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The governance of the water-energy nexus: Co-produced narratives to take stock and address energy dependencies of the urban water cycle in Atlantic Europe

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ABSTRACT

Water and energy (WE) are key resources to support human well-being and are highly interconnected. Intensifying demands of both resources and increasing resource scarcity are exacerbating their interconnectedness and calling for the adoption of an integrated approach called "WE nexus". This paper explores the barriers and opportunities to govern the WE nexus in the Urban Water Cycle (UWC), particularly, the energy dependencies of the water supply and sanitation services in Atlantic Europe, through the assessment of four contrasting and representative regions: Canary Islands (ES), Western Andalusia (ES), Alentejo (PT) and Brittany (FR). We applied a "Quantitative Story Telling (QST)" method to assess the discourses from 49 stakeholders from across the four regions on WE nexus challenges and opportunities in the UWC, and the evidence that exists on them. The result is a pluralistic narrative incorporating the views of different stakeholders on what are the issues at stake and why, what needs to be done and how, and sustained by available data. The resulting narrative explores the formal aspects underpinning WE nexus governance in the UWC, but also informal rules linked to political economy. Our results revealed that WE nexus challenges are context-specific, however, there are important commonalities across regions and phases of the UWC value chain, suggesting that these are relevant at the Atlantic Europe scale. QST is not instrumental in directly inducing policy change or decision-making, but might be a valuable means for knowledge mobilization to question and enrich the quality of dominant discourses, and thus paving the road for action towards sustainability.

1. Introduction

Water and energy (WE) are key resources to support human well-being and as such are becoming security concerns for countries across the world, particularly considering the ongoing climate crisis and increasing geopolitical tensions (IPCC, 2018; IEA, 2022; UN, 2022). The interconnectedness between resource securities and regions is not new, but the combination of intensifying resource demands, increasing resource scarcity, and growing global risks, have intensified the interlinkages, amplifying the cross-sectoral tradeoffs and the costs of inaction

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(Pahl-Wostl et al., 2018).

Within the water sector, enhancing cooperation across sectors has been on for decades i.e., through the promotion of the "Integrated Water Resources Management Approach" (Pahl-Wostl et al., 2018), but the recognition that interconnections exist beyond the water sector (e.g., land for energy) and are also bi-directional (e.g., energy for water) is more recent. This wider perspective paved the road for the development of the so-called "nexus approach" (Hoff, 2011), with the rationale to mainstream an 'integrated approach' in policy spheres to reduce unintended cross-sectoral impacts of sectoral policies, increase its effectiveness and promote the generation of co-benefits (Leck et al., 2015, Stein et al., 2014, Stein et al., 2018).

Water-related nexuses have been proliferating in recent years, since the WE nexus concept introduced 30 years ago by Gleick (1994) and the Water-Food (WF) nexus (McCalla, 1997), further merged in the Water-Energy-Food (WEF) nexus (Mabrey and Vittorio, 2018). During the last decade, WEF nexus has been rapidly expanding in scholarly literature (with ca. 450 publications since 2013) and policy settings as a novel way to address complex resource and development challenges. However, while the WEF nexus offers a promising conceptual approach, the use of a nexus approach in policy and practice has been yet limited (Hussein and Ezbakhe, 2023). Over the years, several other water-related nexuses have been proposed (e.g., Water-Energy-Food-Ecosystems, Water–Soil–Waste, Water–Energy–Food–Land, Water–Energy–Food–Climate, Water–Forest, Water–Climate–Migration, and Water-Employment-Migration nexus), and while they might place emphasis on different sectors or dimensions, they all call for the adoption a systems-based approach that takes all these interlinkages into account to minimize unintended consequences when managing water and associated sectors (Hussein and Ezbakhe, 2023).

The urban water cycle (UWC) is one area within the water sector where resources interconnectedness, and specially the WE nexus, is becoming increasingly important, given that it is an energy-intensive service. Energy is required to provide each service along the UWC, from the supply to the purification, distribution, wastewater treatment, and reuse. Energy demands depend on several factors, including the water source, location and quality, type of infrastructures and ageing, level of wastewater treatment, or the existence of incentives to promote the efficiency of the water cycle (IEA, 2016). Magagna et al. (2019) assessed the energy dependencies of the UWC in the European Union and found that 2.6 % of the electricity consumption is allocated to the supply of water supply and sanitation (WSS). Per domains, water supply (i.e., abstraction, pre-treatment, and transportation/distribution) consumes the largest fraction (35,000 GWh/year), followed by wastewater treatment (24,747 GWh/year) and desalination for municipal use (20, 695 GWh). While these are small electricity requirements when compared to other sectors, Magagna et al. (2019) also showed that between 30 % and 40 % of the electricity costs of municipalities is linked to water services. Since global electricity demands for the supply of water services are expected to increase up to 4 % by 2040, this will only increase the energy costs of the water sector across scales (IEA, 2016).

Municipalities are often the institutional level responsible for providing WSS services, however, there is yet very limited information at European level on the energy dependencies of the UWC other than few technical assessments (e.g., IEA, 2016; Cabrera et al., 2017; Kyle et al., 2021; Magagna et al., 2019). This knowledge gap is largely because energy has not been seen as an element to be managed within the UWC, and therefore not benchmarked. The increasing electricity prices and the need for European Member States to comply with the European Green Deal and associated legislation are likely to reverse this situation.

Improving the energy accounting is one step toward better management of the WE nexus in the UWC. But reducing, greening and optimizing the energy dependencies will require also the use of soft approaches to understand the governance dimension of WE nexus at such a scale, where are the WE nexus challenges along the UWC, what are the underlying barriers and opportunities, and how actors and institutions can further cooperate to reach commitments that are socially acceptable and inclusive (Leidel et al., 2012; Hagemann and Kirschke, 2017).

While overall "nexus" research has grown substantially over the past decade, the existing literature has had limited consideration of the governance dimension, other than making general claims that further cooperation is required to overcome the "siloed" approach (Stein et al., 2014; Williams et al., 2014; Stirling, 2015; Cairns and Krzywoszynska, 2016; John et al., 2023). Further, governance was also identified as an extrinsic gap to advance the nexus approach, together with financing and funding, and approach's timeframe and vision (Ramos et al., 2022).

Diving deeper into the governance dimension of the WE nexus is key to move from theory (understanding resources interdependencies) to practice (how to manage those and minimize unintended policy outcomes). But this requires the development of innovative frameworks that can delve into fundamental governance issues related to who makes decisions on what issues are, when, and above all how (Leck et al., 2015; Stein et al., 2018). As described by Pahl-Wostl et al. (2018), the challenges of cross-sectoral collaboration require a nuanced understanding of the complex web of interdependences that influence the effectiveness of such links to support nexus governance.

The emergence of co-production approaches for addressing nexus challenges (e.g., Wada et al., 2019; Cabello et al., 2021; Di Felice et al., 2023) can support the elaboration of governance narratives that are science-based but include a diversity of knowledge, perspectives, and experiences, and therefore with wider chances of being socially relevant. More broadly, it can also help understanding what are the governance barriers and opportunities to support the joint materialization of related Sustainable Development Goals (SDGs), like SDG6 (safe drinking water and sanitation), SDG8 (clean energy), SDG 11 (sustainable cities) or SDG13 (climate action), among others.

The goal of this paper is to investigate the governance challenges and opportunities that exist to address the energy dependencies of the UWC in order to support a more efficient use of water and energy in Atlantic Europe and using a participatory approach. It builds on the work carried out in the European Interreg Atlantic Area project "Eeres4water: Energy-Water nexus resource efficiency through renewable energy and energy efficiency" (EAPA_1058/2018). Eeres4water was implemented looking at a number of case studies throughout the Atlantic Europe, which represent contrasting but yet representative situations of WE nexus in the UWC. While the broad objective of the project was to investigate technological solutions and governance measures to increase the energy efficiency of the water sector and promote its decarbonization across Atlantic Europe, this paper looks at three specific governance-related research questions: (i) what are the key challenges with respect to the management of the energy dependencies of the UWC in Atlantic Europe from a multi-stakeholder perspective, (ii) what are the underpinning technological and governance drivers and (iii) what are the main opportunities and actions required to improve the management of the UWC to increase its efficiency and sustainability.

