Environmental Policy and Governance

Environmental Policy and Governance

RESEARCH ARTICLE OPEN ACCESS

Challenges in Implementing European Regulation on Water Reuse for Sustainable Agriculture

Patricia Allgaier[1] | Roberta Maffettone[2] | Kevin Grecksch[1]

[1]University of Oxford, Oxford, UK | [2]European Commission, Joint Research Centre (JRC), Ispra, Italy

Correspondence: Patricia Allgaier (patricia.allgaier@reuben.ox.ac.uk)

Received: 20 June 2025 | **Revised:** 7 April 2026 | **Accepted:** 20 April 2026

Keywords: agricultural irrigation | Regulation (EU) 2020/741 | stakeholder theory | water governance | water reuse | water scarcity

ABSTRACT

The Regulation (EU) 2020/741 on minimum requirements for water reuse is a key policy for sustainable water management under growing water scarcity in Europe. This paper examines expert perspectives on the challenges involved in implementing EU regulation for water reuse in agriculture, aiming to broaden existing research, which is largely focused on technical aspects, while governance and socio-economic perspectives remain less explored. The research adopts Stakeholder Theory as the analytical framework with an embedded case study design. A total of 23 semi-structured expert interviews were conducted to collect general stakeholder perspectives at European and national levels, complemented by an in-depth view of a water reuse scheme in Germany. The findings show that the implementation of the regulation is shaped by interlinked legal, technical, economic and social factors. From a legal perspective, results indicate concern about divergence between EU-wide standards and the potential introduction of stricter national rules that may reduce feasibility. From a technical and economic perspective, substantial investments in monitoring, disinfection and risk management could put pressure on small and resource-limited utilities. Socially, acceptance among farmers, retailers and consumers is crucial, since reclaimed water can only be used if it is viewed as safe, marketable and supported by transparent communication. This study underscores the importance of stakeholder engagement and provides insights to support the uptake of water reuse in Europe.

1 | Introduction

Europe faces escalating pressure on water resources as climate change intensifies drought frequency and reduces water availability across many regions. Recent assessments estimate that nearly 40% of the European Union (EU) population already experiences water scarcity, and up to half of Europe's river basins may be affected by 2030 (European Commission 2024a; Rakovec et al. 2022). In response, the EU promotes water reuse as a strategy under the Water Resilience Strategy (European Commission 2025c). The Regulation (EU) 2020/741 on minimum requirements for water reuse (hereafter: WRR) represents a central component of this policy. It establishes harmonised minimum requirements for reclaimed water quality, monitoring and risk management to ensure safe agricultural irrigation.

While the WRR provides a unified framework, its implementation is far from straightforward, particularly in Mediterranean EU countries with pre-existing national legislation and diverse institutional arrangements (Berti Suman et al. 2023; Melchers 2024). Water reuse sits at the intersection of water, agriculture, environmental protection and public health, and its institutional application requires coordination across multiple institutional domains. Moreover, its implementation involves multiple governance levels, similar to challenges faced under the Water Framework Directive (WFD) (Jager et al. 2016; Riazi et al. 2023; Valin 2026; Zingraff-Hamed et al. 2020). The regulation must be interpreted by national administrations, technically implemented by wastewater utilities, adopted by farmers and accepted by consumers.

Despite the demonstrated technical feasibility of water reuse treatment technologies, such as membrane bioreactors, advanced oxidation, photo-Fenton systems and UV disinfection (Antiñolo Bermúdez et al. 2022; Ferreiro et al. 2021; Miralles-Cuevas et al. 2021; Truchado et al. 2021; Carabias et al. 2023), key governance questions remain insufficiently explored. Recent research highlights challenges related to the techno-economic feasibility of water reuse systems (Di Marcantonio et al. 2025), persistent public resistance (Di Marco 2025) and institutional complexity arising from the interaction of multiple actors with different responsibilities, knowledge and interests (Matos et al. 2025). In addition, there remains broader uncertainty as to whether the WRR will lead to a substantial increase in water reuse uptake across the EU (McLennan et al. 2024).

More broadly, governance-related aspects remain less explored in the WRR literature, where most studies focus on technological performance or environmental outcomes, while governance dynamics, regulatory interpretation or stakeholder interactions are only marginally addressed (Berbel et al. 2023; Ramm and Smol 2023; McLennan et al. 2024). Bibliometric analyses further show that the research field is dominated by environmental and engineering sciences, with fewer than 10% of publications in the social sciences and fewer than 5% in economics (López-Serrano et al. 2020). Public resistance to water reuse persists even when framed as a circular economy measure, confirming that social acceptance remains a decisive factor in reuse initiatives (Di Marco 2025; Grecksch 2021; Marks et al. 2008). Despite this, little is known about how acceptance interacts with institutional arrangements, risk management obligations and regulatory requirements introduced by the WRR. Empirical evidence is also limited regarding governance challenges, particularly on how the WRR's risk-based framework is interpreted and implemented by multi-level stakeholders.

This study is motivated by the view that implementing EU water legislation is not merely a technical process, but is shaped by diverse actors with different interests, responsibilities and capacities. As such, it requires analytical tools that capture interdependencies across institutions and sectors. Stakeholder Theory provides a suitable framework as it explores how actors influence and are affected by policy processes, how responsibilities are allocated and how cooperation or conflict emerges. Originating in organisational studies (Freeman 2010) and frequently applied in environmental governance (Grimble 1998; Mitchell et al. 1997; Powell et al. 2011), the theory allows for tracing how regulatory expectations are interpreted by different actors within their institutional and socio-political contexts (Yin 2014).

Methodologically, the study applies an embedded case study design with two units of analysis: (1) general stakeholder perspectives at European and national levels and (2) a detailed examination of a long-running water reuse scheme. Across both units of analysis, 23 semi-structured expert interviews were conducted with stakeholders involved in water governance, wastewater treatment, agricultural use, regulation and research. This design enables the study to move beyond the technical focus of existing research and generate empirically grounded insights into the governance dynamics of implementation.

By integrating these perspectives, the paper offers a multi-level empirical examination of the WRR's implementation, showing how diverse stakeholders translate its requirements into operational practice, identifying key legal, technical, economic and social challenges, and addressing an important empirical gap in the literature.

2 | The EU Water Reuse Regulation

2.1 | Objectives and Scope

The WRR, adopted in 2020 and applicable from June 2023, establishes minimum requirements, a risk-based framework for using reclaimed water in agricultural irrigation, and reporting obligations to the European Environment Agency (EEA). The regulation defines water quality and monitoring requirements for four water quality classes depending on crop types and irrigation methods used. It also requires the preparation of a risk management plan (RMP) that can identify additional parameters for health and environmental protection. This risk-based approach reflects a shift towards a 'fit-for-purpose' approach, in which water quality requirements are tailored to specific uses and risk profiles rather than applied as uniform standards (Hamam et al. 2024; Rebelo et al. 2022). Under Article 2(2), the WRR allows Member States (MS) to determine whether water reuse is appropriate within their territorial and environmental context and to opt out of its implementation, in part or all of their territory, provided that such decisions are justified by climatic conditions, environmental pressures or the relative sustainability of alternative water sources. National uptake has consequently diverged significantly (see Figure 1). This shows that, although best practices developed under the WRR exist, their implementation varies widely across MS due to institutional and contextual differences (Melchers 2024). For example, by mid-2023, Mediterranean MS with established reuse traditions—including Greece, Cyprus, Portugal and Spain—had fully aligned their national frameworks with the requirements of the regulation. In contrast, Germany, Poland and the Baltic States had not yet adapted or approved their domestic legislation or administrative procedures to operationalise the regulation, for example by designating competent authorities, defining permitting procedures or specifying enforcement mechanisms (Berti Suman et al. 2023; Ramm and Smol 2023).

