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ORIGINAL PAPER

Barriers and drivers to the development of an effective water reuse chain: insights from an Italian water utility

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Abstract
Widespread adoption of water reuse technologies is critical to the development of a circular economy and to reduce the pressure on increasingly scarce freshwater resources. However, the adoption of water reuse technologies involves a complex and multi-level decision-making process, influenced by different factors that hinder or support such adoption, namely barriers and drivers. The present research provides a first identification of such factors from a value chain perspective. To do so, the paper first conceptualises the water reuse value chain, including the actors and stages required to bring collected wastewater to the reuse destination. It then conducts an exploratory case study in the context of an Italian water utility facing increasing water stress. External barriers such as societal perceptions and lack of demand for recycled water emerge as particularly influential in hindering the adoption of water reuse technologies. Drivers emerge from both the external and internal environment, with the level of water scarcity and the effectiveness of collaboration and coordination between different institutional and policy actors being particularly strong. Barriers and drivers are found to be of varying relevance depending on the characteristics of the facilities and the reuse value chain analysed, including the operational status of the reclamation facility, the type of final reuse, and the roles in the value chains. The paper provides relevant implications for academics, policymakers, and adopters of water reuse technologies for a more circular and environmentally sustainable water sector, offering useful insights for decision-makers in related sectors.

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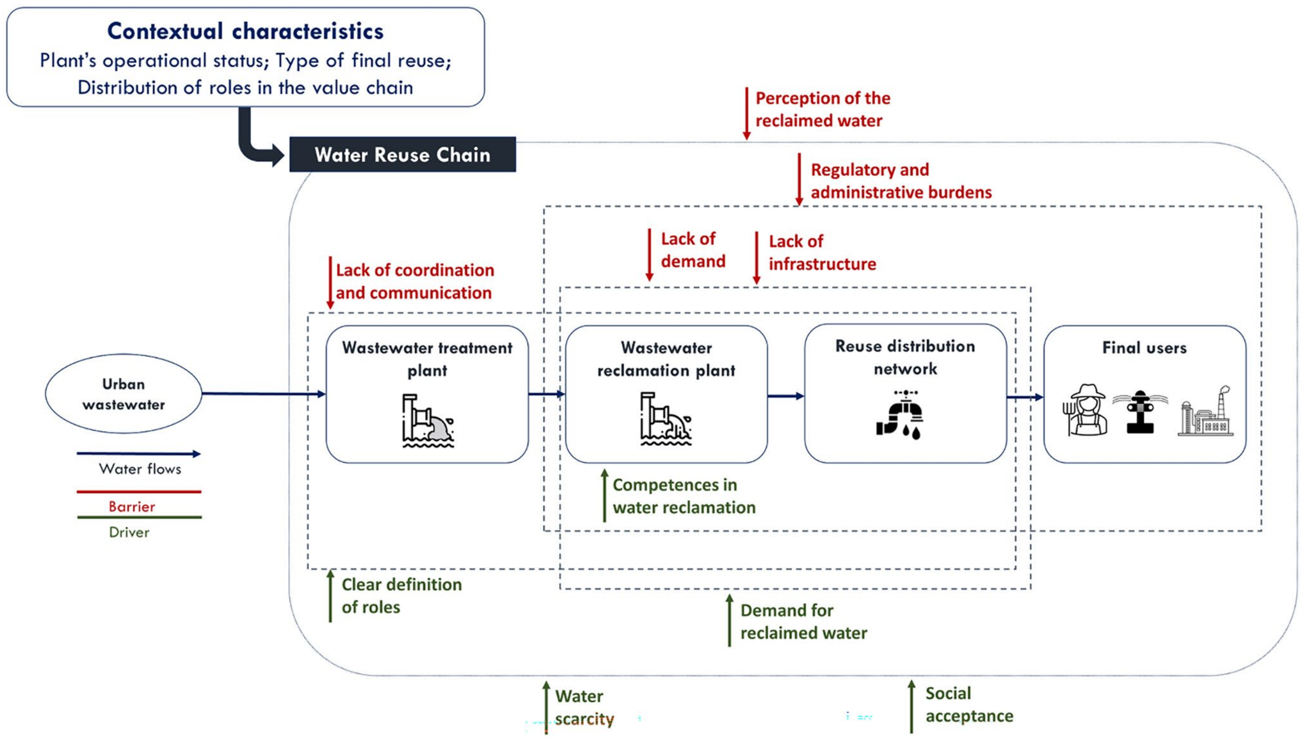
Graphical abstract



Keywords Water reuse · Circular economy · Technology · Barriers · Drivers · Utility

Introduction

Water is a scarce resource, and various current social, economic, and environmental trends and factors—such as population growth, higher living standards, urbanisation, resource-intensive production and consumption, and climate change, are likely to increase the pressure on water resources (Livia et al. 2020). Global risk perceptions over the next decade are centred around natural resource crises, including increasingly frequent water shortages (Fiksel et al. 2021). Currently, severe water scarcity affects around 4 billion people for at least 1 month of the year, with half a billion people facing severe water scarcity all year round, and this trend is worrisome (Mekonnen and Hoekstra 2016). Wastewater reuse is a key lever to mitigate water scarcity (Naghsh Javaheri et al. 2020). Although coherent with the policy goals set by the United Nations through the 2030 Agenda and Sustainable Development Goals (United Nations 2015) and the European Union (European Commission 2020), the adoption of water reuse technologies (Trianni et al. 2021) and the deployment of efficient water reuse chains are neither widespread nor standardised in their organisation (Cagno et al. 2022). Currently, only 11% of the wastewater produced globally is reused (Jones et al. 2021).

Water reuse technologies are recognised as energy and environmentally friendly (Kacprzak and Kupich 2023), yet adopters of these technologies face complex multi-level decision-making processes influenced by several barriers (Jesus et al. 2023) and drivers (Aziz and Chowdhury 2023). Barriers (Trianni et al. 2017) and drivers (Neri et al. 2018) hinder and facilitate, respectively, the decision-making process towards the adoption of water reuse technologies and the deployment of an effective water reuse chain. Therefore, a proper understanding of these factors is fundamental, but the current literature does not provide a comprehensive analysis of the barriers and drivers faced by water utilities in the adoption of water reuse technologies and the deployment of an effective water reuse chain. Furthermore, the literature on environmentally friendly innovation has highlighted the role of the characteristics of the context under study in influencing the relevance of barriers and drivers (Neri et al. 2021) for the adoption of sustainable innovations (Aflaki et al. 2021). However, the current literature on water reuse technologies has neglected the role of contextual characteristics in facilitating or hindering their adoption.

The present study aims to investigate the barriers that hinder and the drivers that support the adoption and scaling up of water reuse technologies, to promote the implementation of an effective water reuse chain. Furthermore, the study aims to investigate how the characteristics of the water reuse chain might influence the importance of barriers and drivers for the adoption of water reuse technologies. Specifically, the study aims to answer the following research questions:

Research question 1: What barriers and drivers influence the adoption of water reuse technologies and the development of an effective water reuse chain?

Research question 2: How do the characteristics and organisation of the reuse value chain influence the barriers and drivers?

