Responsible Potable Water Reuse

Reconciling Acceptance and Acceptability

Karen Moesker

Simon Stevin Series in the Ethics of Technology

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Dissertation

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List of Publications and Manuscripts

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Chapter 2 – Value-Sensitive Design of Potable Water Reuse:
Aligning Academic Research with Societal Concern
Moesker, K., & Wiarda, M. (2025). "Value-Sensitive Design of Potable Water Reuse: Aligning Academic Research with Societal Concerns", Science and Engineering Ethics, 31(4), 1-27.

Chapter 3 – Public Acceptance in Direct Potable Water Reuse:
A Call for Incorporating Responsible Research and Innovation.
Moesker, K., Pesch, U. & Doorn, N. (2024). "Public Acceptance in Direct Potable Water Reuse: a Call for Incorporating Responsible Research and Innovation", Journal of Responsible Innovation, 11(1), 2304382.

Chapter 4 – Uncharted Waters:
How Large-Scale Water Infrastructure Projects Manage Public Acceptance
Moesker, K., & Spackman, C. (under review). "Uncharted Waters: How Large-Scale Water Infrastructure Projects Manage Public Acceptance**".**

Chapter 5 – Making Sense of Acceptance and Acceptability:
Mapping Concept Use in Energy Technologies Research
Moesker, K., Pesch, U., & Doorn, N. (2024). "Making Sense of Acceptance and Acceptability: Mapping Concept Use in Energy Technologies Research", Energy Research & Social Science, 115, 103654.

Chapter 6 – Beyond Social Acceptance in Wicked Problems:
A Socio-Ethical Assessment Framework for Technology Governance
Moesker, K., & Pesch, U. (2025). "Beyond Social Acceptance in Wicked Problems: A Socio-Ethical Assessment Framework for Technology Governance", Journal of Responsible Technology, 100140.

Summary

This dissertation addresses the social and ethical complexities surrounding potable water reuse systems.
In a time of growing global water scarcity and increasing environmental pressures, potable water reuse, the process of treating wastewater to a quality suitable for drinking water, offers an alternative for more sustainable water management. However, despite its increasing technical viability and potential benefits in conserving freshwater resources and reducing pollution, its widespread adoption is often claimed to be hampered by significant public opposition. This resistance is frequently simplistically framed as an issue of 'social acceptance'. It stems from its challenge to the long-established societal and infrastructural separation between wastewater and drinking water, leading to concerns about safety, system reliability, trust in authorities, and psychological aversion (the 'yuck factor'). To tackle this issue, a growing body of literature aims to understand the complex phenomenon of social acceptance and develop interventions to enhance it. However, the persistence of public opposition suggests that these efforts may not fully capture the underlying complexities.

This dissertation argues that although addressing social acceptance is critical, the way it is currently pursued is insufficient and overlooks critical social and ethical dimensions affected by potable water reuse. With this work, I aim to unpack these complexities with the guiding research question: *How can potable water reuse be implemented to ensure social and ethical desirability?* To answer this, the research is structured in three main phases, starting with problem space exploration, moving towards theory development, and ending with an *ethical assessment.*

The *problem space exploration* conducted through literature reviews begins by examining current literature to understand the values pertinent to potable water reuse in Chapter 2. This study revealed that while values such as safety, health, sustainability, and reliability are considered critical in the existing literature, they are predominantly framed as technological performance indicators. Broader social understandings and interpretations of these values are notably underrepresented, suggesting that crucial aspects influencing public opposition may be overlooked. Subsequently, Chapter 3 investigates how opposition, often framed as a 'social acceptance' issue, is understood within the current literature. Although acceptance is recognised as a complex and context-specific phenomenon, interventions designed to

enhance it often narrowly focus on public education, thereby neglecting a wider array of influencing factors.

The *theory development* phase investigates whether these potentially problematic, education-focused methods are implemented in practice. This is achieved by employing qualitative case study analysis of engagement strategies in three U.S. projects, which revealed varied approaches, with some prioritising securing acceptance over genuinely addressing public concerns (Chapter 4). This phase also utilises conceptual analysis to explore the ambiguous concept of 'acceptance' in infrastructure development, drawing from the more mature field of energy technologies. In Chapter 5, I propose the 'funnel of acceptance and acceptability' framework to structure different understandings and highlight 'ethical acceptability' as a key yet underdeveloped concept for assessing the ethical desirability within the potable water reuse field.

Finally, the *ethical assessment* in Chapter 6 synthesises insights from these preceding chapters to assess the ethical acceptability of potable water reuse. Here, I evaluate common acceptance-enhancing strategies on their potential drawbacks and offer an initial overview of additional critical ethical aspects of these projects. This assessment highlights frequently overlooked ethical concerns such as the potential marginalisation of non-vocal publics (including future generations, non-human entities, and indirectly affected communities), the risk that potable water reuse entrenches technological lock-in with large-scale, unsustainable infrastructure, unresolved challenges related to the management of concentrated waste streams, and fundamental equity issues, particularly concerning the affordability and fair access to high-quality drinking water.

Ultimately, I conclude that addressing either social acceptance (which focuses on local, temporal concerns) or ethical acceptability (which ensures morally desirable processes and considers systemic/future implications) in isolation is insufficient for more responsible implementation of potable water reuse systems. To truly ensure social and ethical desirability, these two vital dimensions must be treated in tandem – a strategy for which this dissertation lays the groundwork.

Employing a multi-method approach, this dissertation contributes to the practical field of potable water reuse and the scholarly field of Ethics of Technology. For the practical field, it critically addresses the mismatch between the nuanced theoretical understanding of social acceptance and the often simplistic approaches used in practice. Furthermore, I challenge the pervasive implicit assumption that potable water reuse is inherently 'good,' a viewpoint that risks overlooking significant social

and moral concerns such as the marginalisation of non-vocal publics, technological lock-in, and equity issues. By providing an initial ethical assessment of potable water reuse and analysing typical acceptance-enhancing strategies, this work establishes a foundation for understanding the technology's potential moral shortcomings. Concurrently, the dissertation offers theoretical contributions by adapting responsible research and innovation frameworks to understand infrastructure controversies better and by introducing the 'funnel of acceptance and acceptability' as a novel conceptual tool. This framework aims to clarify conceptual ambiguities and foster greater interdisciplinary collaboration in the study of technology acceptance and desirability.

Samenvatting

In dit proefschrift worden de sociale en ethische aspecten van afvalwaterhergebruik tot drinkwater behandeld.

In een tijd van toenemende wereldwijde waterschaarste en milieudruk, is afvalwaterhergebruik tot drinkwater, het proces waarbij afvalwater wordt gezuiverd zodat het geschikt is voor consumptie, een duurzamer alternatief voor waterbeheer. Echter, ondanks de technische haalbaarheid en de mogelijke voordelen zoals het behoud van zoetwaterbronnen en het verminderen van vervuiling wordt in de literatuur gesteld dat publieke weerstand een brede toepassing belemmert. Deze weerstand komt voort uit zorgen over veiligheid, de betrouwbaarheid van het systeem, het vertrouwen in overheden en een psychologische afkeer van het drinken van toiletwater (de 'ieuw-factor'). Om deze weerstand tegen te gaan is er een groeiende hoeveelheid literatuur die sociale acceptatie probeert te begrijpen en die interventiestrategieën voor een verhoogde acceptatie ontwikkelt.

Dit proefschrift stelt dat, hoewel het aanpakken van sociale acceptatie cruciaal is, de huidige aanpak onvoldoende is en voorbijgaat aan belangrijke sociale en ethische dimensies van het hergebruik van afvalwater. In dit werk probeer ik deze dimensies aan de hand van de volgende onderzoeksvraag in kaart te brengen: Hoe kan de sociale en ethische wenselijkheid van het hergebruik van afvalwater tot drinkwater gewaarborgd worden? Om deze vraag te beantwoorden, is het onderzoek opgebouwd uit drie hoofdfasen: het begint met een verkenning van de probleemruimte, gaat dan over in theorieontwikkeling en eindigt met een ethische beoordeling.

De verkenning van de probleemruimte gebeurt in hoofdstuk 2 met het onderzoeken van de huidige literatuur om de waarden te begrijpen die relevant zijn voor hergebruik van afvalwater tot drinkwater. Uit deze studie blijkt dat waarden als veiligheid, gezondheid, duurzaamheid en betrouwbaarheid weliswaar als cruciaal worden beschouwd, maar voornamelijk worden benaderd als indicatoren van technische prestaties. Bredere sociale opvattingen over deze waarden zijn ondervertegenwoordigd, hetgeen suggereert dat cruciale aspecten die de publieke weerstand beïnvloeden over het hoofd worden gezien. Vervolgens wordt in hoofdstuk 3 onderzocht hoe weerstand inde huidige literatuur wordt begrepen. Vaak wordt die weerstand als een kwestie van 'sociale acceptatie' gezien, waarbij interventies om deze acceptatie te vergroten zich eenzijdig richten op publieke voorlichting.