2.2 | Integration Into the EU Water Acquis

The EU Water Acquis comprises the legal framework through which the EU regulates the protection and sustainable management of its water resources. The WRR forms part of the broader EU Water Acquis and interacts closely with two foundational directives: the Water Framework Directive (WFD) and the Urban Wastewater Treatment Directive (UWWTD). Understanding

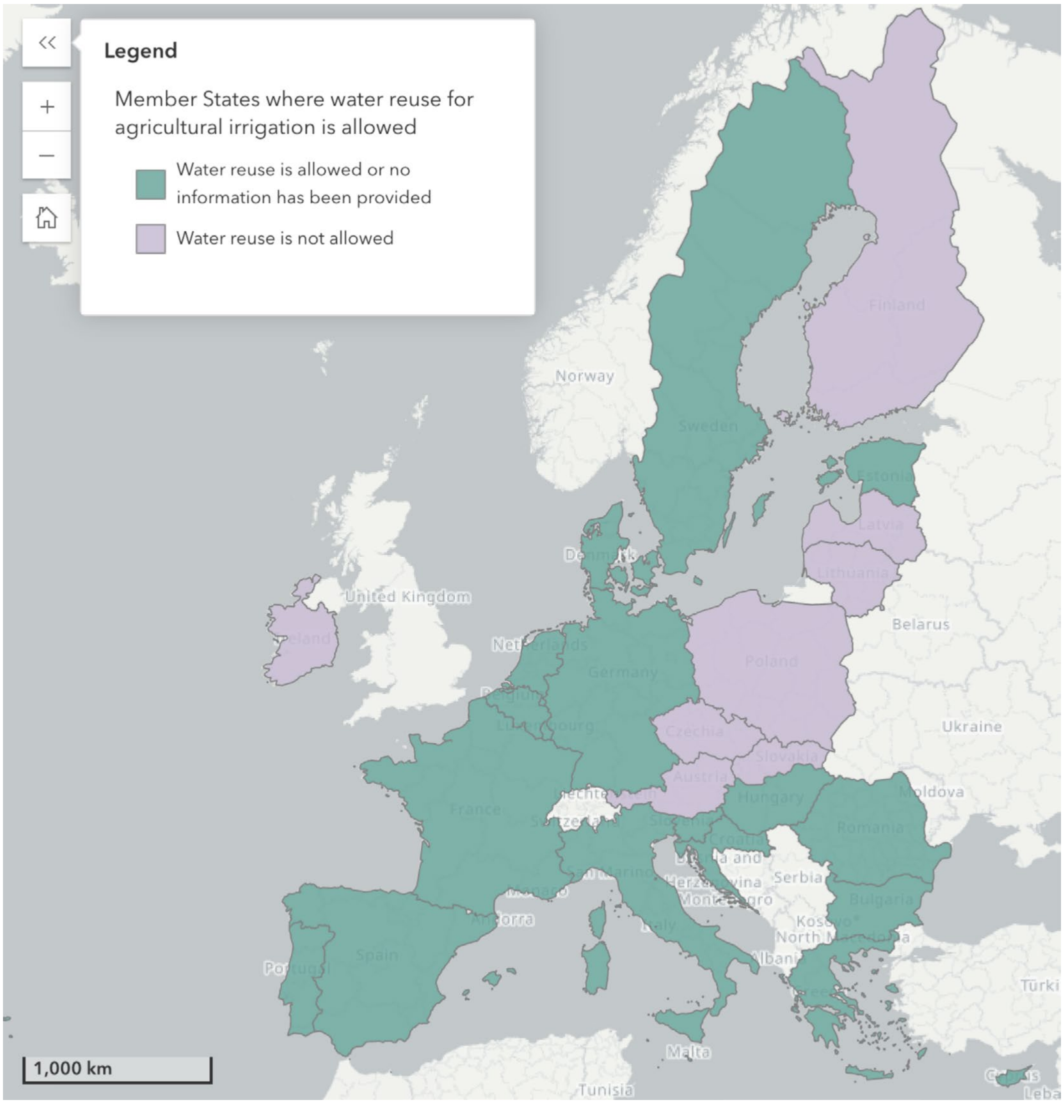

FIGURE 1 | Overview of the implementation status of Regulation (EU) 2020/741. *Source:* https://water.europa.eu/freshwater/europe-freshwater/water-reuse.

these interactions is essential for explaining both the potential and the constraints of the new regulation.

The WFD (2000/60/EC) establishes the overarching goal of achieving good ecological and chemical status for all EU waters. While it does not explicitly regulate agricultural water reuse, it recognises reuse as a potential measure to reduce abstraction pressures and supports integrated, basin-level decision-making. The WRR contributes to its objectives by addressing water scarcity, aligning with river basin planning and embedding risk management requirements to ensure water reuse is done while protecting the environmental status of water bodies. It thereby operationalises this potential by providing a legal pathway, although its contribution to WFD objectives depends on national and local uptake.

The (recast) Directive (EU) 2024/3019 concerning urban wastewater treatment governs the collection, treatment and discharge of wastewater. Adopted in November 2024, the revised version requires MS to introduce an additional quaternary treatment stage in urban wastewater treatment plants to remove micropollutants such as pharmaceutical residues, pesticides and microplastics. Improved treatment, monitoring and pollution control, together with new financing mechanisms under the extended producer responsibility (EPR), are expected to enhance effluent quality and support water reuse while encouraging its inclusion in national water resilience strategies. These changes are expected to facilitate compliance with the quality and risk management requirements set out in the WRR and to make implementation more cost-effective for utilities.

The positioning of the WRR within the wider EU Water Acquis creates a complex governance landscape. Effective implementation requires coordination and a clear allocation of responsibilities across wastewater utilities, agricultural users, environmental and food safety authorities, and regional administrations. Divergent national interpretations, overlapping regulatory logics and the legal uncertainty around direct and indirect (de facto) reuse contribute to uncertainty. As a result, water reuse emerges not only as a technical endeavour but as a multi-level governance challenge (Melchers 2024; Riazi et al. 2023).

3 | Methodology

3.1 | Research Design and Embedded Case Study Approach

The study applies a qualitative, embedded case study design following Yin (2014). The WRR is treated as a single case situated within its real-life policy context, structured through two embedded units of analysis: (1) general stakeholder perspectives at European and national levels and (2) context-specific perspectives in Germany, illustrated through the long-established water reuse scheme in Braunschweig. This design allows for linking broader governance dynamics with the concrete implementation challenges observed in a mature reuse system.

Germany provides a relevant setting due to its federal structure, which distributes responsibilities for water, agriculture and environmental protection across multiple administrative levels. Environmental policies are largely implemented at the level of the 16 German states (Bundesländer), resulting in heterogeneous institutional arrangements. This creates negotiation spaces in which responsibilities under the WRR must be interpreted and assigned. Within this context, the Braunschweig scheme represents a long-standing and information-rich case for examining governance challenges. Several decades of experience in using reclaimed water for agricultural irrigation offer insight into how established practices, monitoring systems and risk management arrangements are reinterpreted under the new EU requirements. While the focus on Germany and Braunschweig limits statistical representativeness, the purpose is analytical generalisation. The case serves to identify governance mechanisms and tensions that may be relevant for other MS with comparable institutional and socio-political conditions.

3.2 | Stakeholder Analysis Framework for Water Reuse Governance

To examine how diverse actors shape the implementation of the WRR, the study employs a stakeholder-oriented methodology grounded in the 'participatory turn' in environmental governance (Bäckstrand 2006; Wilsdon and Willis 2004). This approach emphasises inclusive, deliberative engagement and is well-suited to capturing the diverse interests and capacities that shape water reuse governance. It also reflects recent work highlighting the value of participatory approaches such as co-creation for identifying problems, developing solutions and designing governance strategies for water reuse (Giannoccaro et al. 2025; Matos et al. 2025).

Stakeholders are defined as actors who either (i) are affected by policy outcomes or (ii) have the capacity to influence decision-making (Freeman 2010; Grimble 1998; Mitchell et al. 1997; Powell et al. 2011). In water reuse governance, this includes actors involved in planning, permitting, producing, distributing, applying or regulating reclaimed water. To identify these actors systematically, the study adapts the Five-Step Method developed by André et al. (2012) for climate adaptation and applies it to agricultural water reuse.

1. *Specify stakeholder types:* Four analytical criteria guide identification: functional responsibilities (e.g., water management, agriculture, environmental protection, public health), geographical relevance (e.g., drought-affected regions or existing reuse sites), knowledge and abilities (technical, legal, economic or experiential expertise) and hierarchical level (EU, national, regional, local). These criteria yield a comprehensive set of institutions, utilities, agricultural organisations, associations and scientific experts.

2. *Specify stakeholder roles:* Actors were assigned institutional roles following André et al. (2012): supporters, knowledge providers, disseminators, funders, experts, implementers, coordinators, regulators and affected stakeholders. These roles clarify each actor's relevance and contribution.

3. *Select stakeholders:* Selection combined document analysis, theoretical sampling and snowball sampling to ensure inclusion of actors with formal mandates, practical experience and specialised knowledge.

4. *Associate stakeholders with roles:* Each actor may hold multiple roles. Utilities, for example, act simultaneously as technical experts, implementers and coordinators; agricultural associations may represent both affected stakeholders and knowledge providers.

5. *Analyse stakeholder influence, interest and capacity for change:* Influence refers to the ability to shape how the regulation is interpreted; interest reflects the degree to which actors are affected; capacity for change captures institutional authority and willingness to engage. The analysis draws on power-interest logics similar to the salience framework by Mitchell et al. (1997).