To answer the research questions, a case study is conducted in southern Italy, a region historically and increasingly concerned by water stress, interviewing stakeholders along the water reuse value chain related to a water utility and its reclamation facilities. The study takes the central perspective of the water utility, an actor relatively understudied in the literature, and integrates it with other perspectives along the chain. Water utilities play a key role in the take-off of water reuse projects, since in many contexts (including the one studied), water utilities are the actors that carry out the activities of wastewater collection and treatment (Cagno et al. 2022). The study, therefore, provides a first analysis of the barriers and drivers that influence the decision-making of the actors involved in the adoption of water reuse technologies and in the deployment of an effective water reuse chain.

The remainder of the paper is as follows. After a literature review to identify the main gaps in the current understanding of barriers and drivers (literature review section), details of the methods used for the empirical research are reported (methods section). The results of the empirical research are reported and discussed (results and discussion section). Finally, conclusions are offered, together with a discussion of the contributions and limitations of the study, paving the way for future research (conclusions section).

Literature review

Water reuse is a rapidly growing field of research with significant debate surrounding its barriers and drivers. A key area of study focuses on the analysis of existing policies and legislation around water reuse, with examples ranging from European regulations (Cipolletta et al. 2021) to those in the US (Ryberg and Chanat 2022). Additionally, research explores the design of policy interventions for the uptake of water recycling technologies in various contexts. This includes studies in Australia and Asia (Bichai et al. 2018), Europe (Cagno et al. 2022), and specific countries such as California (Rupiper and Loge 2019) and Jordan (Carr and Potter 2013). Furthermore, research delves into action plans for expanding the water reuse market, including plans for wider market penetration and improved access to safe drinking water. A crucial element in these plans is the stakeholders' acceptance (Massoud et al. 2019), with studies focusing on both local communities (Mankad and Tapsuwan 2011) and investors (McCallum and Viviers 2020).

In terms of the processes addressed (Smol et al. 2020), most of the literature focuses on water reuse but without specifying the end use, the typology of the system, or the context of the study. However, few contributions provide a deeper level of detail, with both a general focus (Lee and Jepson 2020) and a specific focus on rural areas (Cipolletta et al. 2021) or urban areas (Hemati et al. 2016). Other studies focus on industrial reuse, with insights for industrial symbiosis, in the context of Australia (Giurco et al. 2011) and Spain (Prieto et al. 2016), while others focus on agriculture (Mohr et al. 2020). Another stream focuses on wastewater reuse, particularly in terms of access to safe drinking water (Ravindra et al. 2020) and community acceptance (Massoud et al. 2018).

To deepen the understanding of the barriers and drivers identified in the existing literature, an overview can be provided using the PESTLE framework, largely adopted by the literature on the subject, such as Lee and Jepson (2020) or Fernandes and Cunha Marques (2023). The framework allows the study of political, economic, sociological, technological, legal, and environmental factors. Tables 1 and 2 report, respectively, the main barriers and drivers to water reuse identified in the literature. Among the six categories of barriers, social and economic barriers emerged as the most studied to characterise the obstacles to water reclamation and the deployment of water reuse systems. In terms of drivers, economic factors, particularly economic support, emerged as the most important ones.

Although the existing literature has examined several factors that inhibit and facilitate water reuse, four main gaps emerge. Firstly, most studies focus on a single or limited number of categories of barriers (Santos et al. 2023) or drivers (Poškus et al. 2021). For example, Daniel et al. (2018), Massoud et al. (2018), and Ryberg and Chanat (2022) focus only on social and environmental aspects, dealing with developing countries, Lebanon, and the US, respectively, while Cipolletta et al. (2021) focus only on aspects related to policy and regulation. Furthermore, barriers have been investigated more than drivers, with studies focusing on barriers to wastewater treatment in China (Lu et al. 2019), to innovative small-scale wastewater systems (Cipolletta et al. 2021), or to the acceptance of recycled water (Nemeroff et al. 2020). The limited investigation of drivers may represent a limitation for a comprehensive understanding of the factors that favour the deployment of an effective water reuse chain.

Table 1 Overview of the main barriers addressed in the extant literature

Category	Specific barrier	Main reference(s)
Political	Lack of ad-hoc laws and guidelines	Bichai et al. (2018), Ventura et al. (2019), Lee and Jepson (2020), Cipolletta et al. (2021), Poškus et al. (2021), Santos et al. (2023), Fernandes and Cunha Marques (2023)
	Low trust in government	Mankad and Tapsuwan (2011), Carr and Potter (2013), Alam et al. (2020, Gul et al. 2021)
Environmental	No water scarcity and stress	Hemati et al. 2016, Lee and Jepson (2020)
	Lack of concerns about environmental degradation	Gul et al. (2021), Santos et al. (2023)
Social	Perception of risks to public health	Mankad and Tapsuwan (2011), Carr and Potter (2013), Massoud et al. (2018), (2019), Alam et al. (2020), Nemeroff et al. (2020), Lee and Jepson (2020), Gul et al. (2021), Santos et al. (2023)
	"Yuck" factor	Massoud et al. (2010, Giurco et al. (2011), Carr and Potter (2013), Liddle et al. (2014), Kunz et al. (2016), Stathatou et al. (2017), Daniel et al. (2018), Rupiper and Loge (2019), Liu et al. (2021), Santos et al. (2023)
Technological	Insufficient wastewater collection and treatment facilities	Bichai et al. (2018), Lu et al. (2019), Lee and Jepson (2020), Liu et al. (2021)
	Location of infrastructure	Ventura et al. (2019), Lee and Jepson (2020)
	Lack of infrastructure	Bichai et al. (2018), Lee and Jepson (2020), Liu et al. (2021)
	Low performance of technologies	van Rensburg (2016), Massoud et al. (2019), Gul et al. (2021)
	Input water quality	(Mankad and Tapsuwan (2011), Giurco et al. (2011), Carr and Potter (2013), Kunz et al. (2016), van Rensburg (2016)
	Limited technical resources	Carr and Potter (2013), Stathatou et al. 2017, Massoud et al. (2019), McCallum and Viviers (2020), Alam et al. (2020), Lee and Jepson (2020), Cipolletta et al. (2021), Hacker and Binz (2021), Liu et al. (2021)
Legal/institutional	Lack of proper regulations	Rupiper and Loge (2019), Lee and Jepson (2020), Gul et al. (2021), Cipolletta et al. (2021), Hacker and Binz (2021)
	Low institutional support	van Rensburg (2016), McCallum and Viviers (2020), Mesa-Pérez and Berbel (2020), Lee and Jepson (2020), Cipolletta et al. (2021), Hacker and Binz (2021), Poškus et al. (2021)
	Insufficient coordination and communication among institutions	Massoud et al. (2019), Rupiper and Loge (2019), Mesa-Pérez and Berbel (2020), Lee and Jepson (2020), Liu et al. (2021), Breitenmoser et al. (2022)
	Lack of stakeholders' involvement	Massoud et al. (2019), Rupiper and Loge (2019), Lee and Jepson (2020), Liu et al. (2021)
Economic	Initial investment	Maxwell (2005), Mankad and Tapsuwan (2011), Giurco et al. (2011), Prieto et al. (2016), Hemati et al. (2016), Rupiper and Loge (2019), Ravindra et al. (2020), Lee and Jepson (2020), Cipolletta et al. (2021), Hacker and Binz (2021), Poškus et al. (2021), Santos et al. (2023)
	Operating cost	Ventura et al. (2019), Mesa-Pérez and Berbel (2020), Gul et al. (2021)
	Pay-back time	Prieto et al. (2016), Hemati et al. (2016), McCallum and Viviers (2020), Liu et al. (2021)
	Limited market	Mankad and Tapsuwan (2011, Lee and Jepson (2020)