In de fase van theorieontwikkeling wordt onderzocht hoe deze op voorlichting gerichte methoden in de praktijk worden geïmplementeerd. Dit wordt gedaan door middel van een kwalitatieve casestudy van participatiestrategieën in drie Amerikaanse projecten. Uit deze study komen uiteenlopende benaderingen naar voren, waarbij sommigen prioriteit geven aan het verkrijgen van acceptatie in plaats van het wegnemen van publieke zorgen (Hoofdstuk 4). In deze fase vindt ook een conceptuele analyse plaats van het concept 'acceptatie' bij de ontwikkeling van infrastructuur. In hoofdstuk 5 stel ik het raamwerk van de 'trechter van acceptatie en aanvaardbaarheid' voor om verschillende opvattingen van 'acceptatie' te structureren, waarbij benadrukt wordt dat 'ethische aanvaardbaarheid' een belangrijk, maar nog onderontwikkeld concept is dat helpt bij de beoordeling van de ethische wenselijkheid binnen het veld van waterhergebruik.

Tot slot synthetiseert de ethische beoordeling in hoofdstuk 6 inzichten uit de voorgaande hoofdstukken om de ethische aanvaardbaarheid van afvalwaterhergebruik tot drinkwater te bepalen. Hier evalueer ik de mogelijke nadelen van gangbare strategieën om acceptatie te verhogen en bied ik een eerste overzicht van aanvullende ethische aspecten van deze projecten. Tot die aspecten behoren vaak genegeerde zorgen zoals: de mogelijke marginalisering van niet-gehoorde groepen (inclusief toekomstige generaties, niet-menselijke entiteiten en indirect getroffen gemeenschappen); het risico dat waterhergebruik leidt tot een technologische 'lock-in' van grootschalige, niet-duurzame infrastructuur; onopgeloste uitdagingen met betrekking tot het beheer van geconcentreerde afvalstromen en; rechtvaardigheidskwesties zoals de betaalbaarheid en eerlijke toegang tot drinkwater van hoge kwaliteit.

De conclusie van het proefschrift is dat het afzonderlijk aanpakken van sociale acceptatie (dat zich richt op lokale, tijdelijke zorgen) of ethische aanvaardbaarheid (dat gericht is op een ethisch proces en langetermijngevolgen) onvoldoende is voor een meer verantwoorde implementatie van afvalwaterhergebruik-systemen. Om de sociale en ethische wenselijkheid echt te waarborgen, moeten deze in samenhang worden behandeld.

Door een multi-methodeaanpak te gebruiken, levert dit proefschrift een bijdrage aan zowel de praktijk van waterhergebruik als het wetenschappelijke veld van de techniekethiek. Dat gebeurt door op de discrepantie te wijzen die bestaat tussen het theoretische begrip van sociale acceptatie en de reductionistische benaderingen die in de praktijk vaak worden toegepast. Verder draag ik de wijdverbreide, impliciete aanname uit dat hergebruik van afvalwater inherent 'goed' is, een standpunt dat het risico loopt belangrijke sociale en morele zorgen zoals de marginalisering van niet-gehoorde groepen, technologische 'lock-in' en rechtvaardigheidskwesties over het hoofd te zien. Door een initiële ethische beoordeling te geven en veelgenoemde strategieën voor publieke acceptatie te analyseren, legt dit werk een basis voor het begrijpen van de potentiële morele tekortkomingen van de technologie. Tegelijkertijd levert het proefschrift een theoretische bijdrage door kaders voor verantwoord onderzoek en innovatie (Responsible Research and Innovation) te specificeren waarmee controverses rond infrastructuur beter te begrijpen zijn en door de 'trechter van acceptatie en aanvaardbaarheid' te introduceren als een nieuw conceptueel instrument dat duidelijkheid biedt over de vraag naar technologische acceptatie en wenselijkheid.

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Completing this PhD journey has been a challenging experience, and it would not have been possible without the support and guidance of several incredible people and communities. I want to thank all of you for your love, support, and intellect!

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Introduction

1

Introduction

The world is facing a growing water crisis. Safe and reliable water access, a fundamental necessity for human life and well-being, is increasingly jeopardised in many regions. Global water availability is decreasing alarmingly, forcing many nations to look for alternative water sources (United Nations, 2017). Recycling already-used water sources has emerged as one potential alternative to soften water scarcity (Bates et al., 2008; Connor et al., 2017). This approach is praised for its sustainability benefits, such as conserving freshwater, reducing pollution, and even lowering our carbon footprint (Burgess et al., 2015). While these benefits support the freshwater conservation objectives outlined in the Sustainable Development Goals (United Nations, 2021a), reusing water remains deeply controversial.

Especially the systems aiming to treat wastewater directly to drinking water standards – potable water reuse – tend to generate significant tension. This tension largely stems from the way these systems challenge the long-established and deeply ingrained separation between wastewater management and the provision of safe drinking water (Pesch, 2015). The resulting public concerns, such as the safety of the treated water, system reliability, trust in responsible authorities and psychological aversion (the 'yuck factor') have proven persistent and are frequently identified as significantly driving public opposition towards these systems (see, e.g., Fielding et al., 2019; Leong & Lebel, 2020; López-Ruiz et al., 2021).

1.1. Potable Water Reuse

To better understand why potable water reuse raises concerns among the public, some definitional clarification and a general overview of this type of system are beneficial. First, *what does potable mean*? Potable water is essentially a term for drinking water – water that is treated to a quality standard considered safe for human consumption. Since 'potable' is the established term used in this context to describe systems that produce safe drinking water, I will continue using it throughout this dissertation.

The second question is *whether potable water reuse is a technology or a system*. In the context of this dissertation, I view potable water reuse as a socio-technical system that both shapes and is shaped by its social setting. Potable water reuse can take various forms and employ different treatment trains that consist of several sub-systems and technologies. Hence, in this dissertation, potable water reuse is understood as a system that utilises various technologies to treat wastewater to drinking water standards.

The general workings of potable water reuse are best illustrated when drawing from traditional waste and drinking water treatment practices. Conventional drinking water systems use groundwater or surface water as a source. Water reuse, or water recycling, refers to using treated wastewater or seawater as an alternative source (Kayhanian & Tchobanoglous, 2016). Here, wastewater refers to the water that domestic homes, industry, or agriculture have previously used, containing contaminants such as human faeces, oils, soaps, and chemicals. Water reuse systems, in turn, allow the reuse of such wastewater after treatment, which varies in intensity depending on its purpose and whether it will be potable or non-potable.

Two common potable water reuse systems are indirect potable reuse (IPR) and direct potable reuse (DPR). Both systems consist of complex treatment trains that can be constructed with various treatment technologies, depending on contextual requirements and constraints. Still, using an environmental buffer is the most significant difference between the two systems. With IPR, treated water is discharged into an environmental buffer such as a body of water (e.g., surface or groundwater), allowing for water storage in times of excess and providing additional time to identify contamination incidents (Gerrity et al., 2013). DPR does not use an environmental buffer between the wastewater and drinking water treatment plants, making it a viable option in regions where buffers are unavailable or inefficient due to high run-off or evaporation rates (Moya-Fernández et al., 2021).

The increasing similarity between the technologies employed in IPR and DPR systems has led to several institutions dropping the respective identifier and resorting to a single concept of potable water reuse (see, e.g. National Research Council, 2012). Despite increasing technological similarities, the systems differ in their diffusion status. While IPR is increasingly implemented worldwide with 29 operational plants, DPR has only three operating plants, in Windhoek (Namibia), Big Spring (Texas) and Mörbylånga (Sweden) (Jeffrey et al., 2022). The rising water scarcity and need for improved wastewater treatment have led to accelerating development and implementation of both systems (United Nations, 2017; United Nations Environmental Programme, 2023).

Additionally, emerging debates around the difficulty of removing certain substances, such as perfluoroalkyl and poly-fluoroalkyl substances (PFAS), are shifting the arguments for potable water reuse. These so-called 'forever chemicals' raise increased health and environmental concerns (see e.g., Wickham & Shriver, 2021). Adequate removal might require retrofitting current treatment plants with additional treatment steps, such as high-pressure membranes (e.g., reverse osmosis), activated carbon or ion exchange treatment (EPA, 2018; MacKeown et al., 2024). While integrating these treatment systems might be seen as a modification of existing treatment systems, it represents a significant technological and financial investment in technological solutions that closely resemble those used in potable water reuse systems. Once such advanced treatment systems are implemented, technical familiarity can develop and a significant part of the financial investments required for potable water reuse are made. Therefore, if regulations start driving the adoption of such advanced treatments in conventional plants, it seems likely that, together with increasing water scarcity, some form of potable water reuse will become more widely considered in the near future.

