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Institutional arrangements for water reuse: assessing challenges for the transition to water circularity

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ABSTRACT

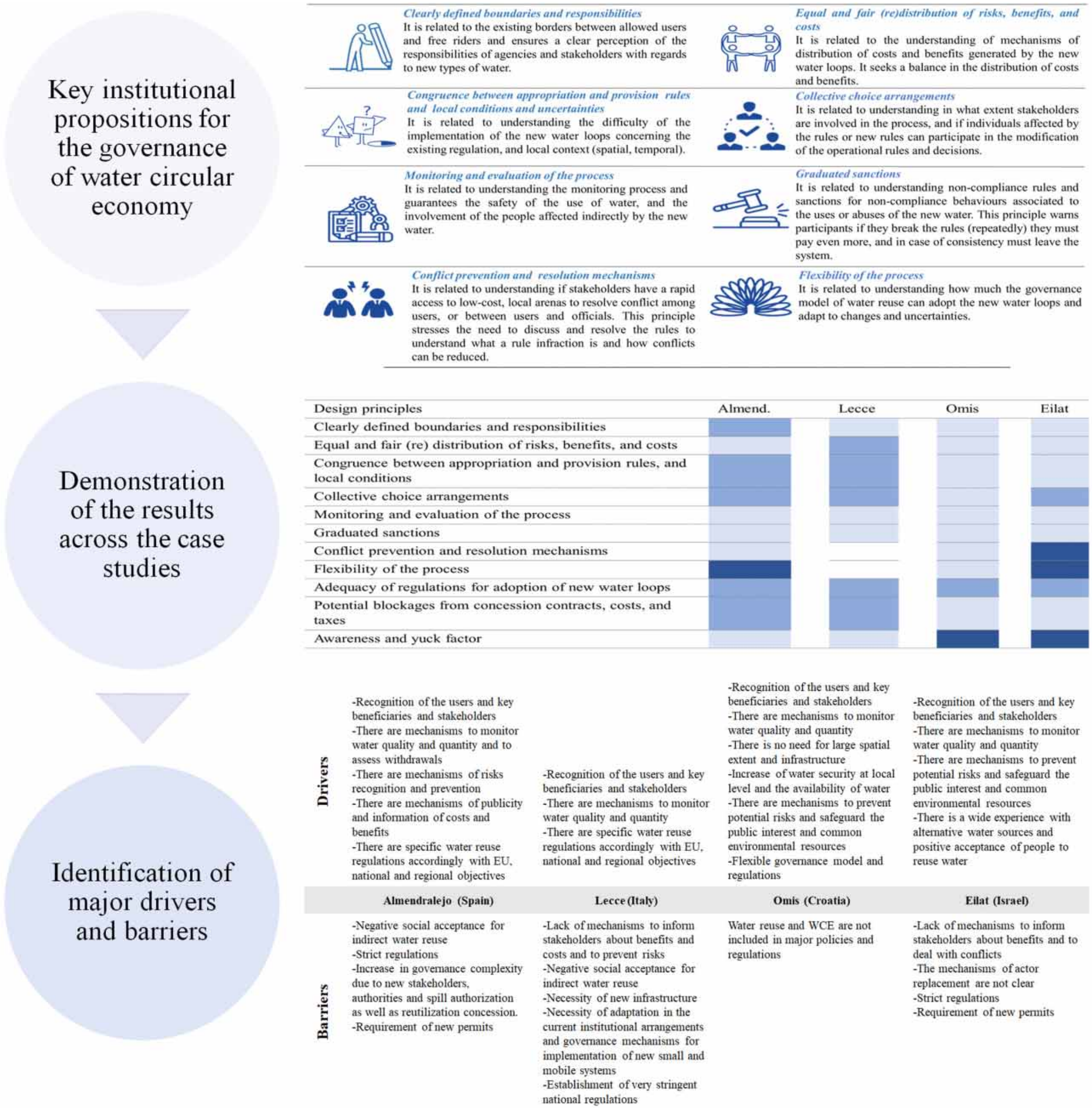
Water scarcity and security drive attention to water reuse in policy and business. However, water reuse may generate new water loops and challenge water governance with new and different types of water, risks, involved actors, and responsibilities. These challenges demand robust institutional arrangements related to water governance. This article assesses the institutional arrangements associated with four case studies in Spain, Italy, Croatia, and Israel. The findings reveal that the more diverse the water uses and users, the more challenges and risks, particularly those associated with institutional arrangements such as quality standards, sanctions, and conflict prevention, are likely to emerge. The weaknesses of governance models and regulations to deal with changes, uncertainties, and public resistance call for special attention to the design of the institutional arrangements before the adoption. Independent of the type of technology adopted, governance may be improved by ensuring internal and external water monitoring; integrating water management with spatial concerns; improving training, expert engagement, and civil society awareness; and reducing water reuse costs. In addition, alternative models that guarantee the efficiency of governance in attaining objectives and assuring the participation of new water users in the management of water reuse loops may also improve governance.

Key words: Institutional analysis and development, Institutional arrangements, Regulation, Water circular economy, Water reuse

HIGHLIGHTS

- Water recycling and reuse need robust institutional arrangements and legal measures.
- Institutional arrangements hinder or drive the transition to water circular economy.
- The more diverse the water uses and users, the more the risks, particularly those associated with institutional arrangements, are likely to emerge.
- The analytical framework in this study contributed to a better understanding of the robustness of institutional arrangements.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Water is becoming more widely recognised as a crucial resource due to the expanding concerns surrounding its security and supply, driving wastewater to get significant business and policy attention (OECD, 2018). As such, attempts to shift the water consumption cycle towards circular economy (CE) may reduce human pressure on water resources (Abu-Ghunmi *et al.*, 2016). The water circular economy (WCE) aims to align the human water cycle and the natural water cycle with measures such as avoiding use (by eliminating ineffective actions), reducing use (by improving water use efficiency and performing better resource allocation and management), reusing water within an operation (by adopting closed loops, recycling within the internal operations, or external uses), and replenishing (by returning water to the river basin) (EMF, 2018).