Secondly, the existing literature has limitations in terms of the actors considered in the analysis of barriers and drivers, which does not allow for a complete overview of the interactions between actors (Morris et al. 2021). The majority of the literature focuses only on the perspective of the final end users, such as households (Ravindra et al. 2020), household members (Massoud et al. 2018), or citizens (Nemeroff et al. 2020), without considering the actors involved in the previous stages of the value chain. A few contributions, such as Ryberg and Chanat (2022) and Cipolletta et al. (2021), focus more on the institutional side, looking, respectively, at the role of government agencies and non-profit organisations and the role of the current regulatory environment for small-scale decentralised technologies with applications in

Table 2 Overview of the main drivers addressed in the extant literature

Category	Specific driver	Main reference(s)
Political	Presence of relevant policies or guidelines	Maxwell (2005), Mesa-Pérez and Berbel (2020), Lee and Jepson (2020), Breitenmoser et al. (2022)
	Tax incentives and special water tariffs	Giurco et al. (2011), Ravindra et al. (2020), Lee and Jepson (2020), Gul et al. (2021), Fernandes and Cunha Marques (2023)
Environmental	Mitigation of water scarcity	Janosova et al. (2006), Giurco et al. (2011), Carr and Potter (2013), Kunz et al. (2016), Prieto et al. (2016), van Rensburg (2016), Hemati et al. (2016), Bichai et al. (2018), Jiang et al. (2018), Massoud et al. (2019), Mesa-Pérez and Berbel (2020), Ravindra et al. (2020), Lee and Jepson (2020), Mohr et al. (2020), Cipolletta et al. (2021), Breitenmoser et al. (2022), Fernandes and Cunha Marques (2023)
	Rising demand for water	Maxwell (2005), Liddle et al. (2014), Bichai et al. (2018), Lee and Jepson (2020), Mohr et al. (2020), Cipolletta et al. (2021)
	Environmental benefits	Liddle et al. (2014), Lee and Jepson (2020), Breitenmoser et al. (2022)
Social	Public perception	Kunz et al. (2016), Hemati et al. (2016), Lee and Jepson (2020)
	Public education campaigns	Mankad and Tapsuwan (2011), Carr and Potter (2013), Daniel et al. (2018), Massoud et al. (2019), Mesa-Pérez and Berbel (2020), Alam et al. (2020), Lee and Jepson (2020), Gul et al. (2021)
	Information sharing	Giurco et al. (2011), Carr and Potter (2013), Mesa-Pérez and Berbel (2020), Lee and Jepson (2020), Gul et al. (2021)
	Environmental awareness	Maxwell (2005), Mankad and Tapsuwan (2011), Liddle et al. (2014), Massoud et al. (2019), Lee and Jepson (2020)
Technological	Innovative and efficient wastewater treatment technologies	Mesa-Pérez and Berbel (2020), Alam et al. (2020), Lee and Jepson (2020), Gul et al. (2021), Fernandes and Cunha Marques (2023)
	Presence of infrastructure	Bichai et al. (2018)
Legal/institutional	Presence of regulations	Bichai et al. (2018), Breitenmoser et al. (2022), Fernandes and Cunha Marques (2023)
	Presence of water quality standards	Bichai et al. (2018), Alam et al. (2020), Mohr et al. (2020)
	Coordination and communication among institutions	Mesa-Pérez and Berbel (2020), Lee and Jepson (2020), Mohr et al. (2020), Santos et al. (2023), Fernandes and Cunha Marques (2023)
	Institutional support	Lee and Jepson (2020); Mohr et al.(2020); Fernandes and Cunha Marques (2023)
Economic	Financing instruments	Bichai et al. (2018), Mesa-Pérez and Berbel (2020), Ravindra et al. (2020), Lee and Jepson (2020), Cipolletta et al. (2021), Breitenmoser et al. (2022), Fernandes and Cunha Marques (2023)
	Market for reclaimed water	Janosova et al. (2006), Mankad and Tapsuwan (2011), Carr and Potter (2013), Hemati et al. (2016), Mesa-Pérez and Berbel (2020), Mohr et al. (2020)

rural areas. Some studies consider the perspective of water utilities, but only a few of them focus on the perspective of the utility as an adopter of technologies (Lu et al. 2019), and specifically of water reclamation technologies (Giurco et al. 2011). Overall, the consideration of the perspective of other technology adopters, such as industrial adopters (Prieto et al. 2016), is also limited.

Thirdly, the current literature does not consider the influence on barriers and drivers of different contextual factors that may characterise the water reuse chain, such as the different end uses of the reclaimed water. For example, Morris et al. (2021) and Mesa-Pérez and Berbel (2020) provide, respectively, through a review and a large-scale survey, interesting assessments of barriers and drivers, but limit their investigation to agricultural reuse.

Fourthly, the European context seems to be less studied than other contexts such as the US (Ryberg and Chanat 2022), China (Liu et al. 2021), or India (Breitenmoser et al.

2022). This focus makes sense, as the European context is less water-stressed than the mentioned countries, but some southern European countries, such as Spain, Greece, or Italy, could be an interesting context of investigation for water reuse, as shown by previous contributions (Cagno et al. 2022).

Overall, despite the interesting insights and results provided by the extant literature, there is still a need to investigate the barriers and drivers to the deployment of an effective water reuse chain, taking into account the perspective of both the users of water reuse technologies and other relevant actors in the water reuse chain.

Methods

To address the research questions and given the lack of prior research on the topic, the study adopts an exploratory embedded case study approach (Streb 2013). An abductive logic, appropriate for the study of topics with limited previous research, is used to generate theory based on the analysis of the case study (Dubois and Gadde 2002), through a continuous interaction and confrontation between real-life observations and existing theories (Kovács and Spens 2005). To fill the above-mentioned gaps, the present study conducts a preliminary exploratory analysis of the barriers and drivers that influence the process of water reuse technology adoption by water utilities and the deployment of an effective water reuse chain. In doing so, the study focuses on the interaction with other stakeholders, involving them in the investigation of barriers and drivers. Insights are provided according to different typologies of water reuse and different characteristics of reuse facilities. The main steps of the present research are detailed in the following subsections.

Sample selection

The focus of this research is a region in southern Italy, where we investigate the local water utility (LWU). The region experiences Mediterranean weather, with hot, dry summers and moderately wet winters, with more rainfall in the autumn. Average temperatures range from 15 to 40 °C during the hottest days. As a result, groundwater is replenished only in autumn and winter. However, even during periods of heavy rainfall, only a portion of the groundwater is replenished, while a significant amount of water flows over the surface. Consequently, the region is frequently at risk of drought and water shortages. It is predicted that water scarcity will increase in the coming decades, with negative social, economic, and environmental impacts. The potential impact could worsen due to the rising frequency and duration of heat waves and other extreme conditions related to water availability. The reuse of water could be a valuable resource for the region, serving purposes such as agriculture, civil use (e.g. irrigation of public green areas), or industrial use (e.g. cooling of plants). Furthermore, if the reclaimed water is used in agriculture, it could reduce the extraction of groundwater, thereby decreasing the salinisation of areas near the sea and preventing desertification (Livia et al. 2020). The case is thus noteworthy for its relevance to the implementation of water reuse technologies and the establishment of a water reuse chain. The LWU manages various reclamation plants in the area, which are our units of analysis. Although all the plants are part of the LWU, each one has unique features. The LWU conducts wastewater treatment operations as part of its regular urban water cycle activities and provides the treated water for reclamation operations. The reclamation plant, with few exceptions, is managed by the LWU and is typically located near the wastewater treatment plant. Costs associated with reclamation operations are cross-subsidised, meaning that they are charged to urban water users through the urban water tariff. The reclaimed water is supplied free of charge by the LWU to the operator of the distribution network, typically a municipality or an irrigation consortium. The operator of the distribution network is responsible for distributing the water to the final users and may receive payment to cover related costs. In rare cases, such as with industrial users, the LWU may directly deliver the reclaimed water to the final user. Figure 1 reports the typical structure of the water reuse supply chain in the investigated context.