2. Methodology

2.1. Case studies

We investigated the energy dependencies of the UWC in four regions spread across Atlantic Europe (Fig. 1). From North to South: Brittany (France), Alentejo (Portugal), Western Andalusia (Spain), and the Canary Islands (Spain). The four regions account for all case studies included in the Eeres4water project. They exhibit contrasting geographical, climate and socio/economic features. Canary Islands, Alentejo, and Western Andalusia are located within the sub-tropical zone of Atlantic Europe and are characterized by mean annual precipitations (MAP) ranging between 300 mm/year in the Canary Islands to about 550–700 mm/year in Alentejo and Western Andalusia (EEA,

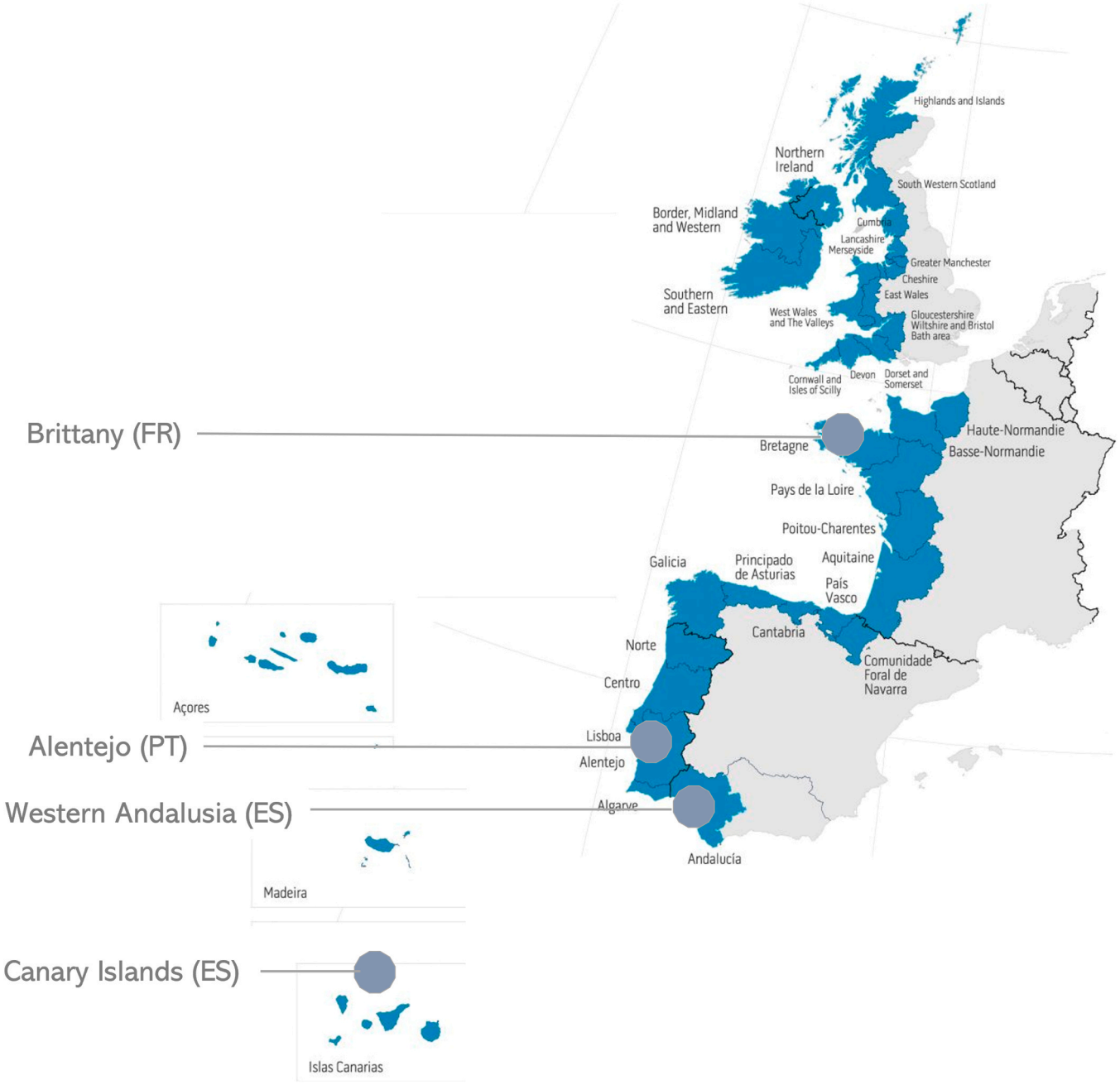

Fig. 1. Case study regions in Atlantic Europe.

2012a). These regions have a significant ocean influence and mean annual temperatures (MAT) remain between 14 and 21 degrees Celsius (EEA, 2012b). In contrast, the northern region (Brittany) is characterized by a temperate Atlantic climate, with its western part wetter than its coastline (MAP exceeding 1300 mm/year against less than 700 mm/year for the East) and MAT between 11 and 14 degrees Celsius (EEA, 2012b).

The Canary Islands is the most arid and warmer region, and its unique feature is being an archipelago of eight main islands. These climatic and geographic conditions have a strong influence in the socio-economic development model, which is water intensive and highly based on tourism. Today, nearly 43 % of the water supplied in the islands is non-conventional, and desalinated waters being the predominant source (Willaarts et al., 2022). Groundwater is the most important source of natural freshwater resources.

The Alentejo and Western Andalusia regions are in the southern part of the Iberian Peninsula, and its landscape is characterized by lowlands, with hilly and mountain areas. Agriculture is an important economic activity in these regions, as well as tourism. The water endowment of the two regions is mostly based on natural resources, with yet very little development of non-conventional sources of water (Willaarts et al., 2022). Groundwater is the predominant source in Western Andalusia (representing up to 60 % of available water resources), while surface water is the predominant in Alentejo (up to 70 % of available water resources).

Brittany is in the northwest part of France and its landscape is characterized by a mixture of small mountain areas, lowlands with hill areas, and several small islands spread along the western coastline.

Seasonal tourism is an important economic activity in the islands, while in the mainland the agro-industry sector is the most relevant. The water endowment is largely based on surface water resources (> 60 %), with no development of non-conventional sources (Willaarts et al., 2022).

Population densities across all regions are above the European average (109 persons/km^2) except for Alentejo which shows a very low population density (23 persons/km^2) and predominantly rural (EUROSTAT, 2019). In all regions the services sector, and particularly tourism, is an important source of income and employment (EUROSTAT, 2019). All these factors have profound implications to secure a reliable and sustainable provision of WSS services. In those regions where population densities are low and sparse over the territory, substantive infrastructure is needed to ensure adequate coverage in the remote areas. Likewise, high reliance on seasonal tourism, means that infrastructure needs to be sized to meet demands during peak seasons. Annex I provides a summary of the main physical, institutional and socio-economic features of the four regions.

2.2. Quantitative story telling for the co-production of nexus governance narratives

Nexus challenges are wicked problems and require the integration of different types of knowledge and analytical methods. The methodology proposed in this research builds on the "Quantitative Story Telling (QST)" described in Cabello et al. (2021) and Di Felice et al. (2023).

QST is a science-based participatory approach suitable to inspect the relationships between the discourses used to frame sustainability issues by different stakeholders and the evidence that exists on those issues (Di Felice et al., 2023). In this paper, QST is used to develop a pluralistic narrative with regards to the following question: *What are the main challenges, underlying drivers, opportunities and recommendations to address the energy dependencies of the urban water cycle in Atlantic Europe?*

The QST approach brings together two unique features to explore this research question. One, is the development of so-called "narratives", which embrace the way that stakeholders produce, represent, and contextualize their perceptions, knowledge, and experience about WE nexus in the UWC. The underlying assumption is that situations can be viewed differently depending on how a problem is framed and analyzed, and by whom (Rosen, 1991; Kovacic and Giampietro, 2015). A second feature, is the consideration of evidence-based information to support the documentation of the narratives. The purpose of collecting such information is to ensure coherence between the different views and perceptions and the data available (Di Felice et al., 2023). The integration of different discourses and knowledge types helps exploring alternative narratives, but also opens the floor for further understanding of how problems are framed and viewed in the different parts of Atlantic Europe, and what barriers and opportunities to improve the sustainability of the WE nexus in the UWC at regional scale. Fig. 2 summarizes the main steps to implement the QST methodology.