However, water recycling and reuse need robust institutional arrangements and legal measures (laws and regulations), aside from effectively implemented policies regarding the environment and safe water use (Abderrahman, 2000; Mekala & Davidson, 2016). This includes well-designed water policy frameworks and regulations to address the administrative fragmentation and fair distribution of benefits, costs, and risks (Ostrom, 2005; Brown & Farrelly, 2009; Saldías *et al*., 2016). As the transition towards WCE (in the sense of water reuse) may generate new water loops with additional challenges to water governance, such as different types or qualities of water and associated risks, new water users and responsibilities (in using, producing, operating, managing, or monitoring), changes in land use (for storing, transporting, for instance), and new sets of involved actors (Abderrahman, 2000; Trapp *et al*., 2017). As a result, institutional arrangements must be well designed to adequately deal with the new water loops, related risks of reuse, new monitoring requirements, and allocation (IWA, 2016). The recent literature on water reuse and institutional arrangements emphasises that the success of a water reuse technology depends on robust institutional arrangements (Trapp *et al*., 2017; Marome & Pholcharoen, 2019; Ricart & Rico, 2019). Due to the added responsibilities, stakeholders, and risks that come with water reuse and cycling, new institutional arrangements are essential. To establish new water users, tariffs, responsibilities, water quality requirements, associated risks, and required land-use changes, institutional arrangements, policy frameworks, and legislation are essential (Abderrahman, 2000; Trapp *et al*., 2017). However, the implementation of a water reuse scheme can be achieved by enforcing cooperative governance, a coherent policy framework, adequate administrative capacity, effective risk management, and social and technical cooperation (Soares *et al*., 2005; Marome & Pholcharoen, 2019).

Furthermore, water reuse and related water loop regulations raise public policy issues (Guérin-Schneider & Nakhla, 2012) because regulations must assure service access and quality while reducing pressure on water resources (Guérin-Schneider & Nakhla, 2012). Regulation is crucial for water services as it addresses many purposes, including tariff regulation; the establishment of efficiency incentives; collection of information; the monitoring of the standards for service access, performance, and quality; and the participation of user organisations (OECD, 2015). Regulations specify what the tasks and responsibilities are, and conventional rules must be reviewed and revised when new technologies are implemented for water resources (Trapp *et al*., 2017). Besides, fair pricing systems, funding, and well-making contracts are relevant issues for developing water reuse schemes (EC, 2016). However, water reuse tariffs must identify and recover the associated expenses based on a sustainable approach, considering economic efficiency, and financial, social, and governmental concerns (Pinto & Marques, 2017). The tariff structure is critical for projects' economic sustainability since it provides for cost recovery while supporting particular political, economic, social, and environmental objectives (Pinto *et al*., 2021). In the European context, the regulation of water and wastewater is undergoing some fragmentation, both horizontally and vertically (EC, 2015). Recently, the European Union (EU) adopted the *Regulation on Minimum Requirements for Water Reuse* (EU, 2020). It lays down the minimum requirements for water quality and monitoring and provisions on risk management for the safe use of reclaimed water in the integrated water management (EU, 2020).

This article analyses the robustness of the institutional arrangements associated with water governance to assess their readiness for a transition to WCE in four sites, namely, Almendralejo (Spain), Lecce (Italy), Omis (Croatia), and Eilat (Israel). The selected sites are currently deploying different novel water reuse technologies under the EU H2020 research project Ô and comprise different types of water loops across a wide range of policy and planning contexts. Robust institutions can adapt to disruptions and new circumstances while maintaining long-term viability (Ostrom, 2005). Therefore, the institutional arrangements' robustness indicates that they are well suited or ready to adapt to the new circumstances arising in water governance (the adoption of new water loops), cope with the potential risks and requirements, and adapt to the water reuse scheme functions as well. In the scope of this study, water governance refers to '*the range of political, institutional, and administrative rules, practices, and processes (formal and informal) through which decisions are taken and implemented, stakeholders can articulate their interests and have their concerns considered, and decision-makers are held accountable for water management*' (OECD, 2018, p. 22). Barriers are understood as obstacles or constraining factors for the adoption of the new water loops. This article identifies major barriers and challenges across local contexts regarding the governance of new water reuse loops using Ostrom's Institutional Analysis and Development (IAD) framework in conjunction with a specific set of regulatory features. Its novelty lies in adapting a set of institutional design principles to water reuse concerns and using them to assess the preparedness of local contexts to accommodate the challenges of governing new water loops.

The article is structured into six sections. Section 2 introduces the main concerns raised in the literature on institutional arrangements for WCE and water reuse. Section 3 covers the methodology and the data utilised to analyse the institutional arrangements in the case studies. Section 4 provides findings within and across case studies. Section 5 discusses the data, the methodological approach for this study regarding its benefits and limitations, the key findings, and the main institutional drivers and barriers of the transition towards WCE in the case studies. Finally, the study concludes with Section 6, which outlines key findings and suggestions for further studies.

2. INSTITUTIONAL ARRANGEMENTS AND WATER CIRCULAR ECONOMY

This section outlines the major institutional arrangements concerns in the context of literature referring to water reuse and provides guidelines for establishing adequate institutional arrangements in response to the new circumstances arising in water governance as a result of the addition of new water loops.

Institutional arrangements '*refers to the regulation on some certain behaviours and relationships*' (Chen, 2009, p. 128), including legal and social norms (Lintz, 2016). These are not just some bricks and buildings or political venues (Heikkila & Andersson, 2018). Institutional arrangements shape policies, regulations, planning, explicit incentives, contractual terms, or voluntary agreements (Yu *et al.*, 2014). For water, institutional arrangements influence user behaviour in terms of sharing and utilising water, as well as water-related policies and decision-making (Hassenforder & Barone, 2019). Laws, regulations, and policies may create the necessary conditions for the transition to CE (Yu *et al.*, 2014; Lu *et al.*, 2020). Also, different modes of property rights are likely to interfere with the public agency or community control mechanisms (Brekke *et al.*, 2007). They are also important for economic growth since they may define the choice set and influence the transaction and production costs and, hence, the profitability and feasibility of engaging in economic activities in new challenges (North, 1991).