This study investigates eight reclamation plants, gathering perspectives from various actors in the value chain and using a heterogeneous sample to examine plant characteristics related to operating status, water final use, governance, responsibility for the distribution of reclaimed water, and reclamation capacity. Table 3 provides details of the sample.

Data collection

The primary source of data is semi-structured interviews, conducted from January to June 2022. Table 4 shows the details.

The interview protocol (Supplementary Information A, Table SA1) was designed to be flexible, allowing for the collection of free comments and the emergence of additional questions during the conversation (Dicicco-Bloom and Crabtree 2006), as a fundamental feature of abductive research (Timmermans and Tavory 2012). Before the interviews, publicly available documents about LWU and the specific reclamation plant (e.g. websites, reports, and news) were retrieved. Interviewees were initially asked to introduce themselves. Subsequently, each interview was conducted in a specific order to obtain information on (i) the reclamation plant and its processes; (ii) the final purpose(s) of the reclaimed water; (iii) the criteria used

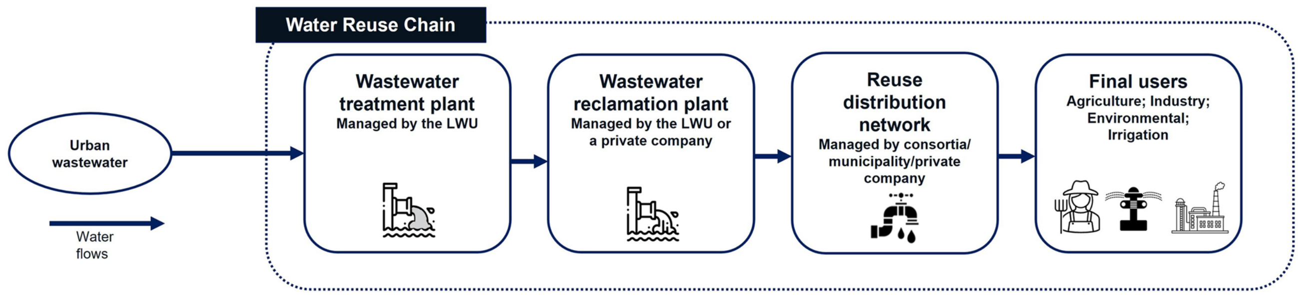


Fig. 1 Water reuse supply chain

to make decisions regarding investments and operational aspects; (iv) the barriers and drivers for the adoption of water reuse technologies and the implementation of an effective water reuse chain; (v) policy instruments that influence the adoption of water reuse technologies and the implementation of an effective water reuse chain; and (vi) interactions with stakeholders that influence the adoption of water reuse technologies and the implementation of an effective water reuse chain. The interviews were conducted remotely and recorded with the participants' consent. The researchers took notes during the interviews. Methodological rigour was ensured by assessing the design tests for construct validity, internal validity, and reliability (Yin 2009) as described in Table 5.

Data analysis

The interviews were transcribed and manually coded together with field notes and secondary documents collected (Supplementary Information A, Table SA1). As mentioned above, the abductive research approach requires a continuous and cyclical interaction between the empirical data and the existing knowledge derived from the current literature (Eisenhardt and Graebner 2007). For the first-order coding, we used open coding, with themes emerging inductively from the data and allowing the identification of the main aspects in the general content; for the second-order coding, axial coding was used to combine related codes and identify relevant categories—see also (Neri et al. 2023). The inductive coding was compared with a coding system developed based on the existing literature, trying to find a reconciliation with the concepts of the literature, based on Greenland et al. (2019) for barriers, Stathatou et al. (2017) for drivers, and Lee and Jepson (2020) for both. The coding for the main theoretical dimensions investigated, namely barriers and drivers, is presented in Supplementary Information B, Fig. SB1 and Fig. SB2.

Results and discussion

The present section reports and discusses the results of the analysis. The analysis considers a full value chain perspective, focusing not only on the utility, but also on its relationships with upstream (water distribution and wastewater treatment) and downstream (reclaimed water distribution and end use) actors. The results are presented and discussed in terms of barriers and then drivers, using illustrative quotes to facilitate understanding of key concepts, and finally considering the influence of contextual factors.

Barriers to water reuse: a value chain perspective

The investigation allowed for the identification of nine categories of barriers (Table 6). The PESTLE categorisation, largely adopted in the current literature (Lee and Jepson 2020), proved to be applicable, but it was necessary to extend the set of categories included. In addition, the barriers were divided into external and internal ones, originating, respectively, outside and inside the LWU. This division is crucial to assign an origin to the barriers (Trianni et al. 2017) and to understand the actors responsible for the presence of each specific barrier (Cagno et al. 2018). Indeed, it is interesting to note that, in the analysis carried out, internal barriers seem to be less numerous than external ones, implying that most of the barriers to the implementation of an effective water reuse chain come from outside the water utilities.

In terms of internal barriers, the categories identified are *economic*, *technology*, and *competences*. As for the *economic* category, some reclamation plants highlighted the importance of maintenance costs. This finding is in line with Gul et al. (2021), who stated that the price of reclaimed water should be set at a level that allows sustainable operation and maintenance of the system, and Cipolletta et al. (2021), who considered adequate

Table 3 Details of the sample investigated according to the following main characteristics: operating status; water final use; actor responsible for the management of the reclamation plant (i.e. governance); actor responsible for the management of distribution (i.e. distribution); capacity of the reclamation plant; context information. Legend. LWU: local water utility, RP: reclamation plant

RP	Operating status	Water final use	Governance	Distribution	Capacity	Context information (at the time of the investigation)
RP1	Operative	Agriculture	LWU	Local irrigation consortium	$< 10{,}000\ m^3$/day	RP1 was built in 2006 and was previously managed by the local irrigation consortium. The reclaimed water is used to irrigate an area of about 500 hectares, mainly orchards, olive groves, vineyards, and artichokes. When not used for irrigation, the water is discharged into the sea. The province where RP1 is located is home to about 10% of the region's population. The area has experienced an increase in water demand, partly due to an increase in the area under irrigation. The risk class for the groundwater bodies is high.
RP2	Not operative	Agriculture	LWU	Local irrigation consortium	$< 10{,}000\ m^3$/day	RP2 is currently inactive, but ready for operation. The reclaimed water will be used to irrigate an area of approximately 5,000 hectares, mainly tomatoes and herbaceous crops. The province where RP2 is located is home to approximately 15% of the region's population. The area has experienced an increase in water demand, partly due to an increase in the area under irrigation. The risk class for the groundwater bodies is high.