Fig. 2. Steps to implement the QST Method.

Step 1 "**Regional Background**" involves the development of a desktop study to contextualize the physical, social, technical, and regulatory context of water and energy in the four Atlantic regions. It combines the analysis of scientific literature, policy and normative documents, and official datasets regarding water and energy use in each region. The result is a report per region with main physical and socio-institutional facts related to energy and water use in the UWC, and associated WE nexus challenges.

Step 2 "Stakeholder Mapping" is intended to identify what stakeholders are involved in the WE nexus challenges identified, and how are they connected to the problems at stake. It involves an institutional mapping to identify actors connected with the provision and management of WSS, their roles, and responsibilities.

Step 3 "**Scoping interviews**" with selected stakeholders identified in Step 2, and through one-to-one semi-structured interviews. Interviews were conducted online (between March and May of 2021), recorded and transcribed using artificial intelligence software (sonix. ia) and supervised by the interviewers. The main purpose of these interviews was: (i) to refine/validate the key WE nexus challenges identified during Step 1, (ii) to understand stakeholders' perceptions with regards to the main underlying drivers, and opportunities, and (iii) to identify recommendations to promote greater energy efficiency and sustainability in the UWC. Annex II includes the outline that was used in all interviews. Table 1 summarizes the stakeholders interviewed.

Step 4 "Co-production of Regional Narratives" involves assessing the commonalities as well as the main divergences that exist among stakeholders with regards to the WE nexus, drivers and opportunities in each region. The objective was to build a pluralistic narrative along three main analytical criteria (Cabello et al., 2021): i) Causality relationships in energy dependencies of the UWC. Three main causality aspects were explored: justification ("What are the challenges?" "Why are these important?" "What are the underlying drivers?"); normative ("What should be done to address the identified challenges?"); and explanation ("What specific actions should be put in place?"); ii) Uncertainty, and specifically to the ambiguity that often surrounds complex sustainability challenges such as WE nexus, in which stakeholders might exhibit divergent or even contested views and framing of the WE nexus challenges; and iii) Positionality i.e., How representative are the views of the interviewees with respect to what are the main challenges, underlying drivers, and potential options to overcome these. To assess how representative emerging narratives are, we included a code that reflects to what extent the narratives emerging in a region are supported by a given % of interviewees. Narratives that reflect the views of more than 50 % of the interviewees are considered representative. Following this analysis, a set of narratives per region were produced.

The elaboration of the narratives was carried out by the research team on the basis of the individual interviews. To build the narrative the qualitative analysis tool consider.ly was selected. This tool is a collaborative platform for qualitative analysis of text, through the development of an iterative coding system developed to address the stakeholder responses (see Annex III). The resulting narratives for each region were shared with interviewees for their refinement and validation and are presented also in Annex III.

Step 5 "Co-production of Atlantic Narrative" involves the comparison and integration of the narratives from the four regions. The overall aim is to generate a higher-level narrative that integrates common challenges across Atlantic Europe and proposed recommendations. Also, highlight good practices that can be potentially scaled/replicated. This broad narrative was developed by the team by integrating the main features of the four validated regional narratives.

Table 1
Typology and number of stakeholders interviewed per region.

General category	Type of institution	Knowledge expertize	Canary Islands (ES)	Western Andalusia (ES)	Alentejo (PT)	Brittany (FR)
Water administration	Regional Planning	Water, Environment	2			2
	River Basin Authorities	Water, Environment	4		2	1
	Municipalities (public service provider)	Water, Tourism, Energy	1		1	
	Water utilities (mixed or private service provider)	Water	3	2	4	3
Energy administration	Regional Energy Planning	Energy	1	1		1
Academia	Universities, think tanks, research centers	Water, Energy, Environment	3	1	1	
Civil Society	NGO	Energy	1		2	1
Private sector	Water utilities	Water	2			2
	Tourism association	Water, Tourism	1			
	Cluster Organization	Water, Energy, Environment		1		
	Expert Consultancy	Water		1		
	Industry Association	Water		1		
	Irrigators association	Water, Agriculture			3	
Total per region			**18**	**7**	**14**	**10**

3. Results

3.1. Regional background: scoping study to identify relevant physical and institutional features in each region and key WE nexus challenges

Annex I presents an overview table with the most relevant features of the four regional backgrounds. Willaarts et al. (2022) also provides a detailed description. From an institutional point of view, the provision of WSS services involves a mixture of public and private institutions from different institutional levels. Water production and wholesale provision are normally the responsibility of regional public institutions such as river basin authorities. These institutions in compliance with the European Water Framework Directive (2000/60/EC) oversee securing the provision of water for different users, identification and management of the drinking water protection zones (i.e., zone where the water is extracted) and maintenance of ambient water quality. The exception is the Canary Islands, where the water law includes provisions that allow private users to extract and supply water for WSS beyond self-consumption. In Alentejo, private water users exist but mostly for self-consumption (Annex IV provides an institutional organigraph of WSS services in the two regions as examples).

The provision of WSS services to end users (service providers or retailers) is decentralized across all regions. Municipalities are responsible for the planning and implementation of several regulations, including the recast Drinking Water Directive (2020/2184 EC) and the proposal for the recast of the Urban Wastewater Treatment Directive (91/271/EEC). Retailers deliver WSS services, directly, through municipally owned company, or also through contracts granted to private utilities. Municipalities sometimes apply economies of scale and develop agglomerations to improve the provision of water services. In Canary Islands and Western Andalusia, there is a mix of retailers, whereas in Alentejo, public retailers predominate.

The four regions also exhibit important differences in terms of the water sources used to meet the UWC demands. In the Canary Islands, 94 % of the domestic demands are met with desalinated waters, and less than 5 % with groundwater. In Alentejo, Western Andalusia, and Brittany, surface water is the most important source for drinking purposes (60–70 %) and non-conventional sources are not developed. The reliance on different sources of water has important energy implications, but the desktop study revealed that there is little accounting and benchmarking carried out by retailers on electricity consumption within the UWC, nor the share of electricity used in the UWC originated with renewable energy. At national level, the share of renewable energy ranges between 40 % and 55 %, except for Brittany, where nuclear power has a larger share and the share of renewable energy is less than 23 % (see Annex I).

The desktop review also revealed that important WE nexus challenges relate to the three main stages of the UWC value chain. In the water supply phase, energy dependencies are strong in all four regions because water needs to be produced, pumped, or transported over long distances. In Brittany, the energy footprint of water production is mostly related to the pre-treatment of water to meet drinking water quality standards given the serious water pollution problem. In the distribution phase, energy dependencies are high in all four regions because existing infrastructure is ageing, which leads to water losses, and/or water needs to be transported over long distances. Lastly, the energy requirements for wastewater treatment are likely to increase give than many municipalities are currently infringing existing legislation and eventually will have to apply more advanced treatments with higher energy requirements.