1.1.1. The Opposition towards Potable Water Reuse

Although potable water reuse systems seem to be on the rise, the opposition towards it has not been resolved and is often seen as a significant, if not the most important, barrier to system implementation. Indeed, in recent decades several projects such as the IPR projects attempted in Toowoomba, Australia (Hurlimann & Dolnicar, 2010) and San Diego's attempt of the '90s (Hartley, 2006; Po et al., 2003) have been halted due to fierce opposition, which manifested through various channels such as vocal community campaigns, organised protests, media coverage (see Figure 1.1) and significant political pressure exerted by concerned citizens and local groups. For example, during the conflict in San Diego, the slogan 'toilet to tap' was created, frequently used alongside a sketch showing a toilet directly connected to the home faucet. Since then, this slogan has been picked up by oppositional groups in various projects worldwide.

As such, a significant part of the current opposition towards potable water reuse seems to lie in the blurring of the waste and drinking water divide. Established centuries ago as a critical measure to prevent contamination and safeguard public health, this separation between waste and drinking water has become deeply ingrained in societal norms. Consequently, dealing with human waste is often considered a profoundly private or even taboo subject linked with shame and discomfort. Past innovations like flushing toilets have further distanced us from wastewater and human waste in our daily lives, reinforcing this separation (Pesch, 2015). Consequently, many people feel uneasy or disgusted by the idea of drinking recycled water, regardless of scientific assurances of its safety. This reaction highlights concerns not only about the reliability of the treatment process but also about the societal norms surrounding drinking water, waste and cleanliness.

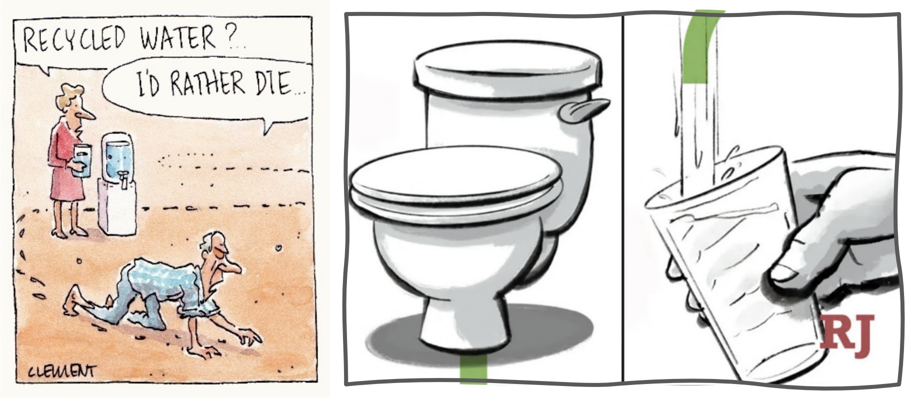

Figure 1.1: Cartoons depicting different responses to potable water reuse in local newspapers. Left image: ‘Recycled water’, © Rod Clement, used with permission. Right image: ‘From toilet to tap: How Las Vegas recycles its sewage water’, © Las Vegas Review-Journal, Inc. (2023), used with permission.

1.1.2. Research Objective and Research Questions

We see, thus, a tension between two narratives surrounding the viability of potable water reuse: (1) increasing water scarcity strengthens its technical necessity in many communities, while (2) the public opposition towards potable water reuse challenges its social viability. Crucially, both perspectives seem to lack a thorough normative evaluation, focusing primarily on technical feasibility or public opinion without considering its ethical dimensions.

The lack of attention to the ethical considerations of potable water reuse presents a critical gap. Overlooking the moral desirability of potable water reuse systems risks implementing technologies with inherent shortcomings (Taebi, 2017). Additionally, it risks resorting to potentially morally unacceptable means to gain social acceptance, ultimately pushing a technology undesirable for a particular society (van de Poel, 2016).

To address such potential adverse effects, this dissertation provides an ethical assessment of potable water reuse systems, operationalised through the central research question:

(RQ) How can potable water reuse be implemented to ensure social and ethical desirability?

This endeavour will be approached on a step-by-step basis throughout this dissertation. Figure 1.2 shows the overall outline, which is clustered into three distinct research phases: *Problem Space Exploration*, *Theory Development* and *Ethical Assessment*. Each of the phases has a different underlying goal supporting answering the research question. The *Problem Space Exploration* aims to provide a grounded understanding of what current literature considers significant challenges to potable water reuse implementation. From a social perspective, one of the most mentioned challenges emerging is the low social acceptance that potable water reuse continues to face. Building on this knowledge, I will commence with the *Theory Development* phase, where I map acceptance-building strategies used in ongoing potable water reuse projects and develop a more fine-grained understanding of the concept of acceptance. The groundwork and theory development allow for the final *Ethical Assessment* phase, combining this knowledge to ethically assess potable water reuse projects. In the following section, I will further highlight how each phase contributes to answering the research question.

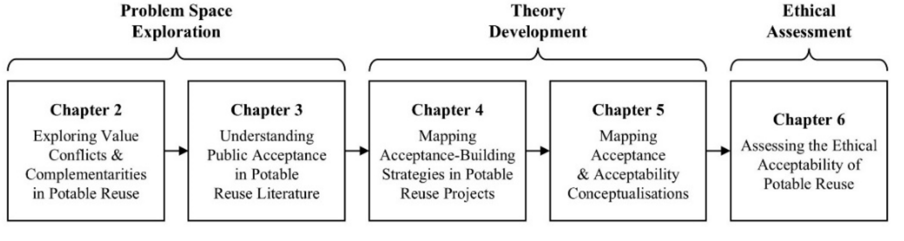

Figure 1.2: Dissertation Outline

1.1.3. Problem Space Exploration

Chapter 2 and Chapter 3 initiate this research with a *Problem Space Exploration.* In this research phase, I review the current literature on potable water reuse to establish a grounded understanding of the challenges the system is facing. To gain a broad overview of the values and challenges deemed relevant in potable water reuse research, Chapter 2 explores the current literature addressing this system with the sub-question:

(SQ 1) Which values are pertinent to potable water reuse in current literature, and how are they related

With the software package 'ValueMonitor' I analysed a large-scale data set of over 2900 articles, including engineering, policy, and social studies. This setup allowed the identification of the values deemed most relevant for this system in the current research literature. A subsequent analysis of the underlying reasons these values are addressed provided a broad understanding of the current challenges that potable water reuse faces, the types of research that address those and the potential conflicts that can arise between different values and their respective challenges.

The values landscape reveals areas of conflict surrounding potable water reuse, especially concerning public opposition, which I further explore and unpack with the second research question:

(SQ 2) How does the current literature frame the opposition towards potable water reuse?

An exploratory literature review showed that opposition towards potable water reuse is usually framed as a 'social acceptance' issue, a complex, context-specific concept with many influencing factors. With the help of an extensive academic and grey literature review of direct potable water reuse articles, I traced frequently recurring factors that impact the acceptance of this system and the proposed interventions to help increase acceptance. This research highlights a significant limitation: existing interventions focus predominantly on public education to enhance acceptance. However, this educational approach primarily targets factors related to public knowledge and awareness, thereby addressing only a small subset of the many factors impacting acceptance of potable water reuse.

1.1.4. Theory Development

The high focus on educating the public about the workings of potable water reuse systems and water scarcity is criticised for not always meaningfully tackling all underlying public concerns, potentially hindering the achievement of overall acceptance. While the literature is a possible indicator of underlying reasons for opposition found in current projects, findings in academic literature do not always translate directly into practice. Therefore, I aimed to investigate whether these potentially problematic methods are, indeed, also implemented in real-world projects. To do so, I analysed the public engagement strategies of three ongoing projects in the Southwest of the United States: San Diego (California), Phoenix and Scottsdale (Arizona). The resulting sub-question, addressed in Chapter 4, is therefore posed as follows:

(SQ 3) What types of acceptance-building strategies are applied in potable water reuse projects?

Through interviews and desk research, I reconstructed how the cities reach out to the public to increase acceptance of their potable water reuse project. To categorise different approach strategies, I adapted and utilised the 'leaving ajar' framework proposed by Russell, Stelmach, Hartley, Carter, and Raman (2022). This categorisation allowed me to assess whether the intention behind the cities' public outreach strategies is to secure acceptance or genuinely address public concerns. I found that each project has approached social acceptance in unique ways, reflecting their specific social, political, and environmental contexts as well as their implementation stage, where some cities focus more on securing acceptance over meaningfully addressing concerns.

Although the term social acceptance is frequently used in the literature on controversial technologies, such as potable water reuse, this concept remains highly ambiguous, with different meanings, variables and synonyms. Chapter 5 follows up on this conceptual ambiguity with the fourth sub-question:

(SQ 4) How is the concept of acceptance understood in large-infrastructure technology development?