Studies in the context of water reuse, around the world, reveal that the success of implementing new water reuse technology is heavily dependent on the establishment of robust institutional arrangements (Marks & Zadoroznyj, 2005; Bixio *et al.*, 2006; van Lier & Huibers, 2010; Marome & Pholcharoen, 2019; Wakhungu, 2019). Implementing an alternative or non-traditional water source (e.g., stormwater, rainwater, desalinisation, recycled water) relies on regulatory, governance, environmental, cost, and community-acceptance factors. The uncertainty around roles and responsibilities, as well as the uncertainty around the quantity and quality of the new water, the disagreements between parties affected by its implementation, and the ambiguity about who will identify, pay for, operate, and/or regulate a particular water source, may hinder the implementation (Furlong *et al.*, 2023). Water infrastructure, particularly for new water reuse schemes, involves new institutional arrangements that require updating the legislation and defining a robust and transparent regulation for reusing or recycling water (Abderrahman, 2000). Institutional arrangements in terms of governance and administrative capacity, policy framework, and regulations are important because they define new water users and responsibilities (in using, producing, operating, managing, or monitoring), standards to control the qualities of water (including crops and soil in the case of irrigation), associated risks, and necessary changes in land use (e.g., for storing and transporting) (Abderrahman, 2000; Trapp *et al.*, 2017). The institutional arrangements barriers for water reuse are as follows:

- Poor policy framework, such as a lack of supportive policy and policy design that integrates water resource management and reuse efforts into its objectives and measures (Marome & Pholcharoen, 2019), besides a lack of cooperation between water utilities and municipalities (land-use planning, water supply, and wastewater management), and a lack of planning instruments to integrate all action in the same space as it happened in Brazil (Soares *et al.*, 2005).
- Inadequate or outdated tariff regulations (Bae *et al.*, 2012; Trapp *et al.*, 2017). Regulation affects the cost-efficiency of the water reuse process, therefore the success of water reuse scheme implementation (Alcalde-Sanz & Gawlik, 2017; Trapp *et al.*, 2017). In theory, a water supply system is after cost reduction, and economics of scale and price recovery from water charges can be used as an effective policy tool to cover the costs and reduce further water consumption (Bae *et al.*, 2012). The conventional rules must be reviewed and revised when new technology is implemented for water resources (Schramm *et al.*, 2018). Nonetheless, apart from the type of institutional arrangements (e.g., private, public, public–private) for water supply, there is a need to improve efficiency by reducing costs and productivity gains (Bae *et al.*, 2012).
- Inadequate administrative capacity, such as lack of focus on policies, the fragmentation of the administrative framework, insufficient skills and knowledge, organisational resistance to change, and lack of political will and limited regulatory incentives (Brown & Farrelly, 2009). The experience of Udon Thani Province (Thailand) for Urban Resilience reveals that the success of water and wastewater management depends on vertical and horizontal institutional arrangements, which refers to the coordination between public agencies at the national, regional, and local levels, and the spatial coordination of public agencies at the same level of governance, respectively. Vertical coordination aids plans and policies in achieving cohesion and integration when defining objectives at various levels (national, regional, and local), while horizontal arrangement encourages effective development, especially when the local level cannot implement the plans due to a lack of resources (Marome & Pholcharoen, 2019).
- Ineffective risks management such as institutional, environmental, health and technological risks, and lack of harmonisation in the regulatory framework to manage health and environmental risks related to water reuse (Alcalde-Sanz & Gawlik, 2017; Trapp *et al.*, 2017). Given the fact that new water loops bring new responsibilities and risks, stakeholders must be updated on their roles and have a clear understanding of them; otherwise, the new scheme would be hampered (Abderrahman, 2000; Koehler *et al.*, 2018; Schramm *et al.*, 2018). Poor public participation and support; the boundaries of powers between policy, delivery, and regulation; the degree of autonomy in managing service delivery; and low accountability are all related to institutional risks (Koehler *et al.*, 2018).
- The yuck factors such as public distrust are related to reusing and health risks (Russell & Lux, 2009; Ching, 2010; Garcia-Cuerva *et al.*, 2016; Alcalde-Sanz & Gawlik, 2017). The yuck factors are public resistance to water reuse and sentiments of disgust about drinking or consuming agricultural goods made with wastewater, which are psychological or based on social and cultural perceptions (Ricart & Rico, 2019). They can hinder reuse policies and the successful implementation of water reuse schemes (Ching, 2010; Ricart & Rico, 2019). For instance, the implementation of new water reuse technology for agricultural products requires a comprehensive approach between farmers (as users of new water producers reusing water) and the public (as users

of agricultural products produced by new water) to make people more familiar with new technologies, as well as long-term water, soil, and crop analysis with an awareness of risks, calling for engineers and social scientists to work together (Ricart & Rico, 2019).

However, the establishment of adequate institutional arrangements for water reuse or WCE adoption requires following several recommendations. Firstly, the transition to more water reuse requires a well-designed water policy framework and regulations, especially when related to quality standards (Abderrahman, 2000; Trapp *et al.*, 2017). The strict CE frameworks and guidelines, accompanied by robust regulations and standards, lead to better water reuse quantity and quality monitoring for different purposes (Saldías *et al.*, 2016). Besides, the transparency of the monitoring process is required to guarantee the adequate performance of the new water loops (Saldías *et al.*, 2016).

Secondly, it is crucial to consider how actors integrate into the cooperative approach. The institutional arrangements must guarantee the engagement of current and new stakeholders and the development of a communicative ground for water information sharing (Schramm *et al.*, 2018), given that the government plays a critical role in fostering recycling by establishing specific measures (Bao & Lu, 2020).

Thirdly, appropriate institutional arrangements for water reuse call for a fair distribution of benefits and costs as well as environmental and health risks (Bixio *et al.*, 2006; Saldías *et al.*, 2016). In highly engaging systems where stakeholders meet shared concepts of fairness, the fair distribution of rules builds trust and enhances their willingness to obey the rules (Ostrom, 2005). In addition, appropriate institutional arrangements ensure a fair pricing system capable of controlling the consumption and pollution of natural resources while enhancing the quality of related services on the other hand (van Lier & Huibers, 2010). Fair pricing relates to a feeling of satisfaction with what we get for what we pay, as well as accessibility for even low-income groups (Chappells & Medd, 2008).

Fourthly, the risk associated with the adoption of WCE needs to be acknowledged. Water management involves various risks and uncertainties such as health, environmental, economic, and institutional (Pahl-Wostl, 2002; Elazegui *et al.*, 2016; Wanda *et al.*, 2017; Koehler *et al.*, 2018; Oulahen, 2021), calling for defined minimum quality requirements and strict monitoring (Alcalde-Sanz & Gawlik, 2017).

Fifthly, responsive institutional arrangements are needed to establish formal institutions at both market and administrative levels and innovative institutional arrangements, standardising the commodity to be traded, establishing a platform for effective information sharing, enacting new regulations to promote CE, and adopting new mechanisms for cross-jurisdictional waste trading (Lu *et al.*, 2020).