3.3 | Data Collection: Semi-Structured Expert Interviews

Data collection followed a qualitative expert-oriented approach consistent with the embedded case study design. Semi-structured interviews allowed experts to articulate specialised knowledge while maintaining comparability across responses. Interviews were conducted between May 2023 and January 2024 and addressed interpretations of the regulation, perceived opportunities and constraints, institutional roles, planning and permitting procedures, cooperation between authorities and utilities, and anticipated needs for policy development. The emphasis of each interview was adapted to the interviewee's institutional role.

In total, 23 expert interviews (IEs) were conducted with participants from Germany, Spain, Italy, Belgium and Jordan. Most of the IEs were based in Germany. Participants held senior positions and had direct responsibilities in wastewater management, regulation or research, with professional experience ranging from 2 to over 50 years. Interview duration ranged from 12 to 58 min. For the Braunschweig unit, interviews additionally focused on historical development, operational models, agronomic practices and the perceived implications of the new regulation for monitoring and risk management.

All interviews were conducted in person or online, recorded with informed consent and anonymised according to institutional ethical procedures.

Table 1 summarises actor classifications, roles and assessments of influence, interest and capacity. Stakeholders from the food sector and consumer organisations were not included because the regulatory boundary requirements end at the irrigation-field level. Although relevant for market acceptance, downstream value-chain perspectives fall outside the WRR's formal scope.

3.4 | Data Analysis: Thematic Coding and Stakeholder Roles

Data from interviews were analysed following a thematic approach combining deductive and inductive elements (Braun and Clarke 2013). Transcripts were imported into NVivo for systematic coding. A deductive coding framework was developed from existing literature on water reuse governance and prior analysis of the WRR, including categories related to public perception, water governance, risk management and financing.

The framework was refined inductively as new issues emerged, such as liability, contractual arrangements, monitoring capacities and cross-sectoral coordination. Codes were merged and reorganised to maintain analytical coherence.

Higher-order themes were consolidated under four dimensions: legal, technical, economic and social aspects of implementation. Within each dimension, the analysis considered stakeholder roles, interests, capacities and interactions. The thematic analysis and the stakeholder framework were mutually informative: roles helped to interpret themes, while themes clarified how actors shape and experience governance processes (see Table 1).

Finally, the two units of analysis—European and national perspectives, and the context-specific insights from the Braunschweig case—were compared to identify areas of convergence and divergence.

4 | Results

The results section presents the opinions of IEs organised into two units of analysis. The first unit synthesises general stakeholder perspectives on the implementation of the WRR across European and national governance levels. The second unit examines the specific context of Germany, illustrated through the case study in Braunschweig.

4.1 | General Stakeholder Perspectives (Unit of Analysis 1)

4.1.1 | Legal Aspects

The legal dimension of implementing the WRR concerns three issues: (i) the feasibility of the regulatory timeline, (ii) national application of minimum requirements and (iii) the perceived legal gap regarding indirect irrigation.

4.1.1.1 | Regulatory Timeline. Stakeholders frequently described the three-year implementation period (2020–2023) as difficult to meet, particularly for operators responsible for upgrading treatment infrastructure. A German utility representative (IE10) argued that decades-old systems require extensive planning and investment, which cannot be completed within 3 years. A similar view was reported from Spain, where an interviewee (IE5) cited short preparation periods, operational constraints and delays caused by the COVID-19 pandemic.

Other stakeholders offered different interpretations. Some interviewees argued that facilities, such as those in Braunschweig and another German water reuse scheme, had sufficient time to prepare but did not prioritise early action. One interviewee suggested that compliance efforts often intensify only when deadlines approach. This interpretation reflects a broader pattern in public administration, where regulatory attention increases when enforcement becomes imminent.

4.1.1.2 | National Application. A second legal issue concerns how MS interpret and apply the WRR within national frameworks. The regulation permits identification of additional measures, if justified under risk assessment. Some stakeholders believed that this allows contextual adaptation but also creates tensions. For example, one IE assumed that German authorities are inclined to introduce stricter national requirements, particularly for bacteriological parameters and trace substances. In their view, this tendency reflects what they perceive as a cautious administrative culture.

Operators and local practitioners, however, often questioned the proportionality of these stricter rules. An IE from the Braunschweig reclamation facility (IE4) described the tightening of national standards as unrealistic and financially unsustainable. A colleague from another German facility (IE1) warned that efforts to regulate trace substances without a clear legal basis or feasible technology could jeopardise water reuse entirely.

A further perspective emerged from interviewees concerned with market integration. One IE questioned whether additional national standards are compatible with the principle of free movement of goods. The point was that the potential rejection of food irrigated with reclaimed water that is legally compliant in another MS could violate EU rules on the free movement of goods.

4.1.1.3 | Regulatory Gap and the Governance of Indirect Irrigation. A third issue concerns a perceived regulatory gap: the WRR focuses on planned reuse, while indirect irrigation remains largely unregulated. Several IEs expressed concern that this situation creates misleading expectations of safety, as stricter requirements apply for planned reuse than for water abstracted after discharge. As IE12 noted, there is no specific European or German legislation governing the quality of water used for agricultural irrigation in such indirect practices.

On the practical side, this legal gap allows treated wastewater to be discharged into surface water and later abstracted by farmers without meeting the WRR quality standards. While this complies with discharge requirements under the UWWTD,

TABLE 1 | Overview of identified stakeholders in water reuse governance under Regulation (EU) 2020/741.

Stakeholder group	Functional role	Geographical relevance	Knowledge/abilities	Hierarchical level	Stakeholder role(s)	Power/influence	Interest	Capacity for change (ability and willingness)
European Institutions (IE 11–14)	Regulate, coordinate and develop guidance	EU-wide mandate	Legal, regulatory and policy coordination	EU level	Regulators, coordinators, disseminators and funders	Very High—Set binding rules and shape national implementation	Very High—Strong interest in coherent, safe uptake	High—Can adapt frameworks, issue delegated acts and mobilise funding
National & Regional Environmental/Water Authorities (IE 8–10)	Transpose and enforce regulation, permitting and drought management	National and regional	Legal and administrative expertise	National and regional level	Regulators, coordinators and implementers	High—Strong authority in permitting and compliance	Very High—Safeguard the environment and public health	High—Can align legislation but is limited by fragmented mandates
Water Utilities & WWTP Operators (IE 1–7, 20)	Produce reclaimed water and implement technical standards	Local and regional	High technical expertise and operational know-how	Local, regional and metropolitan level	Implementers and experts	High—Control feasibility of reuse	Very High—Transition towards becoming "water factories"	High (technical)/Medium (institutional)—Limited by permits and funding
Farmers & Agricultural Associations (IE 21–22)	Apply reclaimed water and manage agricultural risks	Local and regional	Practical and site-specific knowledge	Local and regional level	Implementers and affected stakeholders	High—Decide whether reuse happens in practice	Very High—Need water security under drought	High—Strong willingness to engage in RMPs and adapt practices
Scientific & Academic Experts (IE 15–19, 23)	Provide evidence, risk assessment and innovation	Cross-cutting	Scientific, technical and socio-economic knowledge	National and EU level	Providers, experts, supporters and disseminators	Very High—Shape policy interpretation and standards	Very High—Strong scientific interest	Very High—Produce trusted data, inform policy and drive innovation

Note: This table provides an overview of the stakeholder groups identified through the application of the adapted Five-Step Method. For each stakeholder category, the table summarises how the interviewed experts (IE) were classified according to the four analytical criteria (functional responsibilities, geographical relevance, knowledge and abilities, and hierarchical level) and the stakeholder roles defined in Step 2. In addition, the table presents a power-interest-capacity assessment (Steps 3–5), indicating the degree of influence each stakeholder holds over the implementation of Regulation (EU) 2020/741, their level of interest in water reuse and their capacity and willingness to drive or support change. The table thus integrates all steps of the stakeholder-identification process and illustrates the diversity of actors involved in water reuse governance across scales and sectors.

it circumvents the minimum thresholds set for reuse and may involve additional risks, for example due to salinity or microbiological contamination (IE5).

Interviewees ascribe this situation to a misalignment between the two frameworks: the UWWTD regulates water quality at the point of discharge, whereas the WRR sets requirements at the point of compliance, usually the outlet point at the reclamation facility. As a result, indirectly reused water may fall outside the WRR's scope while still being used for irrigation. Interviewees further noted that this ambiguity contributes to inconsistent public narratives, for example in debates about the safety of imported products irrigated with reclaimed water, despite limited awareness of irrigation water quality used for similar crops in the importing country.

4.1.2 | Technical Aspects

The interviews identified technical aspects of the WRR, notably the distinction between disinfection requirements for reclaimed water and the applicable minimum quality standards.

4.1.2.1 | Disinfection. The regulation requires disinfection for all classes of reclaimed water used in irrigation. Several interviewees described this requirement as a key strength of the new framework. A policy-oriented participant (IE13) saw harmonised disinfection standards as essential for creating uniform market conditions and improving acceptance across MS.