Given that the research field of potable water reuse is rather narrow and only emerging, I turned to another, more mature field that assesses controversial technologies – the field of energy technologies. Social acceptance has gained increasing importance in the past decades, providing a fertile ground for researching different understandings of acceptance and its assumed synonyms. Social Energy Studies, Ethics of Technology and Innovation Studies have been shown to contribute most to varying interpretations of the concept. To provide more structure and better understanding across research fields, I developed a framework, the funnel of acceptance and acceptability, which locates different understandings of these concepts. A major finding is that acceptability can be used as a synonym for acceptance but is also used to assess a hypothetical' willingness to accept' a certain technological system and, more importantly for this dissertation, a system's *ethical desirability*.

An assessment of the ethical desirability of a technological system does not exist in the current literature on potable water reuse yet. Yet, it is seen as complementary to social acceptance by Ethics of Technology scholars (see, e.g., Taebi, 2017; Ibo van de Poel, 2016). Moreover, in the field of energy technologies, this concept has proven to uncover lingering concerns regarding technological developments that severely impact the desirability of technologies (e.g., Künneke et al., 2015; Oosterlaken, 2015). As such, this concept may also be helpful for assessing the ethical desirability of potable water reuse.

1.1.5. Ethical Assessment

Considering the ongoing implementation of potable water reuse projects, the lingering issues with social acceptance and a record of past failed potable water reuse projects, an ethical assessment seems essential. As indicated earlier, such an assessment can identify morally undesirable methods for increasing acceptance and highlight potential technological shortcomings before they become entrenched in society. Consequently, the final phase of this dissertation, the *Ethical Assessment*, will assess the ethical acceptability of potable water reuse. This phase is guided by the fifth and final sub-question, which serves to operationalise this ethical exploration:

(SQ 5) How can the ethical acceptability of potable water reuse be assessed?

Chapter 6 synthesises the insights gained throughout the preceding analyses of social acceptance approaches in potable water reuse. Drawing from the findings of the literature reviews and the case studies of San Diego, Phoenix and Scottsdale, this chapter establishes common overarching strategies employed to increase social acceptance of potable water reuse projects. These methods are then critically assessed for their ethical drawbacks, utilising ethical reasoning grounded in the scholarship of Ethics of Technology and responsible innovation. As such, this chapter serves as a first overview of ethical acceptability aspects critical in potable water reuse projects.

1.2. Ethics of Socially Disruptive Technologies

This dissertation is part of the Ethics of Socially Disruptive Technologies (ESDiT) program. Such disruptive technologies can change society's everyday life and challenge current values or basic concepts. Typically mentioned technologies are artificial intelligence, quantum technology or geo-engineering. The ESDiT program argues that such disruption needs to be analysed morally and that the challenged concepts must be investigated better to understand such technology's normative and social impacts before they diffuse into society. As highlighted, potable water reuse aligns with this characterisation of socially disruptive technology as it directly impacts a fundamental aspect of daily life – our drinking water. The system challenges long-standing societal norms regarding separating waste and potable water sources, thereby raising concerns, opposition and even rejection. As potable water reuse systems are increasingly considered and implemented globally, although still far from being diffused, this research aims to provide the critical moral analysis and conceptual investigation that ESDiT advocates: to better understand and navigate the ethical and social impacts of emerging disruptive technologies before widespread implementation.

Problem Space Exploration

2

Value-Sensitive Design of Potable Water Reuse: *Aligning Academic Research with Societal Concerns*

2.1. Introduction

As global water scarcity intensifies and demand continues to rise, there has been a notable surge in the exploration of sustainable water management practices in recent decades. Among the potential strategies in this pursuit, water reuse is a potential solution for conserving and efficiently utilising this finite resource. However, water reuse systems, particularly those for potable applications (henceforth potable water reuse), persistently encounter resistance (Lee & Jepson, 2020) despite the continuous development of approaches fostering acceptance (e.g. Furlong et al., 2019; Katz & Tennyson, 2015; Wilcox et al., 2016).

One reason for this may be that many approaches rely on the disputed information deficit model, assuming the main underlying issue of public opposition is a lack of information about the technology (Moesker et al., 2024b). This reductionistic perspective is at odds with insights from Value-Sensitive Design (VSD) − and Responsible Research and Innovation (RRI) in a broader sense − suggesting that public opposition arises when the technological design fails to accommodate relevant values (Taebi et al., 2014). Values can be regarded as critical aspects of life (Friedman et al., 2013), shaped by societal beliefs of what is worth striving for, and essentially serve as "orienting judgment devices" for present and future actions (van de Poel & Kudina, 2022). However, addressing all pertinent values can be demanding, partly because values can be conceptualised and can conflict in various ways, requiring design adaptations or value trade-offs (Taebi et al., 2014).

The importance of values in the water management sector is increasingly acknowledged, highlighted by the recently published United Nations World Water Development Report titled 'Valuing Water' (2024) and the rising interest in water ethics (Doorn, 2019; Schmidt, 2023). For example, researchers on public perceptions of potable water reuse often focus on delineating factors that impact acceptance of such systems (e.g., Dolnicar et al., 2011; Hartley, 2006; Po et al., 2003), implicitly suggesting that values such as safety and health are critical and must be addressed accordingly. However, it remains unclear whether current research adequately addresses these values that are relevant to society. There is reason for concern because the broader water management context has repeatedly been criticised for insufficiently considering the values of society (Correljé & Broekhans, 2015; Harrington et al., 2023; Ravesteijn & Kroesen, 2015). Although an important step towards incorporating values into technological design, these proposed values pertain to various water management practices, including flood management, water provision, and wastewater treatment. Some values may be relevant for one practice but less so for another. Moreover, these values emerged from the societal discourse, whereas the values considered relevant in current research may be significantly different.

As such, we do not yet sufficiently understand which values are deemed pertinent by potable water reuse scholars, how these values are conceptualised, and how they relate to each other. This neglect limits our ability to assess whether potable water reuse systems are designed in a value-sensitive manner, as it remains unclear whether academic values pertinent to potable water reuse align with society's values. As a result, engineers may unintentionally disregard values, even if they are essential to the social and ethical desirability of potable water reuse systems.

This paper aims to enhance our understanding of potable water reuse values by conducting a large-scale systematic literature review of scientific literature. We employ probabilistic topic modelling to identify latent values and their temporal development. Additionally, we use thematic analysis to interpret values relevant to potable water reuse, providing a value-sensitive perspective on research efforts. This approach enriches the ongoing debate on sustainable water management and encourages responsible development of these systems.

Following this introduction, Section 2 introduces key concepts like values, VSD, and potable water reuse. We then outline the research methodology, detailing data collection and analysis in Section 3. Section 4 presents the research findings, while Section 5 discusses their implications, limitations, and future outlook. Finally, Section 6 offers concluding remarks.

2.2. Theory

This section outlines the key concepts of this research. Section 2.1 covers Responsible Research & Innovation through Value-Sensitive Design, followed by an in-depth conceptualisation of values (Section 2.2). Then, Section 2.3 explains the workings of potable water reuse systems and their relationship with values.

2.2.1. Responsible Research and Innovation

Responsible Research and Innovation (RRI), occasionally referred to as Responsible Innovation, is an umbrella term for inclusive and risk-mitigating approaches to innovation (Burget et al., 2017; Wiarda et al., 2021) that embody one or more elements of the four dimensions of anticipation, inclusion, reflexivity, and responsiveness (Stilgoe et al., 2013). RRI involves a 'transparent, interactive process' where stakeholders and innovators work together to ensure the acceptability, sustainability, and societal desirability of the innovation process and its products (Von Schomberg, 2011). The approaches are, thus, based on the idea that including a wide range of different perspectives enhances the quality and ethical acceptability of decision-making and, consequently, allows for a better accommodation of society's values (Stirling, 2008). RRI seeks to proactively address unexpected and undesirable consequences of innovation through pre-emptive measures (Von Schomberg, 2011). For instance, Taebi et al. (2014) suggest that innovating responsibly should entail the assessment of technology's ethical and social desirability early on by identifying and embedding values. As such, RRI recognises that innovations are value-laden and that they impose a "vision of (or prediction about) the world" (Akrich, 1992, p. 208). While there are numerous ways in which RRI can be conceptualised and articulated (Fisher et al., 2024), we are specifically interested in the values that are inscribed into the design of potable water reuse systems. It is precisely the approach of VSD that is concerned with identifying and designing for such values (Heezen et al., 2023).