Finally, sixthly, since the main barriers to more effective water management are largely socio-institutional rather than technical, the transition necessitates the adoption of a technical–social approach in water management for the identification of public perceptions, which necessitates collaboration between engineers and social scientists (Ricart & Rico, 2019).

3. METHODOLOGICAL APPROACH AND DATA COLLECTION

This section explains the main steps used to study the features of institutional arrangements on four sites where novel water reuse technologies are on trial under an EU H2020 research project. The sites are on Almendralejo (Spain), Lecce (Italy), Omis (Croatia), and Eilat (Israel). These refer to three European countries under EU environmental policy challenges and one non-European with extensive water reuse experience. The methodological approach adopted for the forthcoming analysis relies on the use of the IAD framework originally developed by Ostrom (2005, 2011). The IAD framework offers a problem-solving orientation (Schlager & Cox, 2018) and a multi-tier conceptual map capable of identifying the significant institutional arrangements features (Ostrom, 2011). The IAD framework also helps to compare water governance across countries (Araral &

Wu, 2016) and explore how institutional arrangements have changed because of technology and governmental involvement in cases (Kamal *et al.*, 2021). Several scholars have also applied the IAD framework to water governance contexts to highlight critical insights on water institutions and identify gaps and benefits of specific institutional arrangements (Schlager & Heikkila, 2009; Heikkila *et al.*, 2011; Ching & Mukherjee, 2015; Sanches *et al.*, 2021). Applying the IAD framework in various complex governance systems necessitates a comprehensive contextual understanding of the new conditions under which new water loops will be implemented (Heikkila & Andersson, 2018). Furthermore, the analysis can be strengthened by investigating the additional regulatory and awareness factors influencing adoption that have been highlighted in the literature (Guérin-Schneider & Nakhla, 2012; Trapp *et al.*, 2017; Ricart & Rico, 2019). However, it comes with a drawback. Although this study suggests a valuable set of institutional propositions for new water loop adoption, these institutional propositions must be tested and refined in different contexts. There are three methodological steps considered for the analysis (Figure 1).

The first step consists of presenting the sites and their major contextual features. This step assumes that the analysis of institutional arrangements requires an understanding of water policy and governance contexts in which new water loops occur, and it is inspired by Heikkila & Andersson (2018). For this purpose, it addresses the objectives of water reuse, the drivers for water reuse, the ownership of the water and new water, the investment patterns, new water users and uses, the types of focal policies affecting water reuse, the key responsible authorities, and finally, relevant stakeholders.

The second step analyses the institutional arrangements on the sites by applying the IAD framework (Ostrom, 1990, 2005). It considered the following set of principles:

i. *Clearly defined boundaries and responsibilities.* It is related to identifying the community of users, the boundaries around the entrance of new users and stakeholders, and the responsibilities that result from the

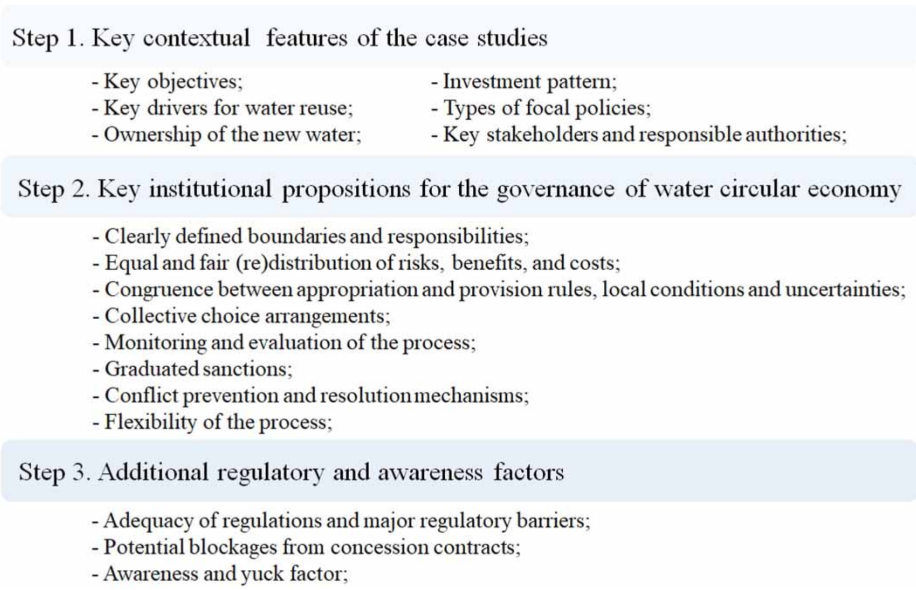


Fig. 1 | Main steps of the analysis undertaken.

implementation of new water loops (Ostrom, 2005; Huntjens *et al.*, 2012). The new water loops generate new types of water with different potential purposes of use and potential new interdependencies.

ii. *Equal and fair (re)distribution of risks, benefits, and costs.* It is related to understanding the mechanisms of the distribution of the benefits, costs, and risks generated by new water loops. Water reuse can be deterred by the unequal distribution of costs and benefits among different groups and potential economic, environmental, and technological risks (Bixio *et al.*, 2006; Trapp *et al.*, 2017). Therefore, fairness is a crucial attribute of rules for water governance, helping to build trusting relationships among stakeholders (Ostrom, 2005).

iii. *Congruence between appropriation and provision rules and local conditions and uncertainties.* It is related to understanding the difficulty of implementing the new water loops concerning the existing regulations and local contexts. Producing new quantities and qualities of water for different purposes can interfere with regulations (Cox *et al.*, 2010) or local agreements (Ostrom, 2005). Moreover, rules must often accommodate the management of uncertainties like water scarcity and pandemics (Cox *et al.*, 2010). Adoption of new water loops may also involve new spatial considerations for the transportation and storage of the treated water for reuse.

iv. *Collective choice arrangements.* It is related to understanding to what extent stakeholders are involved in the process and if individuals affected by the rules or new rules (or representative of them) can participate in the modification of the operational rules and decisions (Ostrom, 2005). Institutional arrangements must ensure the engagement of current and new stakeholders, communicative platforms for learning and knowledge sharing, and the identification of best practices for the new water governance (Huntjens *et al.*, 2012).