Practitioners responsible for implementation offered a different view. A utility representative (IE1) acknowledged the value of disinfection to ensure safety but emphasised constraints in upgrading treatment plants, particularly in facilities with limited space or existing load conditions.

Economic considerations also shaped stakeholders' interpretations. IE20 and IE9 highlighted the substantial costs and energy requirements associated with advanced disinfection technologies. Smaller treatment plants may face difficulties meeting the requirements without external support. Some interviewees proposed integrative technological approaches, suggesting that synergies with the UWWTD could reduce costs if disinfection processes are embedded into broader treatment upgrades.

In contrast, other stakeholders questioned the narrow focus on microbial parameters. A researcher (IE18) criticised that the regulation prioritises disinfection while overlooking other contaminants of emerging concern (CECs), including antibiotic resistant genes and medical substances. A complementary perspective was added by IE9, who pointed to a potential paradox: the strong emphasis on treatment may lead to reliance on pollution removal rather than prevention at the source.

4.1.3 | Economic Aspects

The economic dimension of the WRR concerns two central issues: (i) the costs of preparing and maintaining RMPs and (ii) the energy implications to achieve the required water quality.

4.1.3.1 | Risk Management Plans. The regulation requires all actors involved in a water reuse system to develop a RMP, introducing additional administrative responsibilities for utilities, farmers and authorities. Interviewees from reclamation facilities described the associated workload as substantial. A representative from a German facility (IE22) emphasised the experienced bureaucratic intensity of the process and explained that their first draft plan reached nearly 1000 pages. However, the same interviewee also highlighted that the detailed plan had then enabled authorities to grant a temporary permit extension allowing reuse with a lower quality class.

Policymakers such as IE13 therefore considered this flexibility essential for protecting public health and the environment, as RMPs allow authorities to evaluate site-specific quality requirements rather than applying uniform standards.

IEs also highlighted the various economic implications of RMPs. Large utilities typically have greater technical capacity, while smaller facilities and farmers may face disproportionate burdens due to the need for additional expertise and consultancy. At the same time, RMPs can prevent failures, reduce liability exposure and strengthen trust among authorities and consumers, which can positively affect economic outcomes.

4.1.3.2 | Energy Efficiency. Energy demand was identified as a second major economic concern. Several IEs stressed that meeting the required water quality significantly increases energy use. IE19 highlighted that extensive energy is used to eliminate nitrogen in water, and significant amounts of energy are also used to produce nitrogen for field fertiliser.

IE19 described a governance challenge resulting from interactions between EU water regulatory frameworks. While the WRR explicitly encourages nutrient recovery, local discharge obligations under the UWWTD and the Nitrate Directive (91/676/EEC) may limit such practices.

Another concern relates to the cumulative energy and chemical inputs resulting from potential national impositions to meet stricter quality thresholds. IE5 criticised what he perceived as 'excessive protectionism', noting that this would increase consumption of energy, chemicals and money. Importantly, this statement comes from the German context, where operators must comply not only with the minimum requirements of the WRR but also with additional national rules on micropollutants.

4.1.4 | Social Aspects

The social dimension identified by the IEs concerns the acceptance of agricultural products irrigated with reclaimed water and the perceived public health implications.

4.1.4.1 | Public Acceptance. Public acceptance emerges as a central challenge, as many consumers associate reclaimed water with contamination, even when it meets strict quality requirements. Interviewees, such as IE12, described this perception as a major obstacle. They further noted that both the public and administrative actors often express greater concern about reclaimed water than about the use of manure on the same fields, despite the latter containing substances at concentrations several orders of magnitude higher.

Several interviewees emphasised communication as a key strategy to address this challenge. One participant noted that terminology matters, stating: ‘We do not call it wastewater irrigation, because the understanding is that it is no longer wastewater when it is treated’.

Education and information were frequently mentioned as important tools for building trust. For example, IE15 pointed to the role of targeted communication campaigns, while IE9 suggested integrating water reuse into school programmes to foster long-term awareness.

Resource scarcity also plays a decisive role in shaping acceptance. As IE15 explained: ‘Acceptance is always a question of scarcity. The greater the scarcity, the greater the acceptance’. This dynamic is particularly visible in regions such as Murcia (Spain), where transparency initiatives involving farmers, users, schools and international visitors enhance consumer trust.

4.1.4.2 | Industry Acceptance. Acceptance among farmers and food retailers determines whether reclaimed water can be integrated into agricultural production and supply chains. Representatives from farming associations, such as IE15, emphasised that the sector is generally open to reuse, provided that it is financially viable.

Retailers, however, face reputational and liability concerns. Even minor or unrelated health incidents may affect consumer confidence. As IE15 noted, if a customer experiences illness and associates it with the consumption of a product such as salad, retailers are likely to adopt a precautionary approach to avoid potential risks.

Certification systems may also create structural barriers. IE21 described the rigidity of existing quality schemes, noting that systems such as QS (certification system for food safety) implicitly treat the use of reclaimed water from wastewater as problematic, thereby limiting market access for non-certified products. As a result, producers may be discouraged from using reclaimed water for irrigation even when it meets regulatory quality standards. Adjusting certification criteria is therefore crucial for enhancing supply-side acceptance. As one interviewee explained, farmers remain accountable regardless of regulatory changes: ‘Farmers are the producers of food and feed. As such, they must register and as such they are obliged to comply with the standards that are set’.

4.1.4.3 | Public Health. Public health concerns both consumer trust and regulatory design. While the WRR mandates disinfection for all classes of agricultural use, some interviewees questioned whether the strict thresholds are proportionate to actual risks. Several noted that products irrigated with treated water in countries such as Spain or Jordan have shown no evident health impacts, despite different quality requirements.

IE2 pointed to what they described as double standards in German risk perception: ‘In Germany, the responsible authorities worry about concentrations in the range of nanograms per litre, like amoxicillin [...] because they do not want it entering the wastewater treatment plant and ultimately the food chain up to my carrot or my potato on my plate’.

IE18 identified antibiotic resistance and medical contaminants and CECs as key concerns for human health. At the same time, interviewees acknowledged scientific uncertainty regarding long-term effects. IE18 therefore stressed the need for continued research: ‘It is true that we do not know the effect of some contaminants, so we have to follow and try to investigate and look at the effects on health’.

4.2 | Case-Specific Insights: The Braunschweig Reuse Scheme (Unit of Analysis 2)

This section presents the second unit of analysis by examining the Braunschweig reuse scheme, one of the most established examples of agricultural water reuse in Germany. The case was selected because its long operational history, advanced wastewater infrastructure and strict regulatory context provide a well-developed setting in which the implications of the WRR can be observed in practice. As such, it offers a valuable opportunity to analyse how EU-level requirements are interpreted and operationalised within existing governance structures shaped by national legislation and established practices.

In Germany, treated wastewater reuse for irrigation was previously largely prohibited and permitted only on an exceptional basis. The WRR therefore marks a significant shift by enabling reuse under stricter regulatory conditions, creating both opportunities for infrastructure modernisation and challenges for established operational routines.

Empirically, the case draws on three IEs directly involved in the Braunschweig scheme, complemented by additional German participants from utilities, authorities and professional associations, who situate the case within the broader governance context of water reuse in Germany. Most interviewees held senior positions in wastewater utilities, professional associations or public administrations.

4.2.1 | Legal Aspects

Legal dynamics in Braunschweig show how European requirements could intersect with long-established local practices. Interviewees consistently highlighted that current investment pressure is driven not only by the WRR but even more strongly by the UWWTD, indicating that reuse obligations operate within a broader regulatory framework that collectively raises infrastructure standards.

Perceptions of regulatory timelines vary depending on the institutional role. A government IE stresses that Braunschweig had enough preparation time. By contrast, IE10, involved in operational planning, describes the timeline as challenging, given decades-old practices and the comprehensive planning required.

National adaptation introduces an additional layer of tension. IE4 criticised the potential introduction of stricter national requirements, noting that these could raise quality standards to levels comparable to drinking water, particularly when defining minimum bacteriological criteria for reused water. They also warned that tighter thresholds for trace substances could reduce the attractiveness of reuse for agricultural applications. By contrast, IE3 offered a more optimistic perspective on the flexible approach of the WRR: 'We only irrigate fruit that is intended to be processed and are confident that we can fulfil the requirements of class C, without achieving the highest water quality classes A or B'.

At the same time, local expertise feeds into national rulemaking. IE3 is involved in drafting the national code of practice M1250, which incorporates operational experience from Braunschweig. According to them, this co-design process helps ensure that regulatory standards remain realistic and implementable. At the same time, the case illustrates that tightening national criteria without considering local feasibility may limit implementation in long-established reuse systems.