Table 3 (continued)

RP	Operating status	Water final use	Governance	Distribution	Capacity	Context information (at the time of the investigation)
RP3	Operative	Agriculture	LWU	Municipality	< 10,000 m^3/day	RP3 was built around 2000, but only became operational in 2008 after the municipality transferred its management to LWU. Since 2011, the reclaimed water has been used to irrigate an area of about 150 hectares, mainly olive groves, and pastures. Distribution for irrigation started in 2011. When not used for irrigation, the water is discharged into the sea. The province where RP3 is located is home to about 10% of the region's population. The area has experienced an increase in water demand, partly due to an increase in the area under irrigation. The risk class for the groundwater bodies is high.
RP4	Operative	Agriculture and environment	Private company	Private company	< 10,000 m^3/day	RP4 was built in 2001 and upgraded in 2016. Due to the specific characteristics of the plant, it is not possible to separate the management of the plant from the management of the distribution activities. There is currently no discharge to sea. The use named *environment* is related to the maintenance of green areas and ornamental and experimental crops. The reservoirs are equipped with overflow inlets for spreading the soil and recharging the water table to prevent saline intrusion. The province where RP4 is located is home to about 10% of the region's population. The area has experienced an increase in water demand, partly due to an increase in the area under irrigation. The risk class for the groundwater bodies is high.

Table 3 (continued)

RP	Operating status	Water final use	Governance	Distribution	Capacity	Context information (at the time of the investigation)
RP5	Not operative	Industry	LWU	/	< 10,000 m^3/day	RP5 was built in the 1990s for industrial reuse to serve a particular company. For various reasons, the company decided not to use the water from the reclamation plant and is currently using water from rivers, leading to public demonstrations against the company. The province where RP5 is located is home to about 15% of the region's population. The area has experienced an increase in water demand, partly due to an increase in the area under irrigation. The risk class for the groundwater bodies is high.
RP6	Not operative	Agriculture and industry	LWU	/	> 10,000 m^3/day	RP6 was built in the 1990s for industrial reuse to serve a particular company. For various reasons, the company decided not to use the water from the reclamation plant and is currently using water from rivers, leading to public demonstrations against the company. However, the plant was also built for agricultural reuse and was to cover an area of more than 2,000 hectares. The province where RP6 is located is home to about 15% of the region's population. The area has experienced an increase in water demand, partly due to an increase in the area under irrigation. The risk class for the groundwater bodies is high.
RP7	Operative	Agriculture	LWU	Municipality	> 10,000 m^3/day	RP7 serves an area of 145 hectares. When not used for irrigation, the water is discharged into the sea. The province where RP7 is located is home to about 20% of the region's population. The area has experienced an increase in water demand. The risk class for the groundwater bodies is medium–high.

Table 3 (continued)

RP	Operating status	Water final use	Governance	Distribution	Capacity	Context information (at the time of the investigation)
RP8	Operative	Agriculture and irrigation	LWU	Local irrigation consortium	> 10,000 m^3/day	RP8 was constructed and started to operate between 2008 and 2010. Only a limited part of the capacity is used. Part of the reclaimed water is used to irrigate an area of about 1000 hectares, mainly olive groves, citrus, orchards, potatoes, and watermelons. Part of the reclaimed water is sent to a buffer zone. When not used, the water is discharged into the sea. The province where RP8 is located is home to about 20% of the region's population. The area has experienced an increase in water demand. The risk class for the groundwater bodies is low–medium.

Table 4 Details of the performed semi-structured interviews: interviewee(s); duration; modality; and number of interviewers. Legend. LWU: local water utility and RP: reclamation plant

RP	Interviewee(s)	Duration	Modality	Number of interviewers
LWU	Manager LWU	1 h	Zoom	4
	Manager treatment activities—LWU			
LWU	Manager LWU	30 min	Zoom	5
	Manager treatment activities—LWU			
RP 1	Manager treatment activities area 1–LWU	1 h and 30 min	Zoom	3
	Manager local irrigation consortium			
RP 2	Manager treatment activities area 1—LWU	1 h	Zoom	3
	Manager local irrigation consortium			
RP 3	Manager treatment activities area 2–LWU	15 min	Telephone	1
	Manager water distribution of the municipality			
RP 4	Manager 1 RP–private company	1 h	Zoom	3
	Manager 2 RP–private company			
	Manager assistant 1 RP–private company			
	Manager public works of the municipality			
RP 5	Manager treatment activities area 3—LWU	1 h and 30 min	Zoom	3
RP 6	Manager treatment activities area 3—LWU	45 min	Zoom	3
RP 7	Manager treatment activities area 4—LWU	20 min	Zoom	4
RP 8	Manager treatment activities area 4—LWU	20 min	Telephone	3

maintenance as a critical factor for the implementation of decentralised water reuse solutions. Overall, however, economic barriers are not considered to be strong inhibitors. Nevertheless, new compared to previous findings, barriers due to a lack of economies of scale of the system did emerge, albeit to a limited extent. This barrier is perceived as a missed opportunity compared to the cost implications of economies of scale:

Table 5 Tactics used to assess the design tests of the single embedded case study

Test	Tactics	Implementation	Supporting reference
Construct validity	Triangulation	We triangulated information from primary and secondary data. The analysis of the information was carried out independently by three different researchers, and a common agreement was reached.	Baškarada (2014)
	Creation of a chain of evidence	We created a common database and organised the material in a structured way. The data structure for the analysis (coding) was carried out step by step on an Excel spreadsheet; all steps were properly saved and kept accessible for future reference and modification.	Benbasat et al. (1987)
Internal validity	Multiple sources of evidence	Primary data were collected through semi-structured interviews with various respondents; secondary data were collected from various sources (see Supplementary Information A).	Voss et al. (2002)
	Member check	The interpretations and results were checked by representatives of the wastewater utility.	Creswell (1994)
External validity	Definition of population	We emphasised the relevance of the selected case study and considered embedded cases with different characteristics (see Table 3). We extensively discussed the limitations of our study (see Conclusions section).	Meredith (1998)
	Multiple sources of evidence	Primary data were collected through semi-structured interviews with various respondents; secondary data were collected from various sources (see Supplementary Information A).	Hays (2004)
Reliability	Multiple sources of evidence	Primary data were collected through semi-structured interviews with various respondents; secondary data were collected from various sources (see Supplementary Information A).	Hays (2004)
	Standardisation of data collection	We developed a case study protocol (see Supplementary Information A).	Voss et al. (2002)
	Multiple investigators	The interviews were conducted by multiple researchers, with a minimum of two researchers per interview (see Table 4)—with the exception of RP3.	Baškarada (2014)
	Recording and transcription	We recorded interviews upon participants' agreement and transcribed them as soon after the interview.	Baškarada (2014)
	Coding system	We developed a coding system to categorise and analyse themes and patterns, ensuring consistency across different data sources.	Saldaña (2009)
	Member check	The interpretations and results were checked by representatives of the wastewater utility.	Creswell (1994)

> "At the moment, we do not see any sizeable effect of economies of scale" (RP1, Manager Treatment Activities Area 1)

As for the *technology* category, the reclamation capacity of the plants emerged as a new relevant factor compared to the previous literature, although it was only identified in cases where the capacity of the plant was chosen based on incorrect predictions of future demographics and demand, as for RP1 and RP8:

> "There is an issue with the oversizing of the plants" (RP1, Manager Treatment Activities Area 1)
> "12,000 cubic metres per day is a huge amount: you need hectares, hectares of land to be able to use it entirely" (RP8, Manager Treatment Activities Area 4)

Problems related to non-compliance with the quality standards of the reclaimed water did not emerge as a key issue. The finding contrasts with the previous literature, which largely considered the barrier to be relevant. For example, Mankad and Tapsuwan (2011) considered problems in meeting quality standards to be related to concerns on water quality and threats to personal well-being; Carr and Potter (2013) emphasised that problems in meeting quality standards pose a challenge to reuse, and they may be related to difficulties in achieving effluent of adequate quality due to inadequate treatment process.