v. *Monitoring and evaluation of the process.* It is related to the understanding of the new water quality and quantity monitoring process, stakeholders' behaviour, and compliance with safety and environmental rules. Enforcing rules is essential for the governance of new resources (Ostrom, 2005). Water loops introduce new qualities, quantities, and standards, and monitoring identifies situations, individuals, or organisations that may not comply with rules. It facilitates the effectiveness of rule enforcement (Cox *et al.*, 2010).

vi. *Graduated sanctions.* It is related to understanding rules and sanctions for noncompliance behaviours associated with producers and users of new water types (Ostrom, 2005). Disregarding the rules and compromising the quality and quantity of the treated water endanger its use by others and may cause environmental and health problems.

vii. *Conflict prevention and resolution mechanisms.* It is related to understanding if stakeholders have rapid access to low-cost, local arenas to resolve conflicts among users or between users and officials (Ostrom, 2005). Conflicts over resources are frequent when new types of rules and stakeholders are at stake. This principle stresses the need for mechanisms to understand a rule infraction, how conflicts can be reduced, and trust can be ensured.

viii. *Flexibility of the process.* It is related to understanding how the governance model of water can accommodate the challenges and uncertainties of the new water loop, such as new types of stakeholders, new standards and responsibilities, and new spatial considerations in terms of transportation and storage. It calls for flexibility and adaptivity to achieve robust governance of water reuse, i.e., '*maintenance of a system's performance even when it is subject to external, unpredictable disturbances*' (Ostrom, 2005, 67).

The third step looked for other key selected regulatory and perception features, namely, the adequacy of regulations and major regulatory barriers, potential blockages from water concession contracts, costs and taxes, and awareness and yuck factors (Voulvoulis, 2018; Lee & Jepson, 2020). As referred to in the literature, these factors are critical to promoting water reuse and enhancing sustainable economic growth (Guérin-Schneider & Nakhla, 2012). Making contracts requires a detailed check of the existing regulatory framework and an appropriate contract type choice regarding the utility's needs (OECD, 2011). It is legally and technically risky, requiring a clear definition of the objectives and responsibilities depending on the type of contract (e.g., service contract, management contract, lease contract, concession contract, joint venture contract) (OECD, 2011).

The steps presented earlier were developed using a set of questions formulated and sent to new water producers, users, and selected stakeholders of each site, including the municipality, water utilities, and river basin authorities. The resulting data collection of institutional design propositions for the case studies and key regulatory features is presented in the Supplementary Material. Despite the complexity of the questions and the challenges of collecting the replies during the pandemic period, the information received supported by the replies from local project partners was adequate to conduct a thorough analysis and produce valuable results. An effort was made to ensure a mixture of experts to provide a fair representation of the perspectives on the arrangements being analysed.

4. FINDINGS: ASSESSING THE INSTITUTIONAL ARRANGEMENTS IN PLACE FOR WATER REUSE

This section summarises the key findings of the analysis conducted in accordance with the previously specified methodological steps. The first part of this section identifies the contextual factors that influence the implementation of new water loops. In the second part, the major institutional and regulatory features are analysed based on data from current institutional arrangements and regulations, as well as structured questionnaires and interviews given to local project partners and selected stakeholders in each case study. Finally, the third part provides an overall assessment of the robustness of current institutional arrangements in case studies.

4.1. Contextual features

The major contextual features of the four sites, namely, Almendralejo, Lecce, Omis, and Eilat, are summarised in Table 1. The analysis of the major contextual features reveals that the major drivers for the trial of new water treatment technologies include the need to comply with water quality regulations on water bodies and to reduce water consumption due to the increasing water scarcity problems.

The adoption of new water loops occurs in various institutions and policy contexts with different types of focal policies, ownership, and investment patterns for the new water reuse. Furthermore, the features, the purposes of reusing water, and the number of water reuse loops vary in the case studies. The site of Almendralejo is related to a public wastewater treatment plant where new technologies will treat urban, industrial, and runoff water. The purposes of reuse are for the following three reasons: watering a green park, irrigating agricultural areas, and washing municipal roads and streets. Part of the treated water will also be discharged into a nearby river with improved quality. The site of Lecce is related to a public wastewater treatment plant where the new technologies will treat water for recharging a nearby aquifer system and rehabilitating related degraded wells used in old times for urban and farming water supply. Another part is discharged into the sea. The site of Omis is related to a textile company in which new technologies will treat water to be reused in the production process and discharged into the sea with better quality. Finally, the site of Eilat is related to an aquaculture centre where new technologies will treat wastewater from the fish tanks. Part of this water is feedback to be reused in the fish tanks. Another is for agriculture irrigation under a hydroponic system, and another is released into the sea.

Almendralejo implemented a module to remove complex pollutants from used water, addressing issues associated with organic pollutants while improving wastewater cleaning and reuse. The design of this technology comes with low investment and operational costs and the ability to test the quality of the used water and determine if pretreatment is required. Lecce implemented a technology for a tertiary treatment mobile plant with minimal energy usage, operational costs, and environmental impact. Omis implemented a unit as part of the new water treatment plant that removes harmful chemicals and organic pollutants and recovers salts from the water to reduce their costs, energy, and resource consumption and protect the local environment. Eilat implemented a module as a

Table 1 | Contextual features of new water loops in the case studies.

	Almendralejo	Lecce	Omis	Eilat
Key objectives	• To control the pollution in the wastewater and water abstraction in the Guadiana River Basin • To monitor and control of emerging pollutants and to guarantee safe reuse	• To produce high• quality water that can be reused to recharge the Salentino Aquifer and to rehabilitate the Guardati Well • To reduce the discharge of treated wastewater in the Adriatic Sea	• To produce wastewater for reuse • To reduce the discharge of wastewater and consumption of freshwater to Cetina River	To improve water quality discharged on the Red sea, reuse on rearing fish, and agriculture irrigation
Key drivers for water reuse	• Water scarcity and climate vulnerability • Accidental industrial spills • To comply with national and EU environmental objectives	• Water scarcity • To comply with national and EU environmental objectives	To comply with national and EU environmental objectives	• Water scarcity and climate vulnerability • Water reuse in rearing fish and irrigation
Ownership of the new water	Public with a private concession contract	Public with a private concession contract	Private	Public under public management
Investment patterns	Private under public contract	Public	Private	Public
Types of focal policies	• National and regional CE strategies • The water efficiency plan • National Water Treatment, Sanitation, Efficiency, Saving and Reuse Plan	• The national CE strategy • The water protection plan	Water Management Strategy	Water Master Plan
Key stakeholders and responsible authorities	• Municipality of Almendralejo (owner of the Wastewater Treatment Plant (WWTP) and water infrastructure, user of treated water) • Guadiana Hydrographic Confederation (administrative concession and permits) • Local Health Authority • City Council • The innovative water	• Puglia region (monitoring and control; management and control of the supply chain; define destination of water reuse) • Province of Lecce (authorisation concession, monitoring and control) • Lecce Municipality (owner of the WWTP and water infrastructure) • Puglia Water Authority	• Croatian Waters (permits for wastewater discharge) • Water Institute (monitor and control of chemical and physical status of natural waters) • Public Health Institute (defines the National Laboratories authorised for chemical analysis) • Textile factory	• Government Water and Sewage Authority of Ministry of Energy (responsible for the management, operation, conservation, and rehabilitation of the country's natural water resources and the regulation of the water sector in accordance with the government's policies and the rules); • Local Water