4.2.2 | Technical Aspects

The technical dimension in Braunschweig illustrates how the WRR introduces new operational requirements for a long-established reuse system. Interviewees identified additional disinfection processes and related infrastructure upgrades as the most immediate challenge. IE3 provides a detailed description of the technical steps planned to ensure compliance. They describe a phased approach that combines interim and long-term measures: 'Due to the EU regulation, we are currently planning to construct a fourth treatment stage. Until this is completed, and we can continue irrigation, we are temporarily relying on disinfection with a chemical disinfectant, which can be implemented in the short term. In the medium term, we will switch to UV disinfection. Our aim is to complete this fourth stage by around 2029–2030 and thus fulfil the hygiene requirements on a permanent basis'.

4.2.3 | Economic Aspects

The economic implications of the WRR in Braunschweig primarily concern the costs of new disinfection and the distribution of costs among farmers. IE4 explained that the introduction of additional disinfection steps generates direct operational expenses for the wastewater treatment plant. These costs have so far been balanced by revenues from the agricultural use of sewage sludge, creating a form of internal compensation that benefits local ratepayers: 'The costs of disinfection are borne by agricultural water use'. This cross-financing has helped justify the necessary investments.

However, IE4 also noted that this financial equilibrium is vulnerable. Under the UWWTD, the agricultural spreading of sewage sludge may be restricted or prohibited in the future. If this occurs, the compensation mechanism that currently offsets disinfection costs will erode, leaving the wastewater utility and its customers with higher expenses.

A second concern relates to the cost distribution among farmers. According to IE4, stricter national quality standards may increase operational expenses that are passed on to farmers: 'Farmers' membership fees are likely to increase depending on how much water they use'. This could put pressure on farmers' financial capacity, particularly in regions where irrigation is already cost-sensitive.

4.2.4 | Social Aspects

The social dimension in Braunschweig is shaped by the city's long-standing familiarity with water reuse. IEs generally agreed that the WRR provides a coherent legal framework that can strengthen confidence in the safety and standardisation of reuse practices.

At the same time, local acceptance has remained stable for decades. According to IE10, the population is well accustomed to the reuse system, which is deeply embedded in regional agricultural routines. From this perspective, the regulation primarily adds legal clarity rather than fundamentally altering local acceptance dynamics. This highlights the importance of contextual social factors, such as long-term experience and established practices, in shaping how regulatory frameworks translate into practice.

5 | Discussion

This section analyses and interprets the findings from the interviews in the broader context of water governance, highlighting how the implementation of the WRR intersects with legal, technical, economic and social dimensions. By situating stakeholder experiences within the EU's multi-level regulatory framework, the discussion provides insights into the practical challenges, opportunities and governance mechanisms that shape the uptake of water reuse across different contexts.

5.1 | Legal Aspects

The interviews highlight a key governance-related challenge for implementing the WRR. Their perspectives show how a directly applicable EU instrument is interpreted and operationalised at different levels, and how it interacts with other frameworks (the recast UWWTD and WFD). Overall, three issues recur in stakeholder dialogues: (i) implementation timeline, (ii) proportionality of national practice and (iii) indirect reuse.

5.1.1 | Timeline and Transitional Practice

Operators perceived the three-year implementation period (2020–2023) as difficult to align with ageing infrastructure, a long planning phase and investment constraints, while other actors attributed delays primarily to institutional prioritisation. Comparative research similarly identified a 'patchwork' of the WRR implementation across MS at the time of its entry into force (Ramm and Smol 2023). Evidence from the EEA's WISE Freshwater Water Reuse map further shows that only a subset of countries intends to apply the WRR for agricultural irrigation (European Environment Agency (EEA) 2025). Together, this finding supports IEs' view that uniform compliance within the original implementation period was unlikely. More broadly, this pattern reflects the importance of institutional and organisational alignment for effective implementation. Regulatory complexity, unclear incentives and limited administrative capacities can delay or hinder adoption where governance arrangements are poorly aligned (Santos 2025). As Melchers (2024) shows, this heterogeneity is rooted in differences in national governance structures, regulatory design and contextual conditions. In the Braunschweig case study, some authorities reportedly resorted to time-limited or ad hoc authorisations to operate existing schemes while national guidance and administrative procedures were still being developed.

5.1.2 | National Application, Proportionality and the Internal Market

IEs disagreed on how far national practice should go beyond the EU minimum requirements, depending on their institutional role. Authorities emphasised precaution and legal liability, while operators stressed feasibility and the risk that very conservative interpretations, as seen in parts of the German debate, could incentivise reliance on groundwater and surface water, undermining water resource-saving objectives. Furthermore, they highlighted that stricter national conditions might conflict with the free movement of goods irrigated with reclaimed water treated differently across borders, a concern echoed in broader discussions of regulatory heterogeneity and market fragmentation in the water reuse domain (Malinauskaite et al. 2024).

Legally, the WRR seeks to avoid fragmentation. As a Regulation, it is directly applicable and sets harmonised minimum requirements for reclaimed water quality classes and monitoring. These 'minimum requirements' are not interpreted as an open licence for arbitrary national gold-plating; rather, they establish a baseline that can be complemented where necessary through site-specific risk assessment in the water reuse RMP (Article 5, Annex II), and, more generally, through alignment with national measures adopted in accordance with EU legislation on health and environmental protection (European Parliament and Council 2020). The Commission's technical guidance, together with Commission Delegated Regulation (2020) (EU) 2024/1765 specifying key elements of risk management, further clarifies how risk management should be carried out through the systematic identification of hazards, exposure routes and combinations of treatment and non-treatment barriers across the entire reuse system, rather than through generic national add-ons (European Commission 2024a). In this sense, stakeholder concerns about proportionality and internal-market coherence are attributable less to flaws in the WRR's design and more to the risk that its risk-based tools are not fully or consistently interpreted and applied in national practice. Several operators argued that national practice should avoid 'over-tightening' the minimum requirements set by the WRR. At the same time, regulators and health authorities point to remaining uncertainties in microbiological and aerosol risks (Bonetta et al. 2022; Hamilton et al. 2018). From a governance perspective, such evidence does not justify uniformly raising the WRR standards. Instead, it highlights the need for the systematic identification of hazards, including potentially additional substances or CECs. These should be explicitly addressed in site-specific risk assessments and multi-barrier designs that account for local hydrogeological conditions, rather than assuming that generic, stricter requirements are sufficient in all cases (Rebelo et al. 2020).

5.1.3 | Indirect Reuse, Multi-Barrier Approach and Alignment With the UWWTD

Stakeholder interviews also raised the problem of planned reuse, which is tightly regulated under the WRR, and indirect irrigation, where treated wastewater is discharged into a river or canal and later abstracted for irrigation.

The multi-barrier concept embedded in the WRR provides a partial response. Annex II frames risk assessment across the entire water reuse system and allows treatment and non-treatment barriers to be used after the point of compliance to achieve an equivalent higher water quality class. The RMP should include a system-wide description and assessment, which also includes storage, distribution, blending and on-farm practices. The Delegated Regulation (EU) 2024/1765 explicitly recognises additional treatments or other appropriate barriers applied downstream of the reclamation facility (European Commission 2024a). Whenever water produced in a reclamation facility is intended for reuse, 'indirect-like' elements of the system, such as canals or reservoirs prior to re-abstraction, should thus be assessed under the risk-management framework. These elements could be, where appropriate, used in combination with downstream barrier measures to achieve an equivalent level of protection.

In parallel, the recast UWWTD (Directive (EU) 2024/3019) introduces quaternary treatment for micropollutant removal in large agglomerations, particularly where discharges may affect drinking-water abstraction, bathing, aquaculture or reuse for agriculture, gradually improving effluent quality at the point of discharge (European Commission 2024b). Finally, Article 12 of the WRR mandates the European Commission to assess in its 2028 evaluation the feasibility of extending the Regulation's scope to indirect use of treated wastewater (European Parliament and Council 2020). Together, these elements acknowledge the structural concerns raised by stakeholders and create a formal pathway for progressively integrating indirect reuse into a more coherent governance framework.

5.2 | Technical Aspects

The interview material shows that the key challenges of implementing the WRR arise from integrating new treatment and monitoring obligations into existing infrastructures. Three issues dominate stakeholder accounts: (i) upgrading disinfection capacity, (ii) balancing water quality with nutrient recovery and (iii) aligning national practice with the WRR's risk-based, multi-barrier logic.

5.2.1 | Upgrading Disinfection Capacity and Infrastructural Constraints

Stakeholders repeatedly highlighted that, even where disinfection systems are already in place, additional investment is often unavoidable. Consistent with Carabias et al. (2023), this reflects not a lack of available technologies but the need to retrofit and upgrade existing disinfection systems to meet the WRR requirements, often under conditions of constrained space, ageing infrastructure and long procurement timelines. Stakeholder accounts therefore suggest that implementation bottlenecks stem primarily from infrastructural and organisational constraints rather than technological limitations.

