existing data to reduce knowledge deficits on climate change impacts and encouraging the collection of additional information on water resources, enhancing coordination and knowledge sharing on water consumption and demand, ensuring a reliable future water supply, promoting responsible water use with a focus on citizen engagement, and employing adaptive flood risk management strategies with robust measures, which, as confirmed by Austrian Ministry of Agriculture, (2017b), remain a core responsibility of Austrian water management in protecting society from the impacts of floods. Furthermore, recent initiatives also emphasize the consideration of water temperature in water management planning.

As noted by the Federal Ministry of Agriculture and Forestry, Climate and Environmental Protection, Regions and Water Management (2025), the main tasks, objectives and challenges of Austria's water policy include resource protection, regulation of use, and flood control. Austria's national strategy aims to mitigate the negative impacts of climate change on the environment, society, and economy, while also capitalizing on potential opportunities. In almost all of the countries studied, the monitoring and mapping of hazards have received considerable attention, especially regarding adaptive flood control and management measures. Belgium is highly vulnerable to climate change in the water sector due to geographical (coastal areas), hydrological (flood-prone river basins), and socio-economic (urban centers) factors, which is why flood management has been a key focus across various adaptation policies.

Denmark and Belgium, owing to their geographical locations, have placed greater emphasis on coastal zone management,

prioritizing strategies to address challenges such as sea-level rise, coastal erosion, and flood risk mitigation. In Belgium, which faces significant flood threats, many adaptation policies are directly related to flood management. Special attention has also been given to regulations prohibiting construction in flood-prone areas. Mapping flood risks, as part of efforts to increase knowledge, is carried out by a network of stations that measure water levels in rivers and rainfall. In addition, improving surface and groundwater quality has been one of the government's key policies in Belgium, similar to Latvia and Lithuania. In Flanders, northern Belgium, construction and other projects affecting water are reviewed through the "watertoets" procedure to prevent negative impacts and reduce flood risks. Authorities may require measures such as the use of permeable surfaces or may even reject projects (National Climate Commission-Belgium NAS, 2010b). Water management is a cross-cutting issue, therefore adaptive measures in this sector will also influence activities in other areas. For instance, some of the measures mentioned above within the framework of flood prevention will also contribute to water availability. Current measures to improve surface and groundwater quality (e.g. in connection with nitrates from agricultural fertilizers) will help sustain the availability of affordable drinking water (National Climate Commission- Belgium NAS, 2010b).

Several countries, including Austria and Switzerland, have also developed online platforms to share knowledge on climate change impacts and associated risks. In some instances, these portals serve as multi-purpose tools, providing guidance and practical examples of adaptation measures. At the European level, the European Commission has established a web-based platform to facilitate the exchange of information on adaptation practices among member states, supporting coordinated learning and the dissemination of best practices.

Flood risk management holds a prominent place in Finland also, where 21 areas have been identified as significantly vulnerable to flooding from rivers and the sea because of the country's geographical and natural characteristics. By the end of 2015, tailored plans were developed for these regions, outlining actions aimed at reducing and controlling flood-related risks (Ministry of Agriculture and Forestry of Finland- NAP, 2014). These plans address flood forecasting, monitoring, early warning systems, land use planning, and rescue actions, such as flood insurance. Additionally, Finland's Ministry of Agriculture and Forestry, along with regional environmental centers, aim to direct state subsidies toward investments that improve flood risk preparedness, subsidize fixed irrigation systems, special water services, and regional cooperation.

The Danish water expertise and technological strongholds are the result of Denmark's water supply and wastewater treatment policies, R&D, and investment efforts over the past 40 years (Ministry of Environment of Denmark, 2023). Denmark has focused on sustainable groundwater management, minimizing non-revenue water, urban water management, and flood prevention. Regarding water supply, adapting to climate change may involve adjusting water extraction practices by considering future groundwater availability as well as the flow and quality of rivers and wetlands. Denmark has developed a strategy that enables its water sector to treat wastewater effectively and manage wastewater transport efficiently. In Estonia, mitigation strategies are designed to lower the chance and scale of floods wherever this is feasible and reasonable, or to lessen the potential adverse impacts if flooding does occur. The central goal of these strategies is to enhance preparedness, with an emphasis on raising awareness, while also recognizing and evaluating emerging risks. Latvia's adaptation plans focus heavily on enhancing water management and the sustainable use of rainwater resources. Key initiatives include assessing and improving the capacity for rainwater collection, particularly through the development of urban systems, and encouraging rainwater use. This is complemented by efforts to improve water quality in both surface and groundwater, which are integral to public health and ecosystem sustainability. The country has also emphasized integrating changes in rainwater runoff, with specific guidelines to address increasing variability in precipitation patterns. In addition, Latvia is focusing on advanced modeling for forecasting climate change impacts on water resources and implementing early warning systems for water-related hazards.

In contract, Lithuania's adaptation strategy focuses on physical and infrastructural measures, with particular attention to modernizing irrigation systems, improving the quality of surface and groundwater, and strengthening flood risk management frameworks. The country is actively enhancing the resilience of wastewater treatment facilities and upgrading both rainwater runoff treatment and surface wastewater systems. Efforts also include the reconstruction of outdated wastewater infrastructure and the continuous improvement of water management and protection projects to better cope with climate risks. The study showed that all the countries under investigation have paid attention to information-based instruments to adapt to climate change. In line with this, OECD (2013) reported that such instruments represent the most frequently applied approach among member countries for water-related adaptation. Except for Iceland, every OECD country, as well as the European Commission, reported incorporating information-based measures into their adaptation strategies.