(*Continued.*)

Table 1 | Continued

	Almendralejo	Lecce	Omis	Eilat
	cycling company (manager of the WWTP and municipality water service, monitor and control) • Associations of farmers • Citizens and associations of citizens • Associations of retailers of agricultural products (sellers of agricultural products) • Water transport and storage company	(financial management) • Regional Agency of Environmental Protection of Puglia (water quality, certification of chemical and biological analysis report) • Acquedotto Pugliese (manager of the WWTP and water service, monitor and control, risk management plan) • Associations of citizens, farmers, industries		Authority National Centre for Mariculture (control and monitoring) • National Centre for Mariculture (control and monitoring) • Israel National Water Company (responsible for desalination and water supplement) • Associations of retailers of agricultural and fishery products • Associations of citizens

simple and cost-effective nitrate removal process for land-based mariculture that removes nitrates, other pollutants, and excess salts from the water, allowing it to be reused in fish tanks or to water plants in a sustainable manner. The cost of water treatment modules varies due to differences in technology expenses. The two most expensive costs are labour and the technologies themselves. However, these modules are to be cost-effective, and the costs will be amortised by increasing the output rate through pilot development and industrialisation of the production and adjusting the tariffs. The initial investment in these innovative technologies for water treatment was supported by the H2020 Research Project. In the short term, savings are expected through the reduction of water exploitation and energy consumption. In the future, private investors are expected to disseminate and further exploit their potential. New water tariffs for treated water suitable for reuse are also expected to help cost recovery as they may pay off the effluent treatment costs (Pfleger *et al.*, 2022; Iurlaro, 2023).

However, the various features of case studies display various risks and challenges. In Almendralejo, compared to the other sites, the water loop adds more new water uses and users (directly and indirectly). This calls for varied water quality, health regulations, and risk management schemes to ensure safety and protect consumers of agricultural products and green park users. The possible impact of the new water transportation is likewise a new challenge to address. Lecce brings fewer challenges due to the fewer water users directly involved. However, the indirect use of groundwater for the new uses by citizens implies strict water quality and health regulations to assure safety. Moreover, the aquifer recharge requires new infrastructures that must be planned according to the relevant stakeholders and considering the aquifer safeguard zones defined in the Lecce Municipal Master Plan. Omis involves minor challenges since the new types of water reuse are mostly kept within the premises. Still, it reduces water consumption and improves the quality of wastewater discharged into the sea. Despite the long tradition of water reuse and the limited number of new water users, the site of Eilat has some bottlenecks related to alleged strict water regulations and overlapping of water governance responsibilities. However, the new water loop in Eilat will reduce pressure on the Red Sea.

4.2. Major features of institutional arrangements

Regarding the *clearly defined boundaries and responsibilities*, the boundaries and responsibilities are fairly defined in all case studies. The mechanism to assess withdrawals from current users or the entry of new water users is foreseen in Almendralejo and Lecce. However, in Eilat and Omis, this problem is not raised since the new water loops are within the premises of the mariculture. Besides, the entry of new water users in the future is fairly defined in all case studies. In addition, the actors' responsibilities are listed under the obligations regarding quality standards and monitoring for all cases. However, in the case of Almendralejo, there is not a clear perception of the new challenges and responsibilities created by the adoption of the new water loops.

Regarding the *Equal and fair (re)distribution of risks, benefits, and costs,* the direct beneficiaries of the adoption of new waters are generally recognised in all cases, but the risks involved are not fully acknowledged. The mechanisms to prevent risks and safeguard the public interest are defined in Almendralejo and Eilat. In Lecce, the associated risks and the impacts on water availability and pollution are recognised, but mechanisms to prevent them are not recognised. In Omis, the closeness of the new water loop inside the company reduces the scope of this topic. Nevertheless, in this case, the impacts on water availability are recognised, and risk prevention mechanisms are considered adequate in addition to regulatory protection of the public interest and common environmental resources.

Regarding the *Congruence between appropriation and provision rules and local conditions and uncertainties*, although the current regulations are considered robust to guarantee control over the new water quality and expected quantity in all cases, the congruence of rules for the implementation of the new water loop raises some concerns depending on legal features and social acceptance. Almedralejo, Lecce, and Eilat present a diversity of implications, especially regarding safeguarding the quality and quantity of water reuse. Omis shows minor challenges as it involves only internal water uses in the textile industry. In Almendralejo and Lecce, a negative social perception regarding water reuse was noticed.

Regarding the *Collective choice arrangements*, the case studies did not provide any mechanisms or platforms for engaging stakeholders and ensuring collective choice arrangements. Nevertheless, only Almendralejo informs the stakeholders about the benefits of waste reuse. Lecce and Omis also refer to some engagement between stakeholders. However, in this last case, collective choice arrangements may be misapprehended, because the new water is used internally. Although there is a significant demand for water in Eilat, the central government is strongly relied upon to regulate water quality and establish water consumption regulations. This reduces the perception of new mechanisms' relevance to informing and engaging stakeholders on water management.

Regarding the *Monitoring and evaluation of the process,* and the *Conflict prevention and resolution mechanisms,* and the *Flexibility of the process*, the mechanisms for monitoring the new water quality and quantity are considered well regulated in all case studies. However, the graduated sanctions are not yet foreseen considering the specificities of the case studies, especially when there are new water uses and users. The same happens with the conflict prevention and resolution mechanism. They are foreseen in most sites through existing water laws, but in Eilat, the interviewees consider that conflict prevention mechanisms are not assured for the specificities of the new water loop. Finally, the water governance models are considered quite strict (Almendralejo, Lecce, and Eilat) but flexible in Omis.