One way to address these constraints is to operationalise the RMP as a delivery instrument, linking hazard and pathway assessment to sequenced interventions (e.g., interim controls, commissioning steps and longer-term upgrades), thereby making transitional configurations explicit and auditable. In parallel, technological innovation can enhance feasibility by expanding disinfection options and, in some contexts, reducing energy demand, although its deployment remains strongly context-dependent. In governance terms, this reinforces that harmonised minimum requirements need to be complemented by locally viable technological and investment pathways.

Moreover, the WRR provides flexibility to address economic constraints through the multi-barrier approach. Achieving the highest water quality class (Class A) does not necessarily require the upgrade of existing treatment at the reclamation facility; instead, lower quality classes can be complemented by additional barriers applied after the point of compliance. This allows, in coordination with all the involved actors, higher treatment levels to be targeted only to the volumes used for crops consumed raw, thereby improving cost-effectiveness while maintaining safety.

5.2.2 | Water Quality, Nutrient Recovery and the Risk of Over-Treatment

A second technical tension concerns balancing safety with the agronomic value of reclaimed water. Perulli et al. (2022) demonstrate that secondary treated water rich in nitrogen and phosphorus can support irrigation while reducing fertiliser demand without increasing trace element accumulation in leaves or fruit. These findings reflect stakeholder concerns that overly stringent national thresholds, particularly when combined with enhanced nutrient removal without considering the local context, may undermine the resource-efficiency benefits of reuse.

The interview material suggests that this tension is particularly evident in Germany, where debates on trace substances and bacteriological thresholds exceed the harmonised EU baseline. From a governance perspective, this indicates a risk of misalignment: the WRR is designed to ensure safety through site-specific risk assessment, not through uniformly higher standards. Over-treatment may improve compliance while reducing system-level sustainability and incentives to substitute freshwater with reclaimed water.

5.2.3 | Risk-Based Design and Alignment With the Multi-Barrier Approach

Operationalising the WRR's multi-barrier logic offers a practical route to feasibility, particularly where plant-level upgrades are constrained. Rather than treating compliance as end-of-pipe intensification, robust designs combine treatment barriers with exposure-reducing measures (e.g., irrigation practices, access restrictions, buffer zones) and with distribution/storage controls that maintain quality along the chain. The WRR and the 2024 Delegated Regulation emphasise that compliance is achieved by combining different barriers across the entire system, allowing MS to design context-specific solutions without imposing nationwide plant upgrades.

Literature and interviews together suggest that the challenge lies in operationalising this flexibility. Carabias et al. (2023) and Federigi et al. (2023) illustrate that microbiological risks and aerosol exposure vary across systems, reinforcing the need for precise hazard identification rather than generic thresholds. The interviews echo this logic: operators focused on plant upgrades, while regulators highlighted uncertainties in specific exposure pathways rather than in water quality parameters per se.

Overall, the technical challenges raised by stakeholders do not indicate inherent deficiencies in the WRR, but rather the difficulty of embedding a risk-based, multi-barrier approach into infrastructures built under earlier regulatory frameworks. The literature confirms that technological solutions exist, from UV upgrades to solar photo-Fenton processes, but their feasibility is shaped by climatic, infrastructural and institutional conditions (Corimanya-Yucra and Nolasco 2026). The central governance task is therefore to ensure proportionality: achieving safe irrigation water without undermining the resource-efficiency benefits of reuse or imposing national interpretations beyond the Regulation's requirements.

5.3 | Economic Aspects

The interview material shows that the economic implications of the WRR arise more from organisational adjustments than from stringent quality parameters. Two themes dominate stakeholder opinions: (i) the administrative and coordination effort required for preparing RMPs and (ii) the resource implications, especially energy use, of achieving the required water quality.

5.3.1 | RMPs: Administrative Weight Versus Governance Value

Stakeholders consistently described preparing RMPs as a bureaucratic burden. Berbel et al. (2023) also highlight challenges in documenting hazards, exposure pathways and mitigation options. Interviewees described lengthy documentation processes requiring technical expertise, inter-institutional coordination and substantial time. Yet literature and regulatory design indicate that these plans provide critical governance value. Federigi et al. (2023) demonstrate, by using microbiological and physicochemical data, that structured risk assessment is essential for identifying realistic exposure pathways and ensuring public-health protection. Moreover, coordination among actors is complicated, as utilities and end-users usually have different expertise and needs regarding reclaimed water and risk management (Drei et al. 2025).

Interestingly, the interview data show that this functional value was rarely acknowledged. Stakeholders tended to emphasise administrative cost while overlooking the flexibility embedded in the instrument: RMPs allow operators to tailor treatment to site-specific risks, avoid unnecessary treatment and combine technological and non-technological measures. In governance terms, risk management ensures proportionality: its initial effort represents more of a learning phase requiring additional training and expertise rather than structural inefficiency.

5.3.2 | Energy and Chemical Inputs: Proportionality and Resource-Efficiency Trade-Offs

A second economic concern relates to the resource implications of achieving high water-quality classes. Stakeholders highlighted the cumulative energy and chemical inputs required by disinfection and advanced treatment. This aligns with broader evidence that certain treatment trains may generate significant operational costs, particularly in MS with older infrastructure or limited financial capacity. These costs reduce the competitiveness of reclaimed water relative to conventional sources, limiting uptake in the absence of subsidies or strong policy incentives (McLennan et al. 2024).

Some interviewees raised country-specific concerns. In Germany, debates on micropollutants and bacteriological thresholds shape operators' expectations regarding future cost developments. These concerns underline that economic pressures are not solely driven by the Regulation but by interactions with national priorities, discharge obligations and investment patterns under the recast UWWTD.

From a system-level perspective, these tensions point to a central policy challenge: ensuring that the drive for safety does not inadvertently incentivise groundwater use, reduce the nutrient value of reclaimed water or increase energy demand beyond sustainable levels.

Overall, the economic implications identified by stakeholders reflect the introduction of a new governance instrument and the adaptation of existing infrastructure rather than intrinsic inefficiencies in the WRR. RMPs create administrative costs but enable contextualisation, while advanced treatment improves safety at the cost of higher resource demand. Similar interdependencies between governance, finance and infrastructure are highlighted in systemic studies of reuse adoption, where financial constraints transmit governance deficiencies into infrastructural barriers, underscoring the role of regulatory frameworks in enabling investment (Corimanya-Yucra and Nolasco 2026).

5.4 | Social Aspects

The interview material demonstrates that the social dimension of the WRR is not peripheral but central to its feasibility. Three issues emerge from the synthesis of interviews and literature: (i) the framing effects of terminology, (ii) regionally embedded risk perceptions and (iii) the governance dilemma between transparency and market stability.

5.4.1 | Terminology and the Social Construction of Safety

Stakeholders emphasised that regulatory compliance is insufficient if consumers, retailers or farmers perceive reclaimed-water products as unsafe or commercially risky, a concern also reflected in recent literature (Hamam et al. 2024). This echoes Berbel et al. (2023), who argue that the WRR's technological focus risks overlooking acceptance dynamics across the agri-food chain. Both interviewees and literature highlight that acceptance is also shaped by the terminology used for reclaimed water. Berbel et al. (2023) show that terms such as recycled or eco-friendly evoke more positive associations than reclaimed or treated wastewater. Interviewees similarly noted that avoiding the term wastewater, e.g., by referring simply to treated water, can reduce intuitive rejection without altering the underlying process.

These observations underscore that perceptions of clean water and contamination are socially constructed. Terminology thus becomes a governance instrument that influences how reclaimed water is interpreted before risk information is considered. While linguistic adjustments cannot replace technical safety, they can support acceptance by reducing cognitive barriers.

5.4.2 | Information, Experience and Regionally Embedded Risk Perceptions

Interviewees described how acceptance varies across regions depending on water scarcity, familiarity with reuse and historical exposure to drought. Existing literature confirms that willingness to consume products irrigated with non-conventional water differs significantly across contexts, ranging from an 87% decline in the United States to around 20% in Israel, reflecting variations in cultural norms, institutional trust and exposure to climate impacts (Berbel et al. 2023). Similar patterns are observed at the farm level, where acceptance is shaped by the interaction of trust, individual risk attitudes and local experience (Giannoccaro et al. 2025). Public distrust and limited knowledge further influence acceptance, highlighting the importance of communication and information strategies in governance (Corimanya-Yucra and Nolasco 2026).

These findings suggest that acceptance is not static but evolves through experience and context. Where water scarcity is visible, interviewees noted that public outreach tends to be more effective, as observed in regions such as Murcia. In contrast, in regions without a history of reuse, actors reported concerns about potential public backlash, which may constrain proactive communication and undermine long-term trust. The WRR seeks to enhance public awareness and acceptance by requiring transparency, information provision and data reporting by MS.