Compared to the PESTLE framework, a new *competences* category of barriers was introduced, in line with the previous research on the barriers to the adoption of wastewater technologies by Italian utilities (Garrone et al. 2018). This is particularly evident in cases where the governance of the activities in the reuse value chain differs

Table 6 Barriers to the adoption of water reuse technologies and to the implementation of an effective water reuse chain

Origin	Category	Barrier	RP1	RP2	RP3	RP4	RP5	RP6	RP7	RP8
Internal	Economic	Lack of economies of scale	•		•					
		Investment costs			•					
		Operating costs	•			•				
		Maintenance costs							•	
	Technology	Oversized treatment capacity	•							•
		Failure to meet quality standards	•			•				•
	Competences	Lack of competences			•					
External	Policy	Regulations standards and obligations		•	•					
		Economic measures			•					
		Water tariff			•					•
		Lack of policy on water resources management					•			•
		Fragmented and contradicting policies								•
	Market	Lack of input	•	•						
		Quality of the input	•			•				
		Lack of demand/users not interested	•	•	•		•	•		•
		Market limitations due to the quality of the reclaimed water				•	•			
	Infrastructure	Lack of infrastructure	•	•	•		•			•
		Location of the infrastructure			•					
		Quality issues related to the infrastructure	•							
	Stakeholders and society	Perceptions of the reclaimed water	•	•		•	•	•		•
		Awareness and knowledge		•			•	•		•
		Lack of cooperation and communication among stakeholders	•	•		•	•	•		•
	Legal and institutional	Regulatory and administrative burdens			•	•	•	•	•	•
	Environment	Relative freshwater abundance						•		•

from the standard one. This is the case for RP3, where distribution is managed by the municipality (whereas it is usually managed by the local irrigation consortium):

> "We found ourselves managing the network, even though we did not have precise institutional expertise" (RP3, Manager Water Distribution of the Municipality)

Focusing on external barriers, the categories identified are *policy*, *market*, *stakeholders and society*, *infrastructure*, *legal and institutional*, and *environment*. The *policy* category emerged as crucial, in particular due to the lack of obligations for end users to use the reclaimed water in case of freshwater scarcity, and the lack of adequate and homogeneous regulations to support and develop the reuse strategy. Policies also appear to be fragmented, and contradictions emerged regarding the limits of elements contained in the water entering the reclamation plant. Overall, the barriers identified are consistent with findings from the previous literature. For example, Bichai et al. (2018) discussed that the fragmented institutions regulating water reuse leave technologies mainly in the early stages of the system, where policy-induced path dependency blocks most selection mechanisms. Similarly, Lee and Jepson (2020) highlighted that policy and regulatory fragmentation limits the coordination needed to launch viable urban water reuse programmes. The fragmentation and contradictions of regulations affect, for instance, the operation of RP8:

> "If there was a law that required water to be reused in some way, it would certainly be a positive thing. The law allows the distribution of water resources to have a higher chloride content, but then the reclamation plant, which is not used to breaking down chlorides, finds itself outside the legal requirements" (RP8, Manager Treatment Activities Area 4)

Compared to the PESTLE framework, a new *market* category was introduced. Within this category, the lack of demand for reclaimed water is the most relevant barrier, and one of the most important barriers in general, drawing on Mankad and Tapsuwan (2011) and Lee and Jepson (2020), who, however, categorised it under the umbrella of economic factors of the PESTLE framework. The lack of demand is highlighted for both agricultural and industrial users, as stated by RP1 and RP8:

> "No one demands water for industrial reuse from this plant […] At the moment there is no need for irrigation" (RP1, Manager Treatment Activities Area 1)
>
> "Many reclamation plants are often not operative precisely because there are no end users" (RP8, Manager Treatment Activities Area 4).

The lack of demand is then closely linked to society's perception of reclaimed water, as a significant proportion of stakeholders still have a negative view of it. *Stakeholders and society*-related barriers were indeed found to be relevant. Some barriers, such as the negative perception of reclaimed water, were already suggested by the existing literature. For example, Massoud et al. (2019), focusing on irrigation and agricultural reuse, highlighted barriers related to quality, social equity, and tariff of reclaimed water; Nemeroff et al. (2020) highlighted the role of heuristic-based thinking in guiding human decision-making under uncertainty, incomplete information, and information overload, leading to systematic deviations from "rationality", which can be detrimental in the case of reclaimed water, as it is associated with its history as sewage or wastewater. These barriers, together with the low level of awareness, emerged strongly from the analysis carried out, as in RP3 and RP8:

> "It is sometimes difficult to unhinge certain ideologies" (RP3, Manager Treatment Activities Area 2)
> "They think they are using water from the sewer" (RP8, Manager Treatment Activities Area 4)

Regarding the newly proposed category related to *infrastructure*, which in the existing literature is considered to belong to technological aspects, significant barriers related to the lack of infrastructure emerged, as in RP5:

> "For environmental reuse, it would be necessary to implement the network" (RP5, Manager Treatment Activities Area 3)

Barriers related to the *legal and institutional* context emerged as relevant when it comes to identifying and activating new users of reclaimed water, especially, new compared to previous literature, when considering the bureaucratic process related to the activation of new users. This has been underlined, for example, by RP6:

> "The acquisition of environmental permits is of a certain importance and complexity, so the procedures are very slow" (RP6, Manager Treatment Activities Area 3)

Interestingly, the lack of institutional support did not emerge as a barrier in the context of this study, despite its relevance in the existing literature. For example, Hacker and Binz (2021) focused their study specifically on the institutional barriers that hinder the adoption of new technologies and system designs.

Environment-related barriers did not appear to be particularly relevant, but they are consistent with those suggested by the previous literature, except for the absence of environmental degradation (Gul et al. 2021).

Drivers to water reuse: a value chain perspective

The investigation carried out allowed the identification of 10 categories of drivers (Table 7). The PESTLE categorisation, largely adopted in the current literature (Lee and Jepson 2020), proved to be applicable, but it was necessary to extend the set of categories included. In addition, the drivers were divided into external and internal ones, originating, respectively, outside and inside the LWU. This division is crucial to assign an origin to the drivers (Trianni et al. 2017) and to understand the actors responsible for the presence of each specific driver (Cagno et al. 2018). Indeed, it is interesting to note that in the analysis carried out, the internal drivers seem to be less numerous and less relevant than the external ones, since most of the supporting factors for the implementation of an effective water reuse chain come from outside the water utilities.