3.2. Regional narratives: identifying the main challenges related to WE nexus in the UWC as well as drivers and opportunities

Table 2 summarizes the main elements of the four regional narratives. Detailed regional narratives can be found in Annex III and Willaarts et al. (2022). Overall, the interviews and the resulting narratives have contributed to validating, and refining the energy challenges of the UWC identified in the regional backgrounds, confirming the existence of important challenges across the different stages of the UWC value chain, although challenges were framed differently across the four regions. Likewise, there are differences in terms of what are the underlying drivers but there is an agreement that social drivers (cultural, political, governance) are largely justifying the nature of the challenges, above any physical and technological barrier. As per the normative part of the narrative (what needs to be done), there is an asymmetry in terms of the recommendations provided but the majority are focusing on the need to promote awareness raising of the value of water and its energy footprint, as well as on promoting demand-management approaches to reduce water and energy use as opposed to the prevailing supply-oriented measures. Similarly, several governance recommendations related to water sector architecture are provided, including the need to revisit the institutional setup and cooperation; and to standardize and harmonize the local and national regulations. Lastly, in terms of the best practices identified by the interviews, these can be clustered along two main areas: (1) those aimed at reducing water consumption and energy use; and (2) those focused on promoting the decarbonization of the UWC through the expansion of renewable energy projects. All best practices

Table 2
Synthesis of the regional narratives of the four regions.

Narrative	Codes	Canary Islands	Western Andalusia	Alentejo	Brittany
Justification ***"What are the issues and underlying drivers?"***	Challenge I: Energy use in water supply	High dependency on desalinated waters	Water quality deterioration at source + groundwater overexploitation	Reliance on water transfers from far distances + groundwater overexploitation	Water quality deterioration at source + occasional surface water shortages (gap demand to availability) inland + seasonal water stress in the islands
	Challenge II: Energy use in water distribution	Infrastructure is ageing + high non-revenue waters[a]	Infrastructure is ageing + high non-revenue waters	Infrastructure is ageing + high non-revenue waters	Infrastructure is ageing + high non-revenue waters
	Challenge III: Energy use in sanitation and wastewater treatment	Insufficient level of wastewater treatment + low use of reclaimed waters	Insufficient level of wastewater treatment + high operation and maintenance costs of stormwater infrastructure (storm tanks)	Insufficient level of wastewater treatment	Insufficient level of wastewater treatment
	Drivers	• Socio-economic: development model which is water and energy intensive • Cultural: water can be produced when needed, there is no sense of scarcity • Political: Investing in supply-oriented approaches and big infrastructures renders more votes • Institutions: high decentralization of water supply and sanitation services and limited capacities. • Financing: insufficient cost recovery	• Cultural: water cannot be a limiting factor to the development • Political: Irrigation is a key sector, despite its externalities + investing in supply-oriented approaches and big infrastructures renders more votes • Institutions: high decentralization water supply and sanitation services and limited capacities. • Financing: insufficient cost recovery • Regulatory: absence of an economic regulator for water services + national regulation not fully compliance with EU Urban Wastewater Treatment Directive (UWWTD)	• Socio-economic: development model which is water and energy intensive • Cultural: limited awareness on how to safe water • Institutions: responsibilities highly fragmented and limited cooperation • Financing: insufficient cost recovery + insufficient infrastructure (e.g., wastewater treatment plans) • Regulatory: EU regulations do not always suit regional contexts. Challenges to implement updated EU Directives (e.g., recast Drinking Water Directive)	• Physical: inland and islands have different conditions and water endowments • Socio-economic: islands largely rely on seasonal water intense tourism activities • Cultural: Environmental protection was low on the agenda • Institutions: responsibilities highly fragmented and limited cooperation • Regulatory: Reuse of water is not regulated + regulations are not equally suitable for inland and islands
Normative ***"What needs to be done?"***	Recommendations	• Awareness campaigns on water savings • Shifting investments from supply-oriented to demand management approaches to increase water use efficiency. • Revisiting calculation of water tariffs • Promote renewable energy projects to reduce the carbon footprint of UWC. • Promote agglomerations and public-private partnerships (PPP) to promote the sustainability of water services. • Promote strategic planning of the water and energy sectors • Explore cost-effectiveness of green and gray infrastructure for wastewater treatment • Further efforts for R&D and innovation and data management	• Harmonize the regulations and water tariffs at a regional if not national scale. • Revise national legislation to ensure compliance with EU Directives (particularly UWWTD) • Swift the focus from only promoting the transition to renewable energies to renewable energies and efficiency in the UWC value chain. • Digitalization of the water sector and data mining • Public-private collaboration must play a leading role in terms of technology design and implementation. • Prioritize the restoration and management of groundwater bodies and of those used for drinking water	• Awareness campaigns on water savings • Promote the collaboration between academia and public administration to support knowledge development and transfer. • Increased cooperation across institutions to reduce bureaucracy and simplify administrative processes (e.g., for development or renewable energy projects)	• Include water services explicitly in climate action plans. • Adjust the water and energy legislation to the different context (island versus inland) • Promote the cooperation between the water management agency (responsible for river basin planning), agglomerations (responsible for water supply and sanitation) and the French ecological transition agency (responsible for the energy transition planning) for improved planning of the energy transition in the UWC.
Explanation ***"How should it be done?"***	Best practices[b]	**Challenge I: Water supply** ***Technological***	**Cross-cutting across all stages of the UWC value chain** ***Governance*** • *The Metropolitan Water Supply and Sanitation Company of*	**Challenge I: Water supply** ***Technological*** • *REUSE[c] project The aim is to foster the production and use of recycled water for irrigation*	**Challenge II: Water distribution** ***Technological***

(*continued on next page*)

Table 2 (*continued*)

Narrative	Codes	Canary Islands	Western Andalusia	Alentejo	Brittany
		• *Reverse osmosis in wastewater treatment plants for water reuse* • Development of renewable energy projects for self-consumption in tourism business **Challenge II: Water distribution** ***Technological*** • *Digitalization of water services to control water losses* ***Governance*** • Introduce conditionality on renewable energy use to utilities for service delivery **Challenge III: Sanitation and wastewater treatment** ***Technological*** • *Use of sea water currents for wastewater treatment through ionic exchange* • *Natural wastewater treatment plans for small municipalities* • Development of renewable energy projects for self-consumption in tourism business **Cross-cutting across all stages of the UWC value chain** ***Governance*** • *Development of agglomerations to increase the sustainability of water services (e.g., Mancomunidad del Sureste Gran Canaria)* • *Establishing a water tariff for tourism to sustain operational and maintenance costs*	*Seville (Emasesa) and the Municipal Water Supply and Sanitation Company of Granada (Emasagra) have invested in improving efficiency throughout the UWC value chain and provide annual reports on energy consumption and water use. They have also developed strategic action plans to deal with droughts.*	*in the Alentejo region. One demonstration pilot is placed in Beja WWTP, using treatment technologies with low open (solar collectors to disinfect wastewaters by UV radiation and thermal action) to irrigate pomegranate plantations.* **Challenge II: Water distribution** ***Technological*** • *Water Optimization for Network Efficiency (WONE) – a monitoring system developed and tested by the Empresa Portuguesa de Águas Livres (EPAL) to improve the efficiency of water distribution and reduce non-revenue waters in Lisbon to below 8 % in 2015.*	• *Lorient Agglomeration: Monitoring water networks to monitor leaks.* • *Rennes Metropole: the climate plan foresees the implementation of micro-turbines into water networks for recover energy.* **Challenge III: Sanitation and wastewater treatment** ***Technological*** • Development of renewable energy projects and efficiency programs in several agglomerations. • Lorient Agglomeration: solar panels implemented in a wastewater treatment plans (WWTPs) for self-consumption. • Rennes Metropole: Wastewater treatment is powered by a combination of solar panels and river turbines. **Cross-cutting across all stages of the UWC value chain** ***Governance*** • *Agglomerations have the joint responsibility of managing water services and developing and implementing climate change adaptation plans, making easier the integration of energy transition and efficiency in the UWC*

[a] Non-revenue waters is defined as the difference between abstracted/produced and billed. Water losses can be physical or related to illegal abstractions.
[b] Best practices are described for each step of the value chain in the UWC i.e. water provision, distribution, sanitation and wastewater treatment. Coding: italic refers to best practices that can reduce the energy requirements, whereas non italic refer to practices that support the decarbonization of the value chain stages across the UWC.
[c] https://www.adp.pt/downloads/file284_pt.pdf

are intended to either minimize resource use and/or minimize WE nexus trade-offs.