Next to the institutional design principles, the analysis of regulatory features of water utilities also revealed that the new technology does not significantly interfere with the current water contracts. However, adoptions at larger scales will undoubtedly do, especially for Almendralejo and Lecce. The WCE adoption may call for new permits and more vital coordination and regulation between spill authorisation and re-utilisation concessions. The improvement of current legislation in place, regulating water reuse to accommodate different qualities, and loops and users' responsibilities must also be taken into consideration. Although there is no consensus whether the production of the new water produced by the new water loops may interfere with water costs and taxes in place, the upscaling of the use of the new technologies is likely to do so. In this case, new contracts associated with water use are required. In all cases, the poor awareness and yuck factor, especially in Almendralejo and Lecce, also call for wide-open forums about the risks and challenges of water reuse.

4.3. Overall assessment of the robustness of institutional arrangements

This section assesses the robustness of the institutional design principles, indicating whether they are well suited to deal with new water loop risks and requirements. This analysis was carried out using data gathered through questionnaires and interviews made with key stakeholders in each site (included in the Supplementary Material). Using their replies, the institutional design principles were ranked using a blue colour spectrum. The light blue relates to a situation when the institutional design principle is considered as strong (no adjustments are required). The fair blue refers to a situation when the institutional design principle is considered robust enough to embrace new water loops but requiring minor adjustments. Finally, the dark blue relates to a situation when the institutional design principle is considered poor requiring major adjustments of arrangements in place. White represents a lack of information. An overall assessment of the preparedness of the case studies regarding the institutional arrangements in place to accommodate the new water reuse loops is presented in Figure 2.

The findings suggest that most case studies are not fully prepared to accommodate all the challenges of WCE. When the more types of water and new water users are at stake within a new water reuse loop, the more challenges and risks, notably institutional ones, are likely to be faced. However, closed systems inside companies (like Omis) tend to involve fewer barriers.

Regarding the design principles perspective, the flexibility of the water governance approaches and the adequacy of regulations are the main issues in the adoption of new water loops. They hinder the adaption of the existing rules and practices to the new water types and uses and the integration of new stakeholders in managing the water cycle. Following that, the most critical issues are conflict prevention and resolution mechanisms, clearly defined responsibilities, and awareness of water reuse potentials and problems. Other issues like monitoring and evaluation of the process and graduated sanctions, which are critical for water loops with several water uses and users, raise minor concerns. Also, the negative perception of risks and low acceptance of water reuse are also

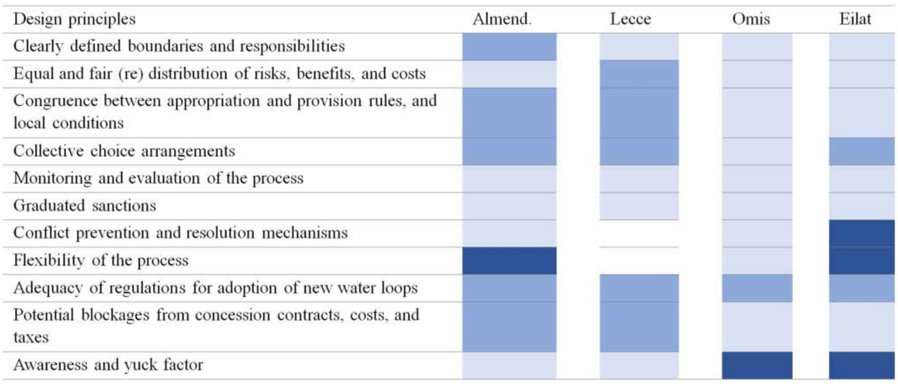


Fig. 2 | The assessment of robustness of institutional arrangements in place. (▭, a robust institutional arrangement; ▬, a nearly robust institutional arrangement; ▬, a poor Institutional arrangement; ▭, no information being available.) Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/wp.2023.155.

barriers that need to be overcome through robust information-sharing mechanisms among stakeholders. Regarding the case perspective, Eilat raises more concerns regarding the robustness of the institutional arrangements in place, followed by Almendralejo and Lecce. The case of Omis is the least challenging in terms of institutional arrangements.

5. DISCUSSION

This section discusses the results having into account the methodological approach used, the relevance of the key findings, and the resulting major institutional drivers and barriers for the transition to WCE in the four case studies.

5.1. The data, the methodological approach

This study assumed that the robustness of institutional arrangements is crucial for the transition to more water reuse or WCE. In this article, we proposed and found empirical support for eight institutional design principles consolidated with a set of selected regulatory features for the adoption of new water loops in four different water governance systems. Keep in mind that the design principles are not blueprints or checklists, and they describe a broad similarity of each system capable of robust to the many social, economic, and ecological disturbances that occur over time (Ostrom, 2005). This article defined a new version of the principles in light of the scale and complexity of the new conditions. Water and spatial planning integration, as well as new risks, stakeholders, and regulatory needs brought about by the deployment of new water loops, are among the new conditions. The first design principle used in this study is not only observing the community of users and boundaries around the resource system but also exploring who has the responsibility, capacities, access to resources, and information to deal with the probable problems. Besides, the *minimal recognition of the rights to organise* sourced from Ostrom is embedded in the *collective choice arrangements*. Since it is considered a pre-condition for the collective choice recognising and without recognising this right, the collective choice will be in problem (Huntjens *et al.*, 2012). Finally, rather than *nested enterprises*, this study adopted flexibility of the process suggested by Huntjens *et al*. (2012). Because firstly, organising monitoring and governance activities in multiple layers does not necessarily lead to the success of projects and can lead to fragmentations. Also, the responsibility and organisation of monitoring are in the other design principles such as clearly defined boundaries and responsibilities and monitoring and evaluation of the process.

The analytical framework in this study helps to understanding the complexity of the institutional and policy context and their gaps and comparing case studies. Furthermore, the framework aided in the diagnosis of institutional arrangements' readiness for the new water loops adoption. However, under the COVID contingencies, the interaction with stakeholders had to be reduced, and consequently, the study used the analysis of regulations, the questionnaires sent to key stakeholders, and the replies from local project partners. The limited direct interaction with stakeholders, and the complexity of the questionnaires (prone to misinterpretation or reply avoidance by interviewees), may have hindered the strength of the results in proposing better institutional arrangements to cope with new challenges of managing water reuse. Nevertheless, the findings are clear and solid in highlighting the relevance of further understanding the institutional arrangements' roles to face water circularity challenges.