There are a few examples of countries, along with the European Commission, that have identified water pricing and water-related taxes as a part of their adaptation response.

In the Netherlands, adaptation efforts highlight the importance of strengthening nature's resilience to withstand climate change impacts. Expanding natural areas is viewed as a key step, not only to achieve conservation goals but also to preserve recreational opportunities, public health, well-being, and rural livelihoods. Emphasis has been placed on enhancing water policies, such as increasing water retention in natural landscapes and adjusting water levels to secure freshwater availability. Maintaining water quality, particularly by addressing salinization risks, remains a priority. Broader application of the Programme-Based Approach to Nitrogen (PAS) is also suggested to lower nitrogen emissions and support ecosystem adaptation. Addressing these challenges calls for stronger collaboration among provinces, government agencies, sectors, civil society, and citizens. Additionally, national dialogues on climate adaptation in areas like agriculture, water management, and insurance have continued, with a focus on addressing currently uninsurable damages.

Floods are the most destructive natural hazard in Spain, causing significant material damage and loss of life. Their management is guided by flood risk management plans (PGRIs in Spanish), which are developed through preliminary risk assessments, identification

of areas most prone to flooding, and the creation of hazard maps defining flood zones. Risk maps also consider land use and potential damages (Ministry for the Ecological Transition and the Demographic Challenge, 2020). Spain's National Adaptation Strategy (NAS) 2021–2030 places strong emphasis on systematically collecting and continuously updating information on the impacts of climate change, including effects on water resources, extreme events such as droughts and floods, water use patterns, and the status of water bodies and associated aquatic ecosystems. It stipulates that river basin management plans must systematically account for these impacts and incorporate risk assessments for each basin district, providing at minimum a medium-term evaluation of risks related to water supply security, environmental objectives, and water infrastructure.

In practice, many adaptation policies in Europe are based on economic and financial instruments. For example, Belgium has recently reformed its insurance system for floods and other natural hazards, Finland has updated its flood damage compensation schemes to better account for climate change, Spain has introduced insurance initiatives for natural disasters and Switzerland has established mandatory insurance schemes for all real estate owners. These cases demonstrate that local and regional implementation can vary substantially, highlighting the need to consider subnational contexts alongside national-level policies. While the countries were selected based on the availability of NAP or NAS documents in English, it is important to note that geographic, economic, and institutional differences among these countries may influence adaptation strategies and the choice of policy instruments. Countries with higher budgets and capacities, such as the Netherlands and Switzerland, can invest heavily in infrastructural and technological tools, such as creating drinking water supply networks, upgrading sewage systems, and implementing flood safety policies. Countries with more limited resources, such as Austria, rely primarily on informational tools, such as mapping flood risk, analyzing existing data and promoting the collection of additional data on water resources, and enhancing coordination and information regarding water consumption and demand. Countries in Northern Europe, such as Finland and Denmark, with high levels of precipitation, usually focus on flood management, water level forecasting and monitoring, and resilient infrastructure. Southern European countries, such as Spain, emphasize surface water and drought management, improving irrigation, and water resource protection, reflecting climatic and geographic differences.

6. Conclusion and limitation

This study analyzed water-related adaptation strategies and plans across European countries. All the countries under study employ a combination of different types of adaptation instruments; however, each may place greater emphasis on a particular policy instrument in their adaptation plans and strategies. Notably, Austria's approach is heavily based on information-driven methods and regulatory instruments, while countries like Belgium and Finland focus on specific infrastructural instruments, such as banning.

In Belgium, special attention has also been given to legal and regulatory instruments, particularly in integrating riverbank management, legislating and licensing surface water extraction, and implementing new legislative changes to address flooding and other natural hazards.

Switzerland's adaptation measures are primarily focused on infrastructural and technical instruments, such as developing water storage, upgrading sewage networks, managing reservoirs, and ensuring the safety of large-scale dams. Legal and regulatory instruments also play a significant role, while information-based and economic instruments are used to a lesser extent. They implement campaigns to raise awareness about water issues and promote responsible water usage.

Overall, the study highlights a strong commitment to adaptive water management practices across these countries, driven by both regulatory frameworks and proactive strategies aimed at mitigating climate change impacts on human and ecosystem.

Despite its systematic approach, this study has some limitations. The analysis relied on publicly available documents, which may vary in detail, comprehensiveness, and reporting standards across countries. A key language limitation is that only documents published in English were included, which could have excluded some important materials and potentially omitted relevant national perspectives. The study's selection of ten countries, although diverse, may not fully represent the entire European context.

CRediT authorship contribution statement

Tahereh Zobeidi: Software, Methodology, Conceptualization, Data curation, Formal analysis, Investigation, Resources, Visualization, Writing – original draft, Writing – review & editing. **Nadejda Komendantova:** Supervision, Project administration, Conceptualization, Methodology, Validation, Funding acquisition, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

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

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Data availability

Relevant links to the documents used have been included within the manuscript.

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