3.3. European Atlantic narratives: Key WE nexus challenges in the UWC and opportunities to improve its management

The WE nexus challenges the UWC are largely determined by the combination of its main physical, governance and socioeconomic features (see Section 3.1). Nevertheless, the analysis and comparison of the four regional narratives (Section 3.2) revealed multiple similarities about areas along the UWC value chain facing the most important challenges and why, as well as the policy recommendations put forward. These challenges can be structured along different three axes:

3.3.1. Value chain of water production and supply

This part of the UWC is argued to be one of the most energy-intensive in all four regions, particularly as the climate becomes more arid and freshwater availability scarcer. In the Canary Islands, water supply has been secured through the development of non-conventional sources of water, particularly desalinated waters. In Alentejo and Western Andalusia, the strategies include groundwater mining and the development of storage infrastructures, and water transfers, which also require large amounts of energy as often are located away from the demand centers. Brittany is more water-abundant, but the energy dependencies of the water production and supply are particularly high, due to the growing problem of water pollution and the need to secure drinking water quality standards. While there are no concrete figures on energy consumption of this phase of the UWC, the assessment revealed that renewable energy

policies are not being sufficiently promoted, which means that this phase is energy and carbon intensive. Key drivers underpinning the energy dependency:

- **Socioeconomic.** The promotion of economic development models that are water-intensive (irrigation, mass tourism), which are exacerbating water stress, and simultaneously triggering the continuous development of supply-oriented approaches to ensure the demands can be met. This is particularly acute in the southern regions of Atlantic Europe.
- **Cultural and political.** Water transfers and water production technologies have eroded the culture of saving water in areas that are naturally water-scarce. Politicians also channel large investments into supply-oriented approaches as big infrastructures (e.g. dams, desalination plans) renders more votes.
- **Institutional.** There are several misalignments between sectoral policies. Water policies have oriented investments to increase water availability despite the energy costs. Energy policies focusing on promoting efficiency and decarbonization have not prioritized the water sector, despite being very energy-intensive. Misalignments also exist between the water sector and regional development agendas. For instance, while water policies are focusing on securing water quality and the protection of drinking water zones, regional development plans are supporting the development of economic activities (industrial, agriculture) responsible for generating significant point and non-point source pollution and for which enforcement is often limited. There are also limited legal requirements to support energy savings and the decarbonization of the UWC.

3.3.2. Value chain of water distribution

A common challenge is related with the little investments to maintain and upgrade the water network for supply and sanitation. Infrastructure is therefore ageing and causing many water leakages and energy losses due to the already high energy footprint of the water extracted. In some regions, water losses i.e., non-revenue waters (measured as the difference between water abstracted/produced and invoiced) can range between 50 % and 80 %. Most interviewees argued that underlying drivers are mostly governance-related and include:

- **Cultural and political.** Investments in distribution networks cause many disturbances to citizens and their benefits are less obvious to the general public. This is also a disincentive for politicians to allocate budgets.
- **Financing.** The European Water Framework Directive (WFD) requires water service providers to meet the principle of cost recovery (i.e., ensure that operational and maintenance costs are covered through the water tariffs and additional charges). Most retailers do not achieve cost recovery, because water tariffs are too low or water losses to high, limiting their financial capacity to re-invest in the maintenance and upgrading of network infrastructure.
- **Regulatory:** In some regions (e.g., Western Andalusia, and the Canary Islands) each municipality must develop its own normative, creating a very complex landscape, and often leading to some inequities and inefficiencies when defining water tariffs for end users but also contract conditions for service providers. For instance, energy costs in some municipalities are borne by the retailer, whereas in other cases these are covered directly by the municipality.

3.3.3. Value chain of wastewater treatment and water reuse

The yet limited volume of water treated with tertiary treatment is an overall challenge across most European countries. Compliance with the Urban Wastewater Treatment Directive (91/271/EEC) and national regulations requires high investments in sanitation and treatment facilities, as well as considerable energy resources. In some regions, such as Western Andalusia and Brittany, wastewater treatment is already very energy-intensive process. In other regions, increasing energy demands linked to wastewater treatment are likely to increase (Canary Islands and Alentejo), given the yet low level of tertiary treatment. Likewise, there is limited promotion of water reuse, which could help to promote circular economy by also reducing the energy footprint of water production. In Brittany, there are yet no regulations to promote reuse of waters, whereas in other regions regulations are developed but also facing implementation challenges. The Canary Islands is the region with the largest development of reused waters, although so far it only accounts for 5 % of the total volume of water available. The main underlying drivers of existing WE nexus challenges for this step of the value chain are governance-related and include:

- **Financing.** The insufficient cost recovery has large implications to cover the operational and maintenance costs of wastewater, especially in small municipalities.
- **Regulatory**: There has been until recently little enforcement of regulations dealing with water quality, which translated into administrations not prioritizing investments into wastewater treatment and measures to tackle water quality deterioration. The development of regulations to promote water reuse is also incipient and faces several implementation challenges in various regions to be adapted to the local conditions.
- **Institutional.** The development of renewable energy projects linked to wastewater treatment plans, is hampered by existing jurisdictional asymmetries in terms of institutional functions. The approval of renewable energy projects is often at a different institutional level than the municipality, which causes important approval delays. Capacities within municipalities are also lacking.

Against this background, several recommendations supported by best practices, identified in all four regions have been provided. These can be grouped into five categories:

1. **Increase awareness raising of UWC stakeholders**

- Develop public campaigns to raise the attention and knowledge of citizens and decision-makers about the value of water, the energy required to deliver the different water services, and the importance of promoting circular approaches and improving the sustainability and efficiency in the water cycle.
- Prioritize the water quality agenda. The deterioration of water quality goes against the principles of many European directives and has multiple environmental, socio/economic and health implications. Unless addressed, water quality deterioration is the new driver of water scarcity.

2. **Investments in R&D and innovation**

- Explore models for promoting circular economy in the UWC, reusing water and sewage, including alternative sources of energy to promote the decarbonization of the water cycle. Some good practices involve many R&D and innovation projects focusing on the use of sewage for electricity production, or the promotion of water reuse to reduce the energy dependency of water production and supply.

3. **Lifting institutional and technical capacities**

- Resource the public administrations with sufficient staff, lifting technical capacities, and greater financial resources to address the multiple challenges.
- Promote the digitalization of the water sector. Such investments will help to have real-time monitoring of water leakages and illegal abstractions. For consumers, it also increases transparency and knowledge awareness on how water is being used and options to reduce overall consumption.

- Audit the barriers and opportunities to achieve full cost recovery. Given that this is a recurrent problem in small to medium size municipalities, it becomes important to understand where are the constrains and identify pathways to reform.
- Strengthen the collaboration between decision-makers and academia, to address the observed gaps in terms of data availability and technical capacities within the public administrations.

4. **Regulatory reforms and improved institutional coordination and cooperation.**

- Update water related regulations to shift the focus away from supply-driven to demand-driven approaches. The introduction of efficiency incentives and benchmark approaches should allow retailers to improve their performance and offer more efficient WSS services.
- Harmonize standard rules for the provision of WSS services and tariffs. Proposed solutions include the development of a national regulator, which is missing in countries like Spain, and who can supervise standards and tariffs to ensure equity and efficiency.
- Enhance partnerships between public and private utilities. The creation of agglomerations has shown to be an effective means to address the problems of lacking economies of scale. Likewise, promoting partnerships with private utilities (Public-Private-Partnerships, PPPs) can also bring the best know-how and capacities of the two sectors.
- Enhance the vertical and horizontal cooperation of public administrations. Horizontal cooperation should include better and strengthened cooperation among water institutions to exchange best practices and find means to increase the efficiency of the UWC and its decarbonization. Vertical cooperation is also required since the energy and water sectors are managed at different institutional levels. Solutions proposed include the development of a "unique administrative window" to supervise and manage UWC projects.