5.2. The findings and the main institutional drivers and barriers

The key finding in this study is that when the more types of water and new water users are at stake within a new water reuse loop, the more challenges and risks, notably institutional ones, are likely to be faced. The main drivers and barriers associated with institutional arrangements are summarised in Figure 3.

	Almendralejo (Spain)	Lecce (Italy)	Omis (Croatia)	Eilat (Israel)
Drivers	-Recognition of the users and key beneficiaries and stakeholders -There are mechanisms to monitor water quality and quantity and to assess withdrawals -There are mechanisms of risks recognition and prevention -There are mechanisms of publicity and information of costs and benefits -There are specific water reuse regulations accordingly with EU, national and regional objectives	-Recognition of the users and key beneficiaries and stakeholders -There are mechanisms to monitor water quality and quantity -There are specific water reuse regulations accordingly with EU, national and regional objectives	-Recognition of the users and key beneficiaries and stakeholders -There are mechanisms to monitor water quality and quantity -There is no need for large spatial extent and infrastructure -Increase of water security at local level and the availability of water -There are mechanisms to prevent potential risks and safeguard the public interest and common environmental resources -Flexible governance model and regulations	-Recognition of the users and key beneficiaries and stakeholders -There are mechanisms to monitor water quality and quantity -There are mechanisms to prevent potential risks and safeguard the public interest and common environmental resources -There is a wide experience with alternative water sources and positive acceptance of people to reuse water
Barriers	-Negative social acceptance for indirect water reuse -Strict regulations -Increase in governance complexity due to new stakeholders, authorities and spill authorization as well as reutilization concession. -Requirement of new permits	-Lack of mechanisms to inform stakeholders about benefits and costs and to prevent risks -Negative social acceptance for indirect water reuse -Necessity of new infrastructure -Necessity of adaptation in the current institutional arrangements and governance mechanisms for implementation of new small and mobile systems -Establishment of very stringent national regulations	Water reuse and WCE are not included in major policies and regulations	-Lack of mechanisms to inform stakeholders about benefits and to deal with conflicts -The mechanisms of actor replacement are not clear -Strict regulations -Requirement of new permits

Fig. 3 | Major drivers and barriers for institutional arrangements and implementation of new water loops in the case studies.

Based on the findings, although Almendralejo and Lecce operate in robust river management governance contexts, well aligned with EU water regulations, the resulting new water uses and users challenge mechanisms for clear monitoring, risk prevention, conflict resolution, dedication sanctions, and collaboration schemes. Cooperation on water use and monitoring, adaptive management, and regulation should be given to prevent risks. This requires a well-designed water policy framework and regulations regarding the new circumstances in governance (Abderrahman, 2000; Trapp *et al.*, 2017).

Aside from robust regulations for quality, policy design also must address the cooperation between water utilities and municipalities (Marome & Pholcharoen, 2019) and include measures for water monitoring and risks (Alcalde-Sanz & Gawlik, 2017; Marome & Pholcharoen, 2019) and wastewater pricing (Bae *et al.*, 2012). For Almendralejo, it is essential to define responsibilities clearly and foster strong collaboration amongst stakeholders in the implementation and operation of the new water loops. This underlines with evidence-based data obtained with the contributions of Abderrahman (2000), Trapp *et al.* (2017), and Ostrom (2005). In this case, social acceptance, trust-building, and transparency are crucial in governance contexts regarding the new circumstances (Trapp *et al.*, 2017).

Besides, Omis raises fewer concerns regarding the institutional arrangements in place, given their private and closed nature. Nevertheless, it is essential to point out that this is related to the existence of mechanisms and regulations and the company's capacity to respond and adapt to institutional principles. In Omis, the good perception and recognition of beneficiaries and responsible parties (Bixio *et al.*, 2006), along with regulations and risk prevention mechanisms (Alcalde-Sanz & Gawlik, 2017), are factors that reduce the challenges of technology implementation. The main barrier to be overcome is the inclusion of WCE and water reuse in the country's main policies and laws (Brown & Farrelly, 2009), which would allow the expansion of the development of water reuse techniques to supply public consumers.

Finally, in Eilat, the levels of trust are also relevant, where despite the weaknesses of the institutional arrangements, the tradition of water reuse and its effectiveness make the trust levels comparatively higher. Deficiencies in the transparency of the monitoring process to guarantee well performance (Saldías *et al.*, 2016), the dissemination of information about water uses, water ownership, water pricing, and incentives (Abderrahman, 2000) are also considered relevant.

6. CONCLUSIONS

WCE adoptions create new circumstances and challenges in water governance by intervening in water loops, despite its benefits for water resource management, including reducing pressure on water resources and eliminating pollution. Remember that adding water loops with various purposes or qualities presents several new issues for water recycling schemes, particularly those involving institutional arrangements for adoption, operation, management, and monitoring. The findings revealed that the success of a water reuse technology depends on robust institutional arrangements. In addition, the more diverse the water uses and users, the more challenges and risks, particularly those associated with institutional arrangements such as quality standards, sanctions, and conflict prevention, are likely to emerge. However, most case studies, especially Almendralejo and Eilat, are not ready to adopt new loops due to the inflexibility and the inadequacy of the governance model and the regulations.

Nonetheless, the transition can be supported by robust institutional arrangements considering well-designed water policy frameworks and regulations, cooperative governance, the acknowledgement of risks and a fair distribution of benefits, costs and risks, and the adoption of a technical–social approach. Concerning the variety of new water uses in the case studies and apart from the type of technology adopted, solutions could be implemented to ensure internal and external water quality monitoring and control, integration of water management with spatial concerns, improve training and raise civil society awareness, expert engagement, and reduction of water reuse costs. In addition, alternative models that guarantee the efficiency of governance in attaining objectives and assuring the participation of the various sections of the water loops may also be considered.

The methodology used in this study, which took advantage of the modified IAD framework in combination with the selected regulatory features, contributed to a better understanding of the robustness of institutional arrangements as well as the identification of institutional drivers and barriers to the adoption of new water loops. The analytical framework of this study produced solid results, which indicates that it may be suitable and adapted for future research in other contexts. Further study on institutional risks and robust institutional arrangements for water reuse would be relevant to comprehend the new challenges, risks, responsibilities, and compliance with norms and regulations.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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