The Value-Sensitive Design (VSD) approach is often considered a cognate and/or a substantiation of RRI (Fisher et al., 2024; Jenkins et al., 2020; Simon, 2017). Both approaches suggest that technology is not simply a material, value-neutral artefact but argue that these technologies reflect the values of designers and engineers and do not necessarily accommodate users' and society's needs (van den Hoven et al., 2015a). VSD was developed initially by Friedman, describing it as "a theoretically grounded approach to the design of technology that accounts for human values in a principled and comprehensive manner throughout the design process" (Friedman et al., 2013, p. 56). It rests on the premise that we can uncover relevant values before technology diffuses in society (van de Poel, 2021). Over time, this approach has evolved into sub-forms like Design for Values, proactively integrating values into technology design (e.g. van den Hoven et al., 2015b), and Values in Design, analysing how values are embedded in existing technologies (e.g. Knobel & Bowker, 2011).

2.2.2. Values, Value Conflicts and Value Change

VSD critically hinges on the notion of values while recognising that they are inherently contested, plural, and open to interpretation. The way values are conceptualised can, therefore, differ substantially across disciplines and studies. For instance, some scholars have conceptualized 'trust' as a value (e.g., Nickel, 2015; Vermaas et al., 2010), whereas others view it as a mediator between values (e.g., Gullberg et al., 2023). Categorizations of values are likewise contested. Schulz et al. (2024), for example, differentiate between governance-related values, fundamental values, and assigned values. Other scholars have similarly categorised different types and domains of values (e.g., Shalsi et al., 2024), such as moral values (Quine, 1979), human values (Schwartz & Bilsky, 1987), organisational values (Bourne & Jenkins, 2013), intrinsic values (Kagan, 1998), amongst many others. Against this background, VSD tends to view values as socially constructed concepts that express what is deemed good or desirable. In this research, we specifically focus on 'public values', which we understand as matters that are widely shared and sustained by a community and which act as a foundation for collective decision-making (c.f., Bozeman, 2007; Jørgensen & Bozeman, 2007). Such values are considered important in life and are shaped by the beliefs and desires of a contextually situated person (Friedman et al., 2013). Yet, values are not merely personally held preferences but reflect an understanding of what is worth striving for within a particular society (van de Poel, 2009b). Hence, values are inter-subjective (Taebi & Kadak, 2010) and serve as "orienting judgment devices" for present and future actions (van de Poel & Kudina, 2022, p. 40).

At the same time, accommodating several values can be challenging as they can be conceptualised differently, oppose each other, or change over time. Values are thus not discrete entities (Demski et al., 2015), and prioritising one value can come at the cost of other values (Popa et al., 2023). Such opposing values are referred to as value conflicts (de Wildt et al., 2019) and can occur when "considered in isolation, they evaluate different options as best" (van de Poel, 2009b, p. 977). For example, the value of performance often comes at the expense of the value of affordability. Such value conflicts can be addressed through adapting innovations but generally require value trade-offs, meaning one value is to be prioritised over the other (Künneke et al., 2015). In contrast to such value trade-offs, innovations can also overcome value conflicts. For instance, the storm surge barrier for Dutch deltas could resolve the conflict of environmental impacts (sustainability) and provide safety from flooding – values that were previously thought to be inconsumable (Correljé & Broekhans, 2015).

Values are often considered to be universal, stable entities. Yet, they are not necessarily static but are "dynamic, holistic and systemic entities" that are subject to change with societal and technical development (Correljé et al., 2022; van de Poel, 2021). The dynamic nature of such value prioritisation is often referred to as value change, alternatively known as technomoral change (Swierstra, 2013) or moral revolution (Appiah, 2011; Baker, 2019). Scholars studying value change seek to understand how and why values change over time, often with a particular focus on the role of technology development. For instance, Swierstra (2013) suggests that value change stems from moral uncertainty introduced by scientific and technological advancements.

Van de Poel (2021) further suggests that value change can manifest in different forms, such as the emergence of new values, shifts in value prioritisation within a technological design or alterations in value conceptualisations. "[Values] carry over from earlier experiences" (van de Poel & Kudina, 2022, p. 1), and from an evolutionary perspective, one may argue that processes of variation, selection, and retention create emergent value trajectories that are path-dependent but prone to contingency (Wiarda et al., 2024). Value change can be radical (i.e., short-term value change) and incremental (i.e., long-term value change) (Abramson & Inglehart, 2009). Here, short-term radical changes are usually a response to substantial alterations in one's environment, while decades-long incremental changes are much harder to explain (Manfredo et al., 2017). Changing values can lead to challenges once embedded in designs and society, exemplified by the current difficulties of accommodating sustainability in our transportation systems, a historically overlooked value (van de Poel, 2021). Value change can become problematic for large infrastructures like transportation and water systems, as these systems have been utilised for decades, risking becoming unacceptable if they no longer align with society's value prioritisation (de Wildt et al., 2022).

2.2.3. Potable Water Reuse and Values

In this study, we view potable water reuse systems as socio-technical systems that shape and are shaped by their social context. Potable water reuse refers to treating wastewater (previously used by households, industry, or agriculture) and repurposing it (Kayhanian & Tchobanoglous, 2016). Wastewater treatment levels vary based on whether the intended reuse is potable or non-potable. Traditional drinking water systems typically rely on groundwater or surface water, while potable reuse offers an alternative source by treating and recycling wastewater.

Two commonly discussed reuse systems for potable water are indirect potable water reuse (IPR) and direct potable water reuse (DPR)[1]. Both systems consist of complex treatment trains that can be constructed with various treatment technologies, depending on contextual requirements and constraints. With IPR, treated water is discharged into an environmental buffer such as a body of water (e.g., surface or groundwater), allowing for water storage in times of excess and providing additional time to identify contamination incidents (Gerrity et al., 2013). DPR does not use an environmental buffer between the wastewater treatment and the drinking water treatment plant, making it a viable option in regions where buffers are unavailable or inefficient due to high run-off or evaporation rates (Moya-Fernández et al., 2021). The growing similarity in technologies used for IPR and DPR has led to a shift towards a unified concept of potable water reuse (see, e.g. National Research Council, 2012).

Potable water reuse scholars often only address values implicitly, together with other factors of public acceptance, rather than discussing them as standalone entities (see, e.g. Po et al., 2003; Scruggs et al., 2020). Yet, the so-called 'Yuck factor' and perceptions of risk (Duong & Saphores, 2015; Leong & Lebel, 2020), knowledge about technologies (Boyer et al., 2017; Khan & Anderson, 2018), and the urgency of addressing water shortages (Scruggs & Thomson, 2017) have been shown to impact public acceptance significantly and indicate that the values of health and safety are deemed essential by society.

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[1] We deliberately exclude desalination systems from our scope because these systems use different technologies than IPR and DPR, and are often used in different geographical and socio-economic contexts.

Despite the recognised importance of values in water management, a specific value landscape[2] for potable water reuse has yet to be established. While the broader field of water management increasingly acknowledges the critical role of society's values (Gullberg et al., 2023; Schulz et al., 2024), historically, designing for values has often been absent or only implicitly considered (Correljé & Broekhans, 2015; Ravesteijn & Kroesen, 2015). The UN's 2021 'Valuing Water' report criticises this historical neglect and highlights significant underdevelopment in capturing societal and environmental values in water management (Sandhu et al., 2023; Shalsi et al., 2024; United Nations, 2021b).

Some prominent studies on values in water management have explored what values are important in the water domain. As discussed, Schulz (2017) works with *fundamental values* (core personal convictions like power, security, and benevolence), *governance-related values* (guiding decision-making processes, such as efficiency, sustainability, and solidarity), and *assigned values* (context-specific values attributed to water resources, like biodiversity, aesthetics, or economic value). Ravesteijn and Kroesen (2015) focus on engineered solutions and differentiate between technology-dependent, management-dependent, and historical cultural-dependent values, highlighting the values of safety, security, sustainability, justice, and participation. Specific technological contexts like reusing coal seam water show a strong focus on technology-dependent values, thereby neglecting societal implications such as justice, conservation and sustainability (Shalsi et al., 2024). Research often overlooks values relevant to society, including cultural understandings of water, justice, and equity concerns (Harrington et al., 2023; Meehan et al., 2020). More recently, justice considerations have gained attention in water ethics (e.g., Doorn, 2019; Schmidt, 2023) and within the Sustainable Development Goals framework (see, e.g., Houngbo, 2023; United Nations, 2022), indicating a potential shift towards broader value considerations.

The inherent complexity of water management in the diverse context of challenges, ranging from scarcity to pollution, makes it difficult to generalise the relevance of specific values. Certain values may be highly relevant to some challenges but less to others, making it difficult to generalise their relative importance. Precisely in such contexts, VSD highlights the need for a well-defined, context-

[2] Following Schulz (2024) the term "value landscape" is used here to denote the pluralistic and often interconnected set of values relevant to a particular domain, acknowledging that these values can be conceptualised and prioritised differently.

specific value landscape for technological success (Friedman et al., 2013; van den Hoven et al., 2015a). Yet, it is crucial to acknowledge that the values pertinent to a technological intervention like potable water reuse represent a subset of the broader water management value landscape. Our study represents a first step in understanding which public values are reflected in potable water reuse research. This study systematically identifies and conceptualises the values featured in the academic literature on potable water reuse, offering a starting point for understanding which public values are reflected and providing a basis for value-sensitive design.