Taken together, this indicates that social acceptance cannot be addressed through uniform approaches but requires regionally adapted strategies that link technical safety to lived experience. Education and stakeholder engagement are therefore critical for overcoming social and psychological barriers to water reuse (Giannoccaro et al. 2025; Ramm and Smol 2024).

5.4.3 | Transparency Dilemmas and Long-Term Trust Building

A recurring tension from the interviews concerns transparency and market stability. Berbel et al. (2023) show that consumers may prefer ambiguity, being more willing to buy products irrigated with unspecified water sources than those explicitly labelled as reclaimed water. Interviewees reported similar dilemmas: detailed disclosure may deter consumers, but withholding information risks future distrust if practices become more visible. In this context, the introduction of common minimum quality requirements is expected to strengthen consumer confidence and improve acceptance of reclaimed water (McLennan et al. 2024). Governance design also matters: participatory models involving farmers in decision-making can significantly increase adoption (Giannoccaro et al. 2025), while education and stakeholder engagement are essential to overcome social and psychological barriers (Ramm and Smol 2024).

Overall, the social challenges associated with the WRR reveal that acceptance is an institutional and cultural process rather than a simple function of water quality. Evidence from other studies similarly highlights public distrust and limited knowledge as key barriers, underscoring the importance of communication, information and engagement strategies in reuse governance (Corimanya-Yucra and Nolasco 2026). Together, these findings suggest that short-term discretion may stabilise markets, but long-term legitimacy depends on transparent standards, stakeholder participation and public education to prevent abrupt shifts in risk perception.

6 | Conclusion

This study examined how actors across governance levels interpret and operationalise Regulation (EU) 2020/741 on water reuse. The findings show that implementation is shaped by interconnected legal, technical, economic and social dimensions. They illustrate how harmonised EU standards intersect with national regulatory approaches, how monitoring and risk management obligations introduce significant organisational and resource demands, and how acceptance among farmers, retailers and consumers remains central to operational feasibility. Implementation is further influenced by partial or defensive interpretations of the Regulation, particularly regarding risk-management provisions, alongside infrastructural, financial and social constraints. The study also highlights the relevance of the post-compliance multi-barrier approach as a practical strategy to manage economic and technical challenges, allowing flexibility in achieving water-quality objectives while maintaining operational feasibility.

Water reuse operates at the nexus of water, agriculture, environmental protection and public health, demanding coordination across multiple institutional domains and governance levels. This is a challenge reminiscent of the complexities faced under the WFD (Jager et al. 2016; Zingraff-Hamed et al. 2020; Riazi et al. 2023). Comparative studies highlight the heterogeneity of EU wastewater reuse regulation, shaped by divergent governance structures, regulatory designs and national contexts (Melchers 2024). At the same time, water reuse is transitioning from a voluntary practice to a conditionally expected component of integrated environmental, climate and energy policy frameworks, underscoring its growing strategic importance within EU governance (Di Marco 2025).

The study contributes to water-governance research in three ways. First, it conceptualises implementation as a multi-level process negotiated between EU-wide standards, national regulatory logics and local operational arrangements. Second, it demonstrates that effective uptake depends on sustained stakeholder engagement and interpretive clarity. Third, the Braunschweig case shows that mature reuse systems can both enable adaptation through established routines and constrain flexibility due to long-standing institutional practices. Taken together, these insights indicate that successful operationalisation of the WRR requires legal clarity, context-sensitive governance and shared understanding among the actors responsible for applying the framework.

The focus on established institutional networks, the German context and the Braunschweig case provides a rich, in-depth perspective on operational challenges, while also highlighting how governance structures, local routines and stakeholder engagement shape implementation. Excluding downstream actors such as retailers, certification bodies and consumers further identifies a promising avenue for research to explore market governance and acceptance. Similarly, cross-national comparisons and longitudinal studies could illuminate how risk-management practices, indirect reuse and national adaptations evolve over time. Practice-oriented efforts on capacity building, training and multi-barrier planning will be crucial to reduce misinterpretations and support the institutionalisation of risk-based reuse. Recent European Commission initiatives, such as the European Water Academy under the Water Resilience Strategy (European Commission 2025a, 2025b), exemplify efforts to strengthen skills and practical uptake, ultimately supporting coherent, feasible and socially legitimate water reuse governance across the EU.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

André, K., L. Simonsson, Å. G. Swartling, and B.-O. Linnér. 2012. "Method Development for Identifying and Analysing Stakeholders in Climate Change Adaptation Processes." *Journal of Environmental Policy & Planning* 14, no. 3: 243–261. https://doi.org/10.1080/1523908X.2012.702562.

Antiñolo Bermúdez, L., J. C. Leyva Díaz, J. Martín Pascual, M.d. M. Muñío Martínez, and J. M. Poyatos Capilla. 2022. "Study of the Potential for Agricultural Reuse of Urban Wastewater With Membrane Bioreactor Technology in the Circular Economy Framework." *Agronomy* 12, no. 8: 1877. https://doi.org/10.3390/agronomy12081877.

Bäckstrand, K. 2006. "Multi-Stakeholder Partnerships for Sustainable Development: Rethinking Legitimacy, Accountability and Effectiveness." *European Environment* 16, no. 5: 290–306. https://doi.org/10.1002/eet.425.

Berbel, J., E. Mesa-Pérez, and P. Simón. 2023. "Challenges for Circular Economy Under the EU 2020/741 Wastewater Reuse Regulation." *Global Challenges* 7, no. 7: 2200232. https://doi.org/10.1002/gch2.202200232.

Berti Suman, A., L. García-Herrero, S. Lavrnić, M. C. Sole, A. Toscano, and M. Vittuari. 2023. "The Advent of EU Water Reuse Regulation in the Mediterranean Region: Policy and Legislative Adaptation to Address Non-Conventional Water Resources Utilization in Agriculture." *Water International* 48, no. 7: 839–860. https://doi.org/10.1080/02508060.2023.2277619.

Bonetta, S., C. Pignata, E. Gasparro, L. Richiardi, S. Bonetta, and E. Carraro. 2022. "Impact of Wastewater Treatment Plants on Microbiological Contamination for Evaluating the Risks of Wastewater Reuse." *Environmental Sciences Europe* 34, no. 1: 20. https://doi.org/10.1186/s12302-022-00597-0.

Braun, V., and V. Clarke. 2013. *Successful Qualitative Research: A Practical Guide for Beginners*. SAGE Publications.

Carabias, A. V., M. I. Gil, J. M. Pérez, et al. 2023. "Fluence Requirements in Existing UV Disinfection Facilities to Comply With EU Validation Performance Targets for Reclaimed Water: A Case Study." *Water Science and Technology* 88, no. 4: 1131–1141. https://doi.org/10.2166/wst.2023.258.

Commission Delegated Regulation. 2020. "(EU) 2024/1765 of 11 March 2024 Supplementing Regulation (EU) 2020/741 With Regard to Technical Specifications of the Key Elements of Risk Management (Text With EEA Relevance)." http://data.europa.eu/eli/reg_del/2024/1765/oj.

Corimanya-Yucra, E. M., and M. A. Nolasco. 2026. "Exploring Systemic Challenges in Wastewater Reuse for Agriculture: A Modified Delphi and Cross-Impact Analysis Approach." *Journal of Cleaner Production* 552: 147899. https://doi.org/10.1016/j.jclepro.2026.147899.

Di Marcantonio, C., F. Mangiagli, M. R. Boni, et al. 2025. "Are We Ready for the Application of the EU Regulation on Wastewater Reuse in Agriculture? A Techno-Economic Preliminary Evaluation Based on a Case-Study." *Journal of Environmental Management* 373: 123973. https://doi.org/10.1016/j.jenvman.2024.123973.

Di Marco, A. 2025. "Water Reuse in the European Union: Fostering and Constraining Public Acceptance." *Journal of Environmental Law* 37, no. 3: 492–510. https://doi.org/10.1093/jel/eqaf026.

Drei, P., G. Mancuso, S. Lavrnić, et al. 2025. "A Novel Methodology to Develop EU Water Reuse Risk Management Plan in Agricultural Water Distribution Networks and Crop Irrigation Systems." *Water Research X* 28: 100395. https://doi.org/10.1016/j.wroa.2025.100395.

European Commission. 2024a. "Water Scarcity and Droughts." https://environment.ec.europa.eu/topics/water/water-scarcity-and-droughts_en#contact.

European Commission. 2024b. "Urban Wastewater." https://environment.ec.europa.eu/topics/water/urban-wastewater_en#review.

European Commission. 2025a. "New European Water Academy Launched to Strengthen Water Resilience." https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/new-european-water-academy-launched-strengthen-water-resilience-2025-06-04_en.

European Commission. 2025b. "European Water Resilience Strategy: Communication and Factsheet." https://environment.ec.europa.eu/publications/european-water-resilience-strategy-factsheet_en.