4. Discussion

Much of the nexus research developed over the last decade has been focused on stressing physical interactions between resources and unraveling the economic inefficiencies of not adopting an integrated approach in the design and implementation of nexus policies (Albrecht et al., 2018; Stein et al., 2018; Blicharska et al., 2023). Many papers often conclude that improved institutional coordination is required but without diving further into fundamental aspects of how this can be achieved in practice (Leck et al., 2015; Pahl-Wostl et al., 2018; Stein et al., 2018). This gap is partly motivated by the lack of methodological approaches to conceptualize and explore nexus governance.

This study aimed to partly fill this gap by testing how QST can be used as a method to build a pluralistic narrative on what barriers and opportunities exist to govern a problem of global concern, and related with the energy dependencies of the WSS services, with the specific application in Atlantic Europe and supported with available data. The resulting narrative dives into formal aspects underpinning nexus governance in the UWC (e.g., institutions, regulatory aspects, and financing), and informal rules linked to political economy considerations (e.g. power asymmetries, politics of decisions), which play a key role in decision-making but have not yet been considered in most nexus studies (Smajgl et al., 2016).

4.1. WE nexus governance challenges and underlying drivers

Our results revealed that WE nexus challenges in the UWC are context-specific, however, there are important commonalities across the regions, which suggest that these are relevant at Atlantic Europe scale and likely beyond. One key finding is that while all regional narratives indicated that the energy intensity of the UWC is a growing sustainability concern, there is barely any quantitative information on the energy performance of water utilities in the regions under investigation, although this has been pointed out as a recurrent problem (Ronen and Jacobsen, 2014). There are different reasons, including the fact that often water services are managed separately i.e., different retailers managing different phases of the UWC (Loubet et al., 2014), and/or because there is no legal requirement to report or incentive to monitor and benchmark energy efficiency. This situation is changing because of the ongoing energy crisis in Europe, which is impacting the energy bill of municipalities, but also because the funds allocated to support the implementation of the European Green Deal are intended to support the decarbonization across all sectors and will require projects to monitor energy and carbon footprints.

The regional narratives revealed that energy demands for water abstraction, production and potabilization are in most cases perceived as very high, because socio-economic development models are water intense, but also because water scarcity (too little water or too polluted) aggravates it. As water becomes more scarce, desalination, groundwater mining or long distance water transfers, become more prominent to secure water supply. Also, potabilization and treatment costs increase if water quality deteriorates. This is aligned with Lee et al. (2017) who concluded that energy intensities of the UWC are positively correlated with areas facing higher water stress such as Portugal and Spain.

Lee et al. (2017) also identified that energy intensity of distribution is among the lowest along the UWC phases. However, stakeholders from the different regions indicated that there is significant room for improvement given that water infrastructure is ageing, causing important leakages of water (and ultimately energy). This was reported as a common feature across all areas, since investments in drinking water and sanitation are mostly concentrated in expanding the network rather than in upgrading the existing one. EurEau (2021) reported that distribution losses in the urban water network are on average 25 % for EU, but in some countries like Portugal average losses are above 30 %. In some of the regions, stakeholders reported water losses ranging between 50 % and 80 %. According to the interviews, drivers underpinning this challenge are related with financial constrains but to a large extent with political factors, given that repairing the water network causes too many disturbances to citizens and its benefits are less visible than building large dams or wastewater treatment plans. The weight of politics in the actual decision-making of resource nexus has also been stressed by several authors such as Soliev et al., (2015), Villamayor-Tomas et al. (2015) and Biba (2016).

Energy intensity associated with wastewater treatment is considered to be among the highest in the UWC phases (Lee et al., 2017). In our analysis, however, there are contrasting arguments in this regard, given that in some regions (e.g. Canary Islands) it was not seen as a major issue, given that the current level of wastewater treatment is moderate, with 77 % of the wastewater treatment plans only applying secondary treatment (EC, European Comission, 2018). The other regions also indicated that the current level of advanced wastewater treatment is at least below the EU legal requirements. There are several drivers underpinning this unambitious wastewater treatment agenda, and political factors are again an important driver. As reported in several regional narratives, the focus of investments in the water sector has been for a long time biased towards production and ensuring water availability to users. Sanitation has had a lower priority in the political agenda. Dynamics are now changing also as a result of the legal actions (infringement procedures) the European Union is taking against Member States to enforce the compliance with EU laws. According to EC (2023), Spain has five infringement procedures currently active and connected with the topic of bad application of the Urban Wastewater Treatment Directive, whereas Portugal has two and France one. Sanctions and the ongoing process to revise and approve a stringent wastewater regulation, is going to surely increase the energy intensity of wastewater treatment.

4.2. Recommendations and actions to address WE nexus challenges

In terms of solutions, technological innovation and improved resource accounting were stressed across most regions as needed to address the identified WE nexus challenges. Such innovation is required to increase resource use efficiency (e.g. digitalization of the water sector, development and adoption of energy efficiency indicators and targets), but moreover, to support the decarbonization of the water cycle and support new circular business models (e.g., R&D in renewable energies). Magagna et al. (2019) states that much of this technology and know-how is already available and therefore these should be options implementable in the short term. However, as Ahmad et al., (2020) recall, technological solutions need to be complemented with socio-institutional and governance measures to prevent the persistent gap between policy design and implementation. The recommendations emerging from the regional narrative place a very strong focus on improving formal aspects of governance, including the revision of the policy and regulatory framework to improve its coherence and effectiveness, as well as lifting institutional capacities of water and energy institutions.

Regarding the revision of the regulatory framework, most recommendations are oriented to improve existing sectoral regulations, especially in the water sector (e.g., revising the water tariff, enforcement mechanism to ensure compliance with wastewater treatment requirements, adapting EU legislation to the national and local context) but some have also clear a nexus focus. In the island of Tenerife (Canary Islands), new contracts with water retailers include the conditionality of having to use renewable energy to deliver WSS services. Such requirements are an effective means to speed up the decarbonization of the UWC across Atlantic Europe. Stakeholders also argued that there is a need to better align water, energy and climate policy measures. For instance, by explicitly linking renewable energy projects with water production and wastewater treatment plans. Munaretto and Witmer (2017) conducted a policy coherence assessment at the European level and found that water-food-energy-climate EU policy goals are generally not contradicting or negatively influencing each other, but trade-offs become much more prominent at the time goals are implemented. The choice of the measures to achieve the goals will determine whether a goal is generating win-win situations with other policy goals, neutral or even counteracting. Our study also supports this idea given that the promotion of renewable energy to decarbonize the UWC can be achieved through different technologies, and the choice of the technology will determine whether the outcomes generate positive, neutral or even negative feedbacks.

Among the institutional reforms, two important recommendations were stressed to support a more sustainable UWC and to improve the management of the WE nexus. One is related to the development of public-private partnerships (PPP) to deliver water supply and sanitation services. This recommendation was highly contested by some stakeholders, who argued that water is a public good and should be managed by public institutions. Also, stakeholders indicated that in some countries like Spain, there is a high risk of creating oligopolies given that few private companies provide much of water retailer services. However, Lima et al. (2021) conducted a review on lessons learned from PPPs throughout the world, and concluded that under well-defined conditions on governance structures, contractual arrangements and risk management, PPPs have shown to be effective means to provide efficient water services.

A second institutional recommendation was related to the development of agglomerations for water services, which have proven to be a means for municipalities to align forces to promote innovation, reduce costs, provide a more efficient and sustainable service, and better coverage and quality of the services. The World Bank (2022) states that fragmentation of water supply and sanitation providers can be a challenge, as performance problems are common in small operators with less capacity and resources, and thus, the development of agglomerations can be a mean to achieve more efficiency.

Lastly, a set of actions that were also highlighted by many stakeholders across the regions was related with awareness raising, and particularly to support a paradigm shift, moving away from supply oriented approaches (i.e., making more water available) to the demand-driven approaches (i.e., raise awareness among consumers to reduce consumption). As described by Stavenhagen et al. (2018), public awareness campaigns have showed few signs of lasting behavioral change, but other measures like introducing water meters in households can raise awareness about consumption and the need of conservation. Similarly, improving the transparency and clarity of water invoices can also have a positive impact on reducing consumption.