2.3. Methodology

To identify dominant values in potable water reuse research and track how these values have evolved, we conducted a systematic literature review in combination with probabilistic topic modelling. Figure 2.1 provides an overview of the review process. Section 3.1 covers our data collection, followed by Section 3.2, which explains the data analysis.

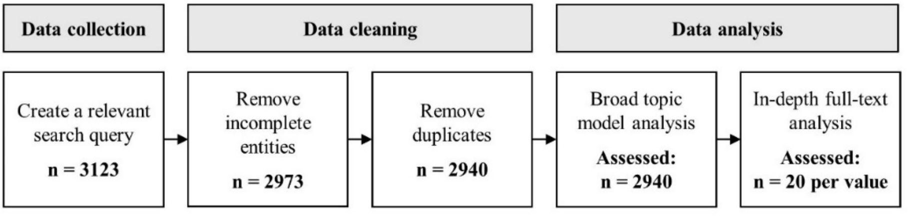

Figure 2.1: Systematic literature review process

2.3.1. Data Collection and Cleaning

We first built a dataset suitable for topic modelling to identify and describe latent values inscribed in potable water reuse research. To do so, we followed the topic modelling guidelines as presented by (de Wildt et al., 2018): (1) choosing an appropriate text corpus, (2) ensuring the sufficient size of the dataset, and (3) restricting the data to the desired research topic.

(1) To assess the current value landscape of academic research on potable water reuse, we used Scopus as our database because it predominantly contains scholarly literature and is the most extensive publication database available (Falagas et al., 2008; Visser et al., 2021).

(2) To make this dataset suitable for topic modelling, the size of the dataset needed to be sufficiently large. A minimum of 1000 entities is often required (van de Poel et al., 2022).

(3) Probabilistic topic modelling research involves text-mining the semantic structures of each document. The dataset must be valid, as no exclusion criteria will apply beyond general data cleaning (e.g., removing incomplete and duplicate entries). Crafting the appropriate search query is critical and requires an iterative process. The desired dataset should be broad enough to capture various studies on potable water reuse but narrow enough to exclude other treatment systems like desalination. Thus, we used terms like "water reuse" and its synonyms, along with "direct potable water reuse" or "indirect potable water reuse" combined with "potable," "drinkable," or "drinking." The used query is as follows:

(4) TITLE-ABS-KEY (("Water Reuse" OR "Water Recycling" OR "Recycled Water" OR "Direct Potable water reuse" OR "Indirect Potable water reuse" OR "Advanced Water Purification") AND ("potable" OR "drinkable" OR "drinking") AND NOT ("Desal*") AND PUBYEAR > 1989 AND PUBYEAR < 2024)

Our data collection resulted in a dataset of 3123 records, including metadata such as titles, publication years, abstracts, DOIs, and more. Then, we manually removed incomplete entities (without an abstract or author information) and duplicates, leaving 2940 records for our topic modelling.

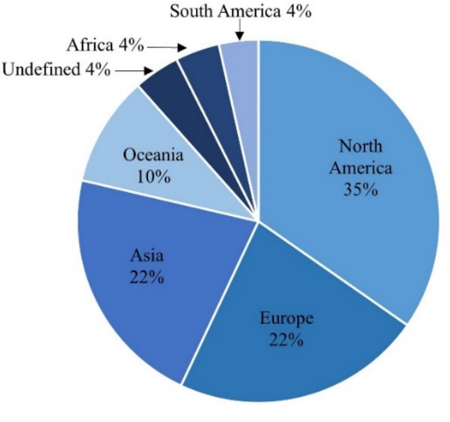

Figure 2.2: Geomapping the continents of potable reuse institutes

Country	Share
United Kingdom (Europe)	3.5%
Germany (Europe)	3.2%
India (Asia)	3.0%
United Kingdom (Europe)	3.5%
Germany (Europe)	3.2%
India (Asia)	3.0%
Brazil (South America)	2.7%
Canada (North America)	2.6%
Netherlands (Europe)	2.4%
Rest	35.1 %

Table 2.1: Affiliated countries of potable reuse institutes

We find that a significant number of our sample's records is attributed to North America (35%), Europe (22%) and Asia (22%)[3] (See Figure 2.2 and Table 2.1). A considerable share of North American contributions come from the United States (31.3%). Australia is the second largest contributor to our sample, following with a share of 9.6% records; other large contributors come from Asia, such as China (6.7%) and India (3%). Based on our geomapping, one could argue that Western-oriented values may be more represented in the sample (e.g., North America, Europe, and Australia).

2.3.2. Data Analysis

Using our cleaned dataset, we conducted topic modelling to identify dominant values in potable water reuse systems (Section 3.2.1) and conceptualised these values using thematic analysis (Section 3.2.2).

Identifying Values

Values are often latently discussed in texts (de Wildt et al., 2018). For instance, when referring to the value of justice, authors do not necessarily use the term justice. Instead, they may use synonyms, cognates, or closely related words that collectively refer to the value of justice (e.g., fairness, equity, equality, etc.). Hence, analyses that solely focus on the word justice may omit essential records that are relevant to our understanding of the value, rendering value identification through keyword-based searches difficult. Using multiple closely related keywords can help identify latent values but commonly results in a higher number of irrelevant documents (de Wildt et al., 2022). For example, the word 'just' could also refer to a phenomenon that 'something just happened'.

To address this challenge, we used a software package called ValueMonitor[4], developed to identify latent values from records, and which relies on a widely used probabilistic topic modelling software called Corex (Gallagher et al., 2017). Topic modelling is a form of text-mining that considers the distribution of words when identifying latent concepts. Each word is assigned a certain weight, corresponding with the likelihood that specific values are found in records. Continuing with the same example, when the word justice is given a relatively low weight, associated

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[3] This analysis is based on the raw dataset provided by Scopus.

[4] https://valuemonitor.eu/

words such as equity and fairness will need to receive a high weight before the software concludes that a record indeed refers to the value of justice.

The creation of word distributions is an iterative process for which keywords are fed into the software to guide specific topic formulations (de Wildt et al., 2022). The ValueMonitor was developed to identify public values across various domains, of which the more detailed theoretical underpinnings have been extensively described and tested in other studies (c.f., De Wildt et al., 2022; van de Poel et al., 2022; Wiarda et al., 2024). The tool was developed for the European Research Center to investigate the latent values embedded within emerging technologies.

ValueMonitor's language model currently contains word distributions for 28 different public values (see Appendix I for definitions). Generally speaking, topic modelling works more reliably when using texts of roughly 50-300 words to identify these latent values and trace their prevalence over time, as van de Poel et al. (2022) demonstrated. We utilized ValueMonitor to identify latent values from our records' abstracts. After identifying values, we use the publication dates of each record to trace the values over time. This yields insight into the relative importance of different values over the last 30 years.

Conceptualising Values

After the ValueMonitor identifies prevalent values in the dataset, we manually review the full text of the top 20 most cited articles for each value, as these are likely the most influential in constructing the contextual conceptualisation in the field. We applied an inductive thematic analysis using open and axial coding and categories, where we first searched for the respective values within the text and then identified relationships and patterns among them. For open coding on the sentence level, we utilise value definitions provided by ValueMonitor as our coding rules. For instance, the value of justice is described as "fair and equal treatment". Here, one author conducts the thematic analysis for each value, after which the remaining authors check the themes against the coding rules for validity. We also examine whether these articles link values to capture potential relationships. While this step is not meant to be an exhaustive analysis of value relationships, we use it exploratively to understand better how values are entangled in research.

2.4. Results

Section 4.1 presents the most frequently mentioned values in potable water reuse literature and their changing prevalence. Section 4.2 explores the dominant conceptualisations, whereas Section 4.3 examines value conflicts and complementarities.

2.4.1. Identifying and Tracing Pertinent Values

As seen in Figure 2.3, reliability and sustainability are the most frequently occurring values in this data set, with 1529 and 1144 document counts, respectively. Moreover, health, with 569 and safety, with 481 counts, seem to be highly common values for water reuse systems. As these four values seem most influential in this case, we will examine how they are conceptualised in the literature.