European Commission. 2025c. "Communication From the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions." https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52025DC0280.

European Environment Agency (EEA). 2025. "Water Reuse." https://water.europa.eu/freshwater/europe-freshwater/water-reuse.

European Parliament and Council. 2020. "Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on Minimum Requirements for Water Reuse (Text With EEA Relevance)." http://data.europa.eu/eli/reg/2020/741/oj/eng.

Federigi, I., M. Verani, R. Salvadori, S. Lippi, and A. Carducci. 2023. "Risk Analysis for the Human Health Derived From Sewage Management: Perspectives for the Reuse." *Population Medicine* 5, no. Supplement: A178. https://doi.org/10.18332/popmed/163765.

Ferreiro, C., N. Villota, A. de Luis, J. I. Lombraña, N. Etxebarria, and J. M. Lomas. 2021. "Water Reuse Study From Urban WWTPs via c-Ultrafiltration and Ozonation Technologies: Basis for Resilient Cities and Agriculture." *Agronomy* 11, no. 2: 322. https://doi.org/10.3390/agronomy11020322.

Freeman, R. E. 2010. *Strategic Management: A Stakeholder Approach*. Cambridge University Press.

Giannoccaro, G., L. Mirra, A. Paparella, and S. Stempfle. 2025. "Farmers' Acceptance of Using Reclaimed Water. What Makes the Difference?" *Water Reuse* 15, no. 4: 735–752. https://doi.org/10.2166/wrd.2025.079.

Grecksch, K. 2021. "Achieving Water Efficiency in the Public Sector Through Social Norms." *Frontiers in Environmental Science* 9: 575583. https://doi.org/10.3389/fenvs.2021.575583.

Grimble, R. 1998. *Stakeholder Methodologies in Natural Resource Management*. Natural Resources Institute.

Hamam, M., R. Pergamo, V. Manganiello, and M. Ferrigno. 2024. "Agricultural Wastewater Reuse as a Circular Economy Model: Future Scenarios Considering Reg.(EU) 2020/741." *Water* 16, no. 24: 3638. https://doi.org/10.3390/w16243638.

Hamilton, K. A., M. Waso, B. Reyneke, et al. 2018. "Cryptosporidium and Giardia in Wastewater and Surface Water Environments." *Journal of Environmental Quality* 47, no. 5: 1006–1023. https://doi.org/10.2134/jeq2018.04.0132.

Jager, N. W., E. Challies, E. Kochskämper, et al. 2016. "Transforming European Water Governance? Participation and River Basin Management Under the EU Water Framework Directive in 13 Member States." *Water* 8, no. 4: 156.

López-Serrano, M. J., J. F. Velasco-Muñoz, J. A. Aznar-Sánchez, and I. M. Román-Sánchez. 2020. "Sustainable Use of Wastewater in Agriculture: A Bibliometric Analysis of Worldwide Research." *Sustainability* 12, no. 21: 8948. https://doi.org/10.3390/su12218948.

Malinauskaite, J., B. Delpech, L. Montorsi, et al. 2024. "Wastewater Reuse in the EU and Southern European Countries: Policies, Barriers and Good Practices." *Sustainability* 16, no. 24: 11277. https://doi.org/10.3390/su162411277.

Marks, J., B. Martin, and M. Zadoroznyj. 2008. "How Australians Order Acceptance of Recycled Water: National Baseline Data." *Journal of Sociology* 44, no. 1: 83–99. https://doi.org/10.1177/1440783307085844.

Matos, M. V., T. Fidélis, M. C. Sousa, F. Riazi, A. C. Miranda, and F. Teles. 2025. "Institutional Challenges in Water Reuse and Circularity: Insights From Co-Creation Processes in Southern Europe and Middle East." *Water Policy* 27, no. 4: 429–446. https://doi.org/10.2166/wp.2025.165.

McLennan, C., G. Rudi, Y. Altchenko, and N. Ait-Mouheb. 2024. "Will the European Regulation for Water Reuse for Agricultural Irrigation Foster This Practice in the European Union?" *Water Reuse* 14, no. 2: 115–135. https://doi.org/10.2166/wrd.2024.012.

Melchers, S. 2024. "European Approaches to Wastewater Reuse Regulation: A Comparison Between Spain, Malta and the Netherlands." *Review of European, Comparative & International Environmental Law* 33, no. 3: 350–366. https://doi.org/10.1111/reel.12577.

Miralles-Cuevas, S., P. Soriano-Molina, I. de la Obra, E. Gualda-Alonso, and J. S. Pérez. 2021. "Simultaneous Bacterial Inactivation and Microcontaminant Removal by Solar Photo-Fenton Mediated by Fe3+-NTA in WWTP Secondary Effluents." *Water Research* 205: 117686. https://doi.org/10.1016/j.watres.2021.117686.

Mitchell, R. K., B. R. Agle, and D. J. Wood. 1997. "Toward a Theory of Stakeholder Identification and Salience: Defining the Principle of Who and What Really Counts." *Academy of Management Review* 22, no. 4: 853–886. https://doi.org/10.5465/amr.1997.9711022105.

Perulli, G., V. Alagna, L. Manfrini, et al. 2022. "Peach Smart Fertigation With Wastewater: Physiological and Nutritional Evaluation." *Acta Horticulturae, X International Peach Symposium* 1352: 299–306. https://doi.org/10.17660/ActaHortic.2022.1352.40.

Powell, R. B., M. J. Stern, B. D. Krohn, and N. Ardoin. 2011. "Development and Validation of Scales to Measure Environmental Responsibility, Character Development, and Attitudes Toward School." *Environmental Education Research* 17, no. 1: 91–111. https://doi.org/10.1080/13504621003692891.

Rakovec, O., L. Samaniego, V. Hari, et al. 2022. "The 2018–2020 Multi-Year Drought Sets a New Benchmark in Europe." *Earth's Future* 10, no. 3: e2021EF002394. https://doi.org/10.1029/2021EF002394.

Ramm, K., and M. Smol. 2023. "Water Reuse—Analysis of the Possibility of Using Reclaimed Water Depending on the Quality Class in the European Countries." *Sustainability* 15, no. 17: 12781. https://doi.org/10.3390/su151712781.

Ramm, K., and M. Smol. 2024. "The Potential for Water Recovery From Urban Waste Water—The Perspective of Urban Waste Water Treatment Plant Operators in Poland." *Journal of Environmental Management* 358: 120890. https://doi.org/10.1016/j.jenvman.2024.120890.

Rebelo, A., A. B. Amaro, and F. Quadrado. 2022. "Water Reuse: A Risk Assessment Model for Water Resources." In 1st International FibEnTech Congress (FibEnTech21): New Opportunities for Fibrous Materials in the Ecological Transition. KnE Materials Science 7, no. 1: 193–203. https://doi.org/10.18502/kms.v7i1.11623.

Rebelo, A., M. Quadrado, A. Franco, N. Lacasta, and P. Machado. 2020. "Water Reuse in Portugal: New Legislation Trends to Support the Definition of Water Quality Standards Based on Risk Characterization." *Water Cycle* 1: 41–53. https://doi.org/10.1016/j.watcyc.2020.05.006.

Riazi, F., T. Fidélis, M. V. Matos, M. C. Sousa, F. Teles, and P. Roebeling. 2023. "Institutional Arrangements for Water Reuse: Assessing Challenges for the Transition to Water Circularity." *Water Policy* 25, no. 3: 218–236. https://doi.org/10.2166/wp.2023.155.

Santos, E. 2025. "Thirst for Change in Water Governance: Overcoming Challenges for Drought Resilience in Southern Europe." *Water* 17, no. 15: 2170. https://doi.org/10.3390/w17152170.

Truchado, P., M. I. Gil, C. López, et al. 2021. "New Standards at European Union Level on Water Reuse for Agricultural Irrigation: Are the Spanish Wastewater Treatment Plants Ready to Produce and Distribute Reclaimed Water Within the Minimum Quality Requirements?" *International Journal of Food Microbiology* 356: 109352. https://doi.org/10.1016/j.ijfoodmicro.2021.109352.

Valin, N. 2026. "Science and Policy in Murky Waters: Four Cases of Compliance With the European Union Water Framework Directive." *Ecology and Society* 31, no. 1: art16. https://doi.org/10.5751/ES-16634-310116.

Wilsdon, J., and R. Willis. 2004. *See-Through Science: Why Public Engagement Needs to Move Upstream*. Demos.

Yin, R. K. 2014. *Case Study Research: Design and Methods*. 5th ed. SAGE Publications.

Zingraff-Hamed, A., B. Schröter, S. Schaub, et al. 2020. "Perception of Bottlenecks in the Implementation of the European Water Framework Directive." *Water Alternatives* 13, no. 3: 458–483.