4.3. Limitations and further research needs

Despite the richness of the narratives co-produced, the current research faces several limitations. The main challenge encountered in the application of the QST was related with the limited evidence base available regarding energy intensities along the different phases of the UWC value chain. This is an important limitation given that the purpose of QST is to contrast stakeholder's views with available data on options to reduce the energy intensity of the UWC and means to decarbonize it. Even though the results of this analysis are substantiated with other quantitative information regarding water availability and use in the UWC, future research should be focused on carrying out a detailed accounting of current energy intensities and establish target goals, so that water service providers can benchmark against, and likewise, information can be used to contrast or support stakeholders perceptions and understanding.

A second limitation of this study as discussed by Stein et al. (2018) is that while the institutional mapping allowed us to understand who are the actors involved in the WE nexus, we did not disentangle how actors and issues are related to each other, to understand the opportunities and constraints that arise from these relations. Understanding the dynamics between actors and power relations, should also provide another layer of information to better understand the magnitude of the formal and informal barriers.

Last but not least, it is important to realize that the emerging narrative, despite being plural, is not value-free and therefore, shape the way in which the challenges are framed and addressed by the stakeholders interviewed. As Stein and Jaspersen, (2019) stated, there are no single optimal solutions to complex sustainability challenges, and this is so not just because we might need multiple fix across different parts of the system (e.g. combination of technological, capacity enhancement, and regulatory measures), but because solutions are made within a political context, and different stakeholders will lobby and defend contrasting solutions. This also suggests that nexus governance is as much about shared problem construction as it is about collective solutions (Leach et al., 2010).

5. Conclusion

Until now very few efforts have been dedicated to addressing the governance dimension of the WE nexus and what soft innovations exist that could be scaled (Stein and Jaspersen, 2019). In this study, we aimed to fill partly this gap by testing the QST as a method to explore the governance challenges related to the management of the WE nexus in the UWC, through the co-development of a pluralistic narrative that is relevant at Atlantic Europe, and which dives into the governance challenges, but also drivers and possible solutions.

Overall, QST may not be instrumental in directly inducing policy change or decision-making, it has proven to be an effective approach to unfold different worldviews and integrate different types of knowledge about complex, ambiguous, and uncertain sustainability challenges such as the WE nexus and its implications for policy and practice in Atlantic Europe. Also, to promote social learning, through the enrichment of individual narratives and integrating the different cultural and social

aspects all stakeholders bring to the discussion, as well as the technological, environmental, economic, legislative, and political challenges and options available. It is through this social learning process that we expect, optimistically, to build an understanding of the different options available that are also socially acceptable and set the ground to develop a strategy for the sustainable management of WE nexus in the UWC in Atlantic Europe. Beyond the regional impact, the QST as an approach has a global relevance since it is suited to gain an understanding of what barriers and opportunities exist to support the localization and materialization of WE-related SDGs in urban environments.

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CRediT authorship contribution statement

Erik Zilliox: Writing – review & editing, Formal analysis. **Baltasar Peñate Suárez:** Supervision, Methodology, Funding acquisition, Conceptualization. **Germán López Lara:** Project administration, Funding acquisition, Formal analysis. **Manuela Morais:** Writing – review & editing, Formal analysis. **Maria Helena Novais:** Writing – original draft, Formal analysis. **José María González Navarro:** Writing – review & editing, Formal analysis. **Barbara Willaarts:** Writing – original draft, Methodology, Formal analysis, Conceptualization.

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.

Data availability

Data will be made available on request.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2024.103835.

References

Ahmad, S., Jia, H., Chen, Z., Li, Q., Xu, C., 2020. Water-energy nexus and energy efficiency: A systematic analysis of urban water systems. Renew. Sustain. Energy Rev. 134, 110381 https://doi.org/10.1016/j.rser.2020.110381.

Albrecht, T.R., Crootof, A., Scott, C.A., 2018. The water-energy-food nexus: a systematic review of methods for nexus assessment. Environ. Res. Lett. 13 (4), 043002 https://doi.org/10.1088/1748-9326/aaa9c6.

Biba, S., 2016. The goals and reality of the water–food–energy security nexus: the case of China and its southern neighbors. Third World Quart. 1–20. https://doi.org/10.1080/01436597.2015.1086634.

Blicharska, M., Smithers, R.J., Kuchler, M., Munaretto, S., van den Heuvel, L., Teutschbein, C., 2023. The water–energy–food–land–climate nexus: policy coherence for sustainable resource management in Sweden. Environ. Policy Gov. 1–14. https://doi.org/10.1002/eet.2072.

Cabello, V., Romero, D., Musicki, A., Guimarães Pereira, A., Peñate, B., 2021. Co-creating narratives for WEF nexus governance: a quantitative story-telling case study in the Canary Islands. Sustain. Sci. 16 (4), 1363–1374. https://doi.org/10.1007/s11625-021-00933-y.

Cabrera, E., Gómez, E., Espert, V., Cabrera Jr, E., 2017. Strategies to improve the energy efficiency of pressurized water systems. Procedia Eng. 186, 294–302.

Cairns, R., Krzywoszynska, A., 2016. Anatomy of a buzzword: the emergence of 'the water-energy-food nexus' in UK natural resource debates. Environ. Sci. Policy 64, 164–170. https://doi.org/10.1016/j.envsci.2016.07.007.

Di Felice, L.J., Cabello, V., Ripa, M., Madrid-López, C., 2023. Quantitative Storytelling: Science, Narratives, and Uncertainty in Nexus Innovations. Sci. Technol. Hum. Values 48 (4). https://doi.org/10.1177/01622439211053819.

EC, European Commission, (2023) Environmental infringements interactive map. Available at https://app.powerbi.com/view?r=eyJrIjoiNzZiNDEzYjktYjM2ZS00MTIxLWIzY2MtNzFlYWQ5NzJlZDVhIiwidCI6ImIyNGM4YjA2LTUyMmMtNDZmZS05MDgwLTcwOTI2ZjhkZGRiMSIsImMiOjh9 (Last visit: 6 January 2024).

EC, European Comission (2018) Implementation Report on the Urban Wastewater. Country profiles: Spain. Available at: https://water.europa.eu/freshwater/countries/uwwt/spain [Last Access: 4 January 2024].

EEA, European Environment Agency (2012a) Average annual precipitation in the EEA area, available at: https://www.eea.europa.eu/data-and-maps/figures/average-annual-precipitation (Last visit: 1 September 2023).

EEA, European Environment Agency (2012b) Main Climates of Europe, available at: https://www.eea.europa.eu/data-and-maps/figures/climate (Last visit: 1 September 2022).

EurEau (2021) Europe's Water in Figures. An overview of the European drinking water and wastewater sectors. Available at https://www.eureau.org/resources/publications/eureau-publications/5824-europe-s-water-in-figures-2021/file (Last visit: 5 January 2024).

EUROSTAT (2019) Population density per NUTS 2 region. Available at: https://ec.europa.eu/eurostat/databrowser/view/demo_r_d3dens/default/map?lang=en (Last visit: 1 September 2022).

Gleick, P.H., 1994. Water and energy. Annu. Rev. Energy Environ. 19 (1), 267–299. https://doi.org/10.1146/annurev.eg.19.110194.001411.

Hagemann, N., Kirschke, S., 2017. Key issues of interdisciplinary NEXUS governance analyses: Lessons learned from research on integrated water resources management. Resources 6 (9), 1–8. https://doi.org/10.3390/resources6010009.

Hoff, H. (2011). Understanding the Nexus. Background Paper for the Bonn2011 Conference: The Water, Energy and Food Security Nexus. Stockholm Environment Institute, Stockholm. Available at: https://uploads.water-energy-food.org/resources/SEI-Paper-Hoff-UnderstandingTheNexus-2011.pdf (Last visit: July 2024).

Hussein, H., Ezbakhe, F., 2023. The water–employment–migration nexus: buzzword or useful framework? Dev. Policy Rev. 41, e12676 https://doi.org/10.1111/dpr.12676.