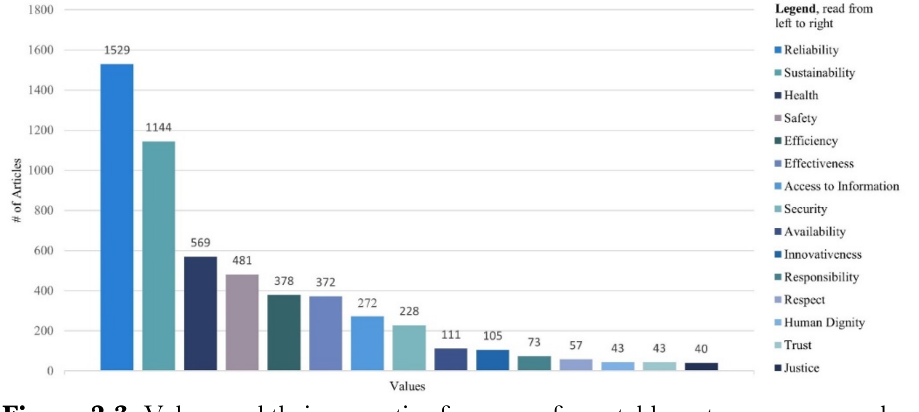

Figure 2.3: Values and their respective frequency for potable water reuse research

If we trace the prevalent values over time (see Figure 2.4) we observe a stark growth in all values proportionally corresponding to the increase of potable water reuse studies. The results suggest that the relative importance of the four key values has remained roughly consistent over time, with reliability and sustainability being significantly more prominent than health and safety. As such, societal debates and changing requirements do not seem to have affected these values over time. The precise cause of this peak is unclear, although it may speculatively be linked to increased global discussions around the human right to water, with the release of the IPCC's Fourth Assessment Report in 2006/2007 (IPCC, 2007), and a UN Special Rapporteur appointed in 2008 (Human Rights Council, 2008), which could have stimulated research on water-related challenges.

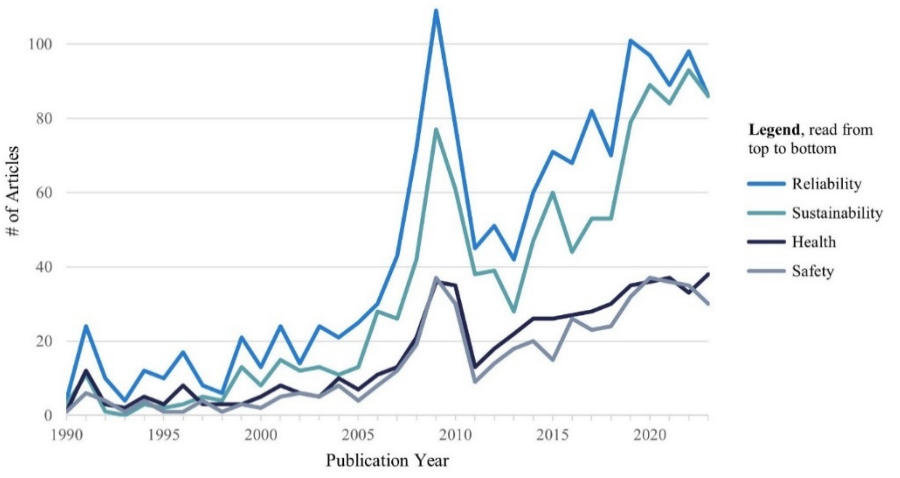

Figure 2.4: Value dynamic of potable water reuse between 1990 and 2023

2.4.2. Understanding Pertinent Values

Reliability

Population growth and the exacerbating effects of climate change, such as more extreme and longer-lasting droughts, "make traditional supplies unreliable" as a source of drinking water (Warsinger et al., 2018, p. 211). In this context, reliability is measured by a region's climate and the ability of a specific water source to meet water demand.

Yet, the ValueMonitor reveals that the concept is predominantly linked to another conceptualisation: the water reuse system's performance. For example, Tang et al. (2018) postulate that water reuse "[…] offers a reliable and sustainable solution to cities and regions facing a shortage of water supply" (p. 10215). In such a context, the system's reliability is often directly associated with the ability of a system to produce high-quality water, meaning that drinking water quality standards are sufficiently met (see Ahmad et al., 2003; Tang et al., 2018). However, these standards are criticised as outdated and needing revision, especially regarding emerging organic contaminants (Pal et al., 2014).

Reliability is also a recurring concept in membrane research, particularly in addressing the common issue of fouling. Membranes are pretreatments within wastewater treatment processes and are regarded as potentially viable solutions, receiving much attention (e.g. Bellona et al., 2004; Lutchmiah et al., 2014; Warsinger et al., 2018). Filtration membranes are often threatened by fouling.

Consequently, scholars have researched various pretreatment options and membrane materials to decrease the fouling rate (e.g. Ahmad et al., 2003; Kimura et al., 2004). Yet, membrane filtering is generally "less reliable for water treatment than physical sieving" for contaminant particles smaller than the membrane pores (Huang et al., 2009, p. 3012). Moreover, inconsistent study results on the reliability of contaminant removal, incomplete tracking of substances, and the uncertainty about the effect of emerging contaminants shed doubt on the performance of particular water treatment trains (Escher et al., 2014; Le-Minh et al., 2010).

Sustainability

The value of sustainability has several meanings in the context of water reuse systems but specifically refers to environmental sustainability. Drinking water is becoming increasingly scarce (Gomes et al., 2017; Oki & Kanae, 2006) because of climate change and water pollution with heavy metals, biological agents, and other miscellaneous substances (Gupta et al., 2009). This trend motivates research to understand better how to remove pollutants without further harming the environment through byproducts. As Li et al. (2008) put it: "The challenge to achieve appropriate disinfection without forming harmful disinfection byproducts by conventional chemical disinfectants [...] calls for new technologies for efficient disinfection and microbial control" (Li et al., 2008, p. 1). Various absorbents have been proposed to combat pollutants (Gupta et al., 2009), such as bioreactor technologies (Melin et al., 2006; Yang et al., 2017), forward/reverse-osmosis membranes (Lutchmiah et al., 2014; Tang et al., 2018) and biochar (Inyang & Dickenson, 2015).

Water reuse systems are "critically examined according to specified criteria for performance and sustainability" (e.g., quality of treatment, energy usage; Sobsey et al., 2008, p. 4261), facing at least three types of sustainability challenges. First, sustainability may be affected by a lack of the value 'effectiveness'. Authors report cases in which water treatment technologies inadequately remove artificial sweeteners (Scheurer et al., 2009) and antibiotics, the latter leading to bacterial resistance and the contamination of local surface, ground, and drinking water (Fick et al., 2009; Le-Minh et al., 2010). Second, the treatment technologies themselves may also be harmful. While carbon nanoparticles can remove bacterial pathogens, natural organic matter, and cyanobacterial toxins (Li et al., 2008), particular water filters can severely affect aquatic life and our food chain when released into the environment (Upadhyayula et al., 2009). Third, water reuse systems can create unsustainable byproducts such as residual sludge; how this waste can be managed sustainably remains unclear. However, Babatunde and Zhao (2007) propose that residual sludge should be used for several purposes, including construction materials and land-based applications in the future.

Health

The concept of health can be related to two distinct subjects, humans and the environment, where the former has received significant attention. Moe and Rheingans (2006) suggest that human health is related to water for drinking, hygiene and feed production. Water affects public or human health, but "poor and disadvantaged populations are the ones who will suffer most from the negative effects of climate change on water supply" (DeNicola et al., 2015, p. 1).

In water reuse systems literature, a significant fraction assesses the challenges related to physical health. Bruce et al. (2010) draw attention to the "public health significance of trace levels of pharmaceuticals in potable water [...] particularly with regard to the effects of long-term, low-dose exposures" (p. 5619). For example, Xi et al. (2009) express concerns over current water treatment systems that cannot effectively remove antibiotic-resistant bacteria and argue that these bacteria could subsequently spread via potable water distribution systems. Other scholars are concerned with disinfectant byproducts and their potential health impacts (Krasner, 2009). Moreover, uncertainty about the health implications of trace organic contaminants such as pharmaceuticals and personal care products remains due to the lack of long-term research data (Alexander et al., 2012). As a result, wastewater treatment methods, such as coagulation-based processes or plasma-based water purification, are tested on their adequateness in removing such contaminants (e.g. Alexander et al., 2012; Foster, 2017).

Next to physical health, some scholars suggest that health concerns are linked to social acceptance and environmental sustainability. For example, in the United States, public debates reflect unease about the health implications of using water reuse systems (Hartley, 2006). Hartley (2006) observes that even within the scientific and technical communities, these debates are not simply resolved as they "disagree over the public health viability of indirect potable water reuse, with major water resource professional associations and respected research and expert panels taking opposing positions" (p.117). At the same time, the potential impacts of contaminants are prone to high degrees of uncertainty (Reungoat et al., 2010). Studies have, therefore, examined the environmental effects of pollutants produced or not removed by wastewater treatment methods (see, e.g. DeNicola et al., 2015; Pal et al., 2014).