Focusing on internal drivers, the categories identified are *economic*, *technology*, *management*, and *competences*. Regarding the *economic* drivers, new compared to the extant literature, the low operating cost related to the reclamation process is considered a factor supporting the adoption of water reuse technologies. Indeed, the economic impact of the reclamation process is relatively modest compared to, for example, the economic impact of treatment processes, as highlighted by both Molinos-Senante et al. (2014) and Molinos-Senante (2018) who discuss, respectively, operational costs and savings due to energy efficiency. As for the *technology* category, innovation and automation drivers can improve the quality and control of the process, while promoting cost reduction, as also highlighted by Lee and Jepson (2020), or increase the public acceptance of reclaimed water, as also discussed by Gul et al. (2021). The relevance of *technology* drivers was underlined, for example, by RP4:

Table 7 Drivers to the adoption of water reuse technologies and to the implementation of an effective water reuse chain

Origin	Category	Driver	RP1	RP2	RP3	RP4	RP5	RP6	RP7	RP8
Internal	Economic	Economies of scale	•						•	•
		Operating costs						•		•
	Technology	Innovative automated technology				•				
		Reliability of the technology								•
	Management	Vertical integration	•		•				•	•
		Management commitment				•	•			•
	Competences	Competences in water reclamation and supply	•		•	•			•	•
External	Policy	Regulations standards and obligations	•		•	•				•
		Economic support	•		•	•		•		•
		Water tariff			•	•				
	Market	Demand for reclaimed water	•	•	•	•	•	•	•	•
		Possibilities for alternative uses			•	•	•			•
	Infrastructure	Storage infrastructure	•			•	•			
		Distribution network		•			•	•		
	Stakeholders and society	Perceptions of the reclaimed water	•	•	•			•		
		Society's acceptance for environmental reasons	•					•		•
		Society's acceptance for quality reasons	•		•		•	•		
		Society's acceptance for economic reasons					•	•	•	•
		Communication and educational programmes	•		•	•	•	•		•
		Stakeholders' involvement	•			•				
	Legal/institutional	Clear definition of roles	•	•	•		•	•		
		Collaboration and coordination among institutions				•	•	•		•
		Institutional support			•	•	•			•
	Environment	Water scarcity	•	•	•	•	•	•		•
		Climate concerns			•	•				
		Protection of tourist areas	•		•	•			•	•

> "We developed a technology that can metre the correct solid and liquid gaseous products and reagents into the flow" (RP4, Manager 1)
> "The reclamation process is based on fully automated systems: beyond the normal monitoring and control of system operation and functionality, it does not require dedicated personnel" (RP4, Manager Assistant 1)

The new *management* category was proposed to acknowledge the management decisions that influence the adoption of water reuse technologies and the deployment of an effective water reuse chain. Vertical integration of treatment and reuse processes emerged as a new and highly relevant driver. Indeed, vertical integration allows for strict control of the quality of the effluent from the reclamation plant, thus preventing potential opportunistic behaviour from the treatment plant. Thus, vertical integration allows for smooth management of the interactions between the two plants, preventing problems with the quality of the incoming effluent. This concept was emphasised, for example, by RP1 and RP7:

> "The fact that LWU manages the treatment and the reclamation process, that there is the consortium that manages the distribution in an organised way, facilitates the whole process" (RP1, Manager Treatment Activities Area 1)
> "The management of the reclamation plants is facilitated by the verticalisation between treatment and reclamation" (RP7, Manager Treatment Activities Area 4)

Besides, the commitment of the management emerged as of interest, as underlined, for example, by RP8:

> "Within LWU there are movements at the managerial level to encourage this type of use of water resources" (RP8, Manager Treatment Activities Area 4)

Under the newly introduced *competences* category, LWU's considerable expertise in managing water treatment and reclamation processes meant that they had little difficulty in managing different facilities and technologies, as pointed out by RP8:

> "There are no obstacles for us, LWU is in the vanguard" (RP8, Manager Treatment Activities Area 4)

Focusing on external drivers, the categories identified are *policy*, *market*, *infrastructure*, *stakeholders and society*, *legal and institutional*, and *environment*. *Policy*-related drivers often have a positive impact. Standards and regulations are particularly important to guide the operation of reuse facilities and to unlock the potential for increased reuse. This finding is consistent with the previous literature. For example, Gul et al. (2021) considered national guidelines to be relevant for the promotion of integrated expertise and skills, while Giurco et al. (2011) linked pollutant-targeted regulations to opportunities for the development of industrial water reuse.

The newly proposed *market* category plays a crucial role in supporting the adoption of water reuse technologies and the deployment of an effective water reuse chain. In particular, the demand for reclaimed water, considered in the existent literature as belonging to economic aspects, e.g. (Mohr et al. 2020), is perceived as significant by all the reclamation plants. The perceived change in farmers' attitudes and opinions towards wastewater reuse is thus seen as an encouraging signal, as is the identification of alternative uses for reclaimed water, such as street cleaning or urban green watering. RP6 and RP2 emphasised these aspects:

> "Farmers, especially the younger ones, look at us with attention" (RP6, Manager Treatment Activities Area 3)
> "One could imagine watering private gardens in the coastal area, where we have many tourist settlements" (RP2, Manager Local Irrigation Consortium).

Regarding the newly introduced *infrastructure* category, which is considered to belong to technical aspects in the existing literature, e.g. (Bichai et al. 2018), support may arise from the presence of reclaimed water distribution infrastructure, which was not previously addressed in the literature.

Stakeholders and society-related drivers were found to be relevant. The result confirms the previous literature. For instance, Massoud et al. (2019) emphasised that community acceptance plays an important role in the adoption and implementation of alternative water systems, while Daniel et al. (2018) highlighted that the level of community acceptance is based on a mix of different aspects, such as perceived threats, connection to the pipe system, and education level. Communication and education programmes emerged as crucial to create positive attitudes among communities and other stakeholders towards reclaimed water, which is recommended to reduce freshwater consumption. This was also found relevant in the previous literature, such as Massoud et al. (2019) for communication and Mankad and Tapsuwan (2011) for education programmes. The above-mentioned concepts were emphasised by the reclamation plants studied, such as RP5 and RP4:

> "Every summer LWU launches an advertising campaign just like a company, but the aim is of course cultural" (RP5, Manager Treatment Activities Area 3)
> "There have been conferences where we have extended invitations and allowed active participation by the

> users, who have increasingly come to appreciate the positive effects this water has on the land […] dialogue is very important, as is communication" (RP4, Manager 1)

Also new compared to the previous literature is the acceptance of reclaimed water by society for economic reasons. This was expressed, for example, by RP8:

> "The reclaimed water is in practice supplied free of charge to the consortia. The consortia then charge for the use of the irrigation network by the various users" (RP8, Manager Treatment Activities Area 4)

Regarding the *legal and institutional* drivers, collaboration and coordination among institutions is one of the most important facilitators. This driver was already identified in the previous literature. For example, Lee and Jepson (2020) emphasised that coordination at different institutional levels is needed to launch viable urban water reuse programmes, while Mohr et al. (2020) called for the coordinated efforts of the different actors along the water chain towards quality assurance. Collaboration and coordination among institutions also leads to a clear definition of the roles and responsibilities of the different actors involved in the reuse water chain, which is recognised as crucial to speed up the implementation of the reuse strategy and to regularise the different roles and functions, as underlined, for example, by RP4 and RP1:

> "The Region ensures the involvement and coordination of the competent local bodies, consortia and all categories interested in reuse" (RP4, Manager 1)
> "As a model it works well: everyone is responsible for their own [part]" (RP1, Manager Local Irrigation Consortium)

Concerning the *environment* category, the scarcity of water undoubtedly favours the activation of plants and represents an opportunity to reduce the discharge of treated wastewater into the sea, as largely stressed by the investigated reclamation plants:

> "Our territory is in a systematic water emergency condition" (RP1, Manager Local Irrigation Consortium)

> "Things are changing, because the aquifer is becoming salinised" (RP6, Manager Treatment Activities Area 3)

New compared to the previous literature, the protection of tourist areas adjacent to the treatment and reclamation facilities resulted to support the reuse of reclaimed water, avoiding its discharge into the sea, as underlined by RP8:

> "To reduce the amount of water we discharge into the sea, we created an irrigation network around the treatment plant in the entire buffer zone […] The plant is well-accepted by local communities because it avoids discharges into the sea" (RP8, Manager Treatment Activities Area 4)

Characteristics of the reclamation plants and their influence on barriers and drivers

We conducted additional analyses to consider whether and how the characteristics of the reclamation plants presented in Table 3 influence the relevance of barriers and drivers. Given the exploratory nature of these analyses, the small sample size, and the lack of previous similar studies to support the findings, further research is needed.