IEA, International Energy Agency (2016) World Energy Outlook 2016. Paris. Available at: http://www.oecd-ilibrary.org/energy/world-energy-outlook-2016_weo-2016-en.

IEA, International Energy Agency (2022), World Energy Outlook 2022, Pari. Available at: https://www.iea.org/reports/world-energy-outlook-2022, License: CC BY 4.0 (report); CC BY NC SA 4.0 (Annex A).

IPCC, Intergovernmental Panel on Climate Change (2018) Global Warming of 1.5°C.An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

John, T.W., Sušnik, J., Masia, S., Jewitt, G., 2023. Towards realization of nexus-doing at the grassroots level: Water-energy-food governance assessment in the Songwe River Basin (Tanzania and Malawi). Environ. Sci. Policy 150, 103596. https://doi.org/10.1016/j.envsci.2023.103596.

Kovacic, Z., Giampietro, M., 2015. Beyond "beyond GDP indicators:" The need for reflexivity in science for governance. Ecol. Complex 21, 53–61. https://doi.org/10.1016/j.ecocom.2014.11.007.

Kyle, P., Hejazi, M., Kim, S., Patel, P., Graham, N., Liu, Y., 2021. Assessing the future of global energy-for-water. Environ. Res. Lett. 16 (2), 024031 https://doi.org/10.1088/1748-9326/abd8a9.

Leach M., Scoones I., Stirling A. (2010) Dynamic sustainabilities: Technology, environment, social justice. London, UK; Washington, DC: Earthscan.

Leck, H., Conway, D., Bradshaw, M., Rees, J., 2015. Tracing the water-energy-food nexus: description, theory, and practice: tracing the water-energy-food nexus. Geogr. Compass 9, 445–460. https://doi.org/10.1111/gec3.12222.

Lee, M., Keller, A.A., Chiang, P.C., Den, W., Wang, H., Hou, C.H., Yan, J., 2017. Water-energy nexus for urban water systems: a comparative review on energy intensity and environmental impacts in relation to global water risks. Appl. Energy 205, 589–601. https://doi.org/10.1016/j.apenergy.2017.08.002.

Leidel, M., Niemann, S., Hagemann, N., 2012. Capacity development as a key factor for integrated water resources management (IWRM)—improving water management in the Western Bug river basin, Ukraine. Environ. Earth Sci. *65*, 1415–1426. https://doi.org/10.1007/s12665-011-1223-5.

Lima, S., Brochado, A., Marques, R.C., 2021. Public-private partnerships in the water sector: a review. Environ. Earth Sci. 65 (5), 1415–1426. https://doi.org/10.1007/s12665-011-1223-5 (Utilities Policy, 69, 101182).

Loubet, P., Roux, P., Loiseau, E., Bellon-Maurel, V., 2014. Life cycle assessments of urban water systems: a comparative analysis of selected peer-reviewed literature. Water Res. 67, 187–202. https://doi.org/10.1016/j.watres.2014.08.048.

Mabrey, D., Vittorio, M., 2018. Moving from theory to practice in the water–energy–food nexus: An evaluation of existing models and frameworks. Water-Energy Nexus 1 (1), 17–25. https://doi.org/10.1016/j.wen.2018.04.001.

Magagna, D., Hidalgo, I., Bidoglio, G., Peteves, S., 2019. Water: Energy Nexus in Europe. Publications Office of the European Union, Luxembourg.

McCalla, A., 1997. The Water, Food, and Trade Nexus [Paper presentation]. World Bank, Marrakesh.

Munaretto, S., Witmer, M., 2017. Water-Land-Energy-Food-Climate nexus: policies and policy coherence at European and international scale: Deliverable 2.1 SIM4NEXUS project - Horizon 2020 - 689150. (D2.1 ed.) PBL Netherlands Environmental Assessment Agency. http://www.sim4nexus.eu/userfiles/Deliverables/WP2_Deliverable%202.1_FINAL_1.pdf.

Pahl-Wostl, C., Bhaduri, A., Bruns, A., 2018. Editorial special issue: the nexus of water, energy, and food–an environmental governance perspective. Environ. Sci. Policy 90, 161–163. https://doi.org/10.1016/j.envsci.2018.06.021.

Ramos, E., Kofinas, D., Sundin, C., Brouwer, F., Laspidou, C., 2022. Operationalizing the Nexus Approach: Insights from the SIM4NEXUS project. Front. Environ. Sci. 10, 787415 https://doi.org/10.3389/fenvs.2022.787415.

Ronen P., Jacobsen B.N. (2014) Performance of water utilities beyond compliance (No. 5). EEA Technical report.

Rosen, R. (1991). Life itself: a comprehensive inquiry into the nature, origin, and fabrication of life. Columbia University Press.

Smajgl, A., Ward, J., Pluschke, L., 2016. The water–food–energy nexus–realising a new paradigm. J. Hydrol. 533, 533–540. https://doi.org/10.1016/j.jhydrol.2015.12.033.

Soliev, I., Wegerich, K., Kazbekov, J., 2015. The costs of benefit sharing: historical and institutional analysis of shared water development in the Ferghana Valley, the Syr Darya Basin. Water 7 (6), 2728–2752. https://doi.org/10.3390/w7062728.

Stavenhagen, M., Buurman, J., Tortajada, C., 2018. Saving water in cities: assessing policies for residential water demand management in four cities in Europe. Cities 79, 187–195. https://doi.org/10.1016/j.cities.2018.03.008.

Stein, C., Barron, J., Moss, T., 2014. Governance of the nexus: from buzz words to a strategic action perspective. Nexus Netw. Think. Piece Ser. 3, 1–23.

Stein, C., Jaspersen, L.J., 2019. A relational framework for investigating nexus governance. Geogr. J. 185 (4), 377–390. https://doi.org/10.1111/GEOJ.12284.

Stein, C., Pahl-Wostl, C., Barron, J., 2018. Towards a relational understanding of the water-energy-food nexus: an analysis of embeddedness and governance in the Upper Blue Nile region of Ethiopia. Environ. Sci. Policy 90, 173–182. https://doi.org/10.1016/j.envsci.2018.01.018.

Stirling A. (2015) Developing 'Nexus Capabilities': towards transdisciplinary methodologies. University of Sussex, Brighton, UK, 38.

UN, The United Nations World Water Development Report 2022: Groundwater: Making the invisible visible. UNESCO, Paris.

Villamayor-Tomas, S., Grundmann, P., Epstein, G., Evans, T., Kimmich, C., 2015. The water-energy-food security nexus through the lenses of the value chain and the institutional analysis and development frameworks. Water Altern. 8, 735–755.

Wada, Y., Vinca, A., Parkinson, S., Willaarts, B.A., Magnuszewski, P., Mochizuki, J., Mayor, B., Wang, Y., Burek, P., Byers, E., Riahi, K., Krey, V., Langan, S., van Dijk, M., Grey, D., Hillers, A., Novak, R., Mukherjee, A., Bhattacharya, A., Tong, J., 2019. Co-designing indus water-energy-land futures. One Earth 1 (2), 185–194. https://doi.org/10.1016/j.oneear.2019.10.006.

Willaarts B.A., Novais M.H., Corral V.J., Hurtado A., Morais M., Zilliox E., Musicki Savic A., de la Fuente Bencomo J.A., Peñate Suárez B. (2022) "Narratives of the Water-Energy nexus in the European Atlantic Area. Quantative Story Telling" Eeres4water Project, Atlantic INTERREG, Project Deliverable, Action 4.1 Available at: https://www.desalinationlab.com/wp-content/uploads/2024/06/Final-Deliverable-Action-4.1-QST-30-March-2022.pdf.

Williams J., Bouzarovski S., Swyngedouw E. (2014) Politicising the nexus: Nexus technologies, urban circulation, and the coproduction of water-energy. Nexus network think piece series, Paper 001.

World Bank, 2022. Water Matters: Resilient, Inclusive and Green Growth through Water Security in Latin America. World Bank.