Operating status

Five reclamation plants of those investigated were operative (RP1, RP3, RP4, RP7, and RP8), and three were not operative (RP2, RP5, and RP6). The plant operating status does not appear to have a significant impact on the relevance of barriers and drivers. However, the lack of demand and infrastructure hinders the deployment of an effective water reuse chain in the case of non-operative plants.

Water final use

The reclamation plants investigated are mainly dedicated to the agricultural (RP1, RP2, RP3, and RP7), agricultural and irrigation (RP8), agricultural and environmental (RP4), agricultural and industrial (RP6), and industrial (RP5) final use. Although no relevant differences in the presence of barriers between agricultural and industrial reuse can be identified, several differences in the relevance of the barriers emerged during the discussion. Industrial reuse seemed to be strongly discouraged by the need for government permits, which are not easy to obtain. This also relates to the need to understand and clearly define the responsibility for the development of a dedicated distribution network from the reclamation plant to the final industrial user, in terms of capital investment and management of the infrastructure. In addition, standards and regulations regarding the microbiological and physical limits of treated water further hindered the spread of industrial use. A consensus emerged on the need to reduce unnecessary regulatory and administrative burdens by giving more support to industrial reuse. From this point of view, a clear definition of roles and cooperation between institutions can promote industrial reuse.

Actor responsible for the management of the reclamation plant

The reclamation plants studied are all managed by the LWUs, except RP4, which is managed by a private company. Overall, RP4 and its associated water reuse chain appear to face fewer barriers, particularly in terms of *policy*-related barriers. Interestingly, differences can be identified in terms of drivers. The private company, which proved to be particularly innovative and efficient, is more autonomous than the LWU in testing and installing new technologies, leading also to a significant reduction in operating costs. Nevertheless, the results obtained suffer from limited generalisability, as only one of the reclamation plants studied is not managed by the LWU.

Actor responsible for the management of distribution

The distribution of reclaimed water can be managed by different entities, such as the local irrigation consortium (RP1, RP2, and RP8), the municipality (RP3 and RP7), or a private company (RP4). There were no differences in terms of barriers and drivers, but the expertise and skills of the consortia appeared to be more appropriate than those of the municipalities, which were often burdened with several projects in addition to the distribution of reclaimed water.

Conclusions

The present study provides a first exploratory analysis of the barriers and drivers influencing the adoption of water reuse technologies and the deployment of an effective water reuse chain, approaching the issue from the perspective of water utilities, but confronting it with insights from other actors involved in the reuse chain. The study proposed new categorisations of both barriers and drivers: keeping the PESTLE as an overarching reference framework, the categories for barriers and drivers were extended, and a distinction between internal and external ones was proposed through the results of our empirical analysis. In addition, the study provides an exploratory understanding of the possible influence of plant characteristics in determining the relevance of barriers and drivers, with interesting differences emerging with respect to the operational status of the plant, the type of final reuse, and the distribution of roles along the reuse value chain.

The paper offers contributions for academics and actors in the reuse value chain, as policymakers and technology adopters. For academics, the research is a first contribution to a systematic understanding of the factors influencing the decision to adopt water reuse technologies and the deployment of an effective water reuse chain, on which further research can be based. Furthermore, the proposed categorisations of barriers and drivers provide additional insights compared to those already available in the literature, by enriching the perspective of the actors studied, and the type of factors mapped thanks to an empirical study, by conceptualising the reuse value chain as an interrelated system, and by focusing on an under-explored but promising geographical context.

For policymakers, this work could provide insightful findings on strategies to support the reuse of reclaimed water. There is a strong emphasis on effective institutional alignment to support water reuse, such as effective definition and enforcement of clear standards for different reuse applications, collaboration and coordination between different institutional levels, as well as on the usefulness of different tariff and non-tariff measures. However, differences could be identified depending on the specific end use. In particular, the major barriers to industrial reuse need to be highlighted. The authorisations required for industrial reuse seem to be rather unclear, which hinders the development of a value chain for industrial reuse. Actions could also be taken to address the current lack of demand, for example, by reducing barriers to the activation of industrial reuse and defining the economic relationship between the water utility and the industrial user. Policymakers should also work on social awareness and acceptance of water reuse as a safe and valid alternative to conventional freshwater. In addition, where possible, vertical integration between treatment and reuse processes should be encouraged and incentivised to promote internal coordination. Finally, the study has important implications for technology adopters, such as water utilities or other actors involved in the reclamation stages of the reuse value chain. The study provides insights into some recommended technology design practices, such as the importance of sizing and locating reclamation facilities considering the size and geographical distribution of potential end demand from the outset to avoid mismatches. It is also recommended that technology adopters work actively with authorities and users to understand how the distribution network should be developed, including the final price to be set, so to promote water reuse while making the distribution activities economically sustainable, possibly involving forms of public support.

The present study is not free from limitations, which, however, offer opportunities for future research on the topic. First, the study is conducted in a specific geographical and socio-economic context, namely southern Italy, through a single embedded case study. Therefore, the extent to which our findings can be generalised to other contexts is an open question, and caution should be exercised in extending them too far. Despite these limitations, the study provides valuable insights into the barriers and drivers to the development of an effective water reuse chain in the context studied. The findings can be used to inform further research with a broader scope and to guide the ongoing development and refinement of the results obtained. Future research is, therefore, encouraged to complement the analysis by investigating different contexts that differ in terms of their institutional landscape, freshwater availability, societal perceptions of wastewater, and other aspects. It is also suggested to focus on the particularities and specific requirements that different public policies and institutional levers supporting water reuse may have in different contexts. Furthermore, the present research provides an exploratory analysis focusing for the first time on the integrated water reuse chain, but mainly from the perspective of the water utility and its interrelationship with other actors in the value chain. Further research could consider actors other than the water utility as relevant technology adopters, recognising, for example, the possibility of internal water reuse loops in industrial plants. Finally, the study provides an initial examination of the characteristics of reuse facilities that influence the barriers and drivers according to the context studied, but additional characteristics may be of interest to researchers studying water reuse technologies in different contexts. For example, future research could investigate the role of different technologies in moderating barriers and drivers, or the differential role of different socio-institutional factors, such as policies, institutional arrangements, governance systems, and societal perceptions. Researchers should also focus on identifying potential additional uses for reclaimed water and identify tailored actions needed at the political, industrial, and societal levels to promote their uptake.

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