Safety

The goal of any drinking water treatment plant, irrespective of whether it is part of a water reuse system, is to provide safe drinking water. In this context, safety appeals to the composition of water – devoid of pollutants. Research primarily aims to understand the long-term impacts of pollutant exposure better, but this appears challenging due to limited data availability (see, e.g. Bruce et al., 2010; Rayne & Forest, 2009).

The value of safety is applied to either understanding particular contaminants (see, e.g. Cacciò et al., 2003; Johnson et al., 2008; Rayne & Forest, 2009) or assessing and developing methods to remove these (see, e.g. Fanourakis et al., 2020; Upadhyayula et al., 2009; Westrick et al., 2010). For example, Cacciò et al. (2003) found a presence of giardia cysts in several Italian wastewater systems after treatment, which "increase the risk of human infection with these pathogens" (p. 3397). From a methodological perspective, Upadhyayula et al. (2009) criticise the use of carbon nanotube technologies for their potential cytotoxicity, which induces "drastic safety and environmental impacts" (p.10). Moreover, impact assessments of other cytotoxic contaminants (e.g., chemotherapeutic drugs) on the aquatic environment are severely lacking (Johnson et al., 2008). Scholars, therefore, advocate for regulations that help safeguard the environment and urge to "[…] first consider the safety of receiving water bodies" (p.550) before turning to water reuse systems (Qu & Fan, 2010, p. 550).

The value of safety is also discussed in relation to public perceptions, acceptance and system security. For example, de França Doria (2010) claims that factors such as trust in authority, familiarity with tap water, and perceived water quality contribute to the public's perceived risk. Research shows that risk perception is highly influenced by trust in executing authorities (Ross et al., 2014). Moreover, safety perceptions seem to be intricately linked with social acceptance. Supporting this, a study on online shopping behaviour found that consumers' acceptance of recycled water products relies heavily on safety perceptions provided by consumers' reviews (Fu et al., 2020).

2.4.3. Value Conflicts and Complementarities

With the key values identified and conceptualised, we can examine their relationships – value conflicts and value complementarities[5]. Value conflicts often arise when prioritizing one value results in compromising another. Our research identified a significant value conflict within the study of specific technologies used in potable water reuse systems, illustrated by a critical and extensively researched treatment stage: membrane filtration.

Membranes are increasingly vital elements in waste and drinking water treatment systems. Although they are considered to produce low-cost (affordability), high-quality water (safety) with a low carbon footprint (sustainability), membrane fouling remains a significant challenge (Huang et al., 2009). This accumulation of contaminants on membrane surfaces can jeopardise the long-term quality of the produced water (reliability) (Tang et al., 2018). To overcome this challenge, extensive research has focused on optimizing the membrane design and adding another treatment step, introducing complexity to the treatment system. For example, membrane pretreatments have been shown to provide superior reliability but often necessitate additional non-reusable chemicals (Huang et al., 2009), are highly energy intensive (Tang et al., 2018), or create toxic sludge (Babatunde & Zhao, 2007), again impacting the treatment system's sustainability.

These examples show that optimizing for one value must be balanced with other relevant values in water treatment technology. The currently proposed technologies and approaches prioritize reliability over sustainability, making them appear incompatible. However, ongoing research aims to overcome this dichotomy, indicating rising awareness about the importance of sustainability. For example, advancements in membrane technology employing biodegradable materials or innovative pre-treatment processes reducing chemical usage and energy consumption are being explored to balance these competing values (see e.g., Li et al., 2008; Lutchmiah et al., 2014)

Moreover, this research shows that several values are intricately interlinked, where the promotion of one value triggers a chain reaction affecting others. We refer to these relationships as value complementarities which particularly arose when considering the challenge of effectively removing contaminants, thereby explicitly affecting the safety of the produced drinking water. The complementarity between

[5] These value conflicts and complementarities are based on the four most frequently identified values. A reflection on the limitations of this methodological decision is given in Section 5.2.

reliability and safety is widely recognised, though often implicitly addressed through the enhancement of specific technologies (e.g., Kimura et al., 2004; Warsinger et al., 2018). Furthermore, safety concerns can also extend to sustainability concerns of these systems, particularly regarding the environmental impact of discharging inadequately treated wastewater. For instance, releasing contaminants such as carbon nanotube particles (Upadhyayula et al., 2009) or cytotoxic substances used in chemotherapy (Johnson et al., 2008) can cause significant harm to the aquatic environment. Lastly, the inadequate removal of contaminants not only impacts sustainability but can also pose health concerns. For example, contaminants can enter the human body through drinking, promoting the development of antibiotic resistance in humans (Fick et al., 2009; Le-Minh et al., 2010) or accumulate in the food chain, inducing additional health risks (Upadhyayula et al., 2009).

Thus, value complementarities are often observed when one particular value is harmed, leading to a chain reaction that affects other values. Safety emerges as a central concern in potable water reuse systems, playing a critical role in supporting both health and sustainability, while reliability is vital to maintaining safety.

2.5. Discussion

This paper offers a value-sensitive perspective on water reuse by identifying and conceptualizing pertinent values in research. We identified four most pertinent values in research on potable water reuse, namely:

- Reliability: interpreted at the system level as increased water availability but is mainly used in the context of the ability of water reuse systems to produce 'high-quality' drinking water standards by effectively removing contaminants.
- Sustainability: understood as the environmental impact of technology. It appears critical for overall water availability but is mainly associated with effectively removing pollutants before releasing treated wastewater into the environment.
- Health: relates to human and environmental well-being, focusing on the threats posed by pollutants. Research often emphasises treatment systems that eliminate harmful contaminants, as health concerns drive public concerns about water reuse.
- Safety: addresses specific pollutants remaining in treated water. Most research aims to identify and remove these contaminants, while some emphasise the relationship between safety and public perception.

Research primarily focuses on the ability of potable water reuse systems to produce safe, high-quality water, which is critical for health and sustainability but remains challenging. Notably, we see that the pertinent values are often conceptualised in a technical manner. This observation is unsurprising, as this review revealed that most academic research on potable water reuse focuses on developing and optimizing treatment technologies, which aligns with findings from previous studies that examine values in the broader field of water management (see Ravesteijn & Kroesen, 2015; Shalsi et al., 2024). A reason for this technocentric focus may be that choosing technological interventions, like potable reuse, often reflects an underlying anthropocentric worldview from a monodisciplinary perspective that implicitly prioritises values associated with human control and manipulation of natural systems (see Schulz et al., 2017).

We furthermore analysed the relationships between the four most recurring values in academic research. Reliability, safety, and health are widely recognised as complementary, while the relationship between safety and sustainability is somewhat ambivalent, at times conflicting and at others complementary. The nature of the relationship between safety and sustainability appears to depend on the research perspective (illustrated in Figure 2.5). Here, especially the value of sustainability appears to be defined in various ways, which does not necessarily imply direct value conflicts but could also be symptomatic of different understandings of the concept. As such, concept clarity is essential to mitigate ambiguity.

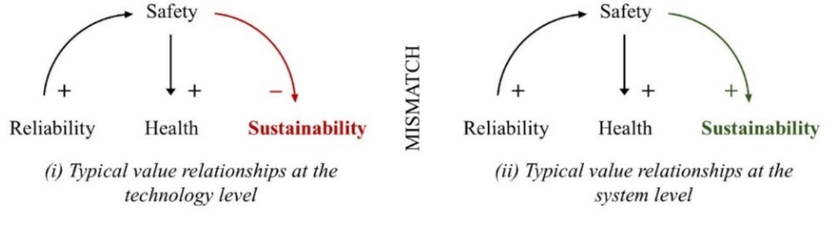

Figure 2.5: Schematic of typical value relationships [+ denotes value complementarities, and – denotes value conflicts]

Technology-level research focuses on developing or optimizing specific technologies used in potable water reuse systems. From this perspective, engineers seem able to design for reliability, safety, and health effectively, where improving one value benefits the others. However, broader sustainability issues may be overlooked. System-level research emphasises the broader implications of these values, such as overall environmental and human impacts, but can overlook technical limitations.

Given the dominance of technology-level research, these broader sustainability aspects are likely underemphasised and raise the question of to what extend academic values reflect societal concerns.

2.5.1. Does Academic Research Align With Society-Level Values?

At first glance, the prevalence of reliability, sustainability, health, and safety suggests a reasonable alignment of research with societal concerns. However, this apparent alignment masks discrepancies and complexities in conceptualising these values. While research addresses these values, it does so primarily through a *technical* lens. Although this is important for developing effective treatment systems, other critical social aspects may be overlooked – a concern supported by broader critiques of technology development (van den Hoven et al., 2015a; Winner, 2017). For example, studies on public acceptance and water security emphasise the perceptual and social dimensions of health and safety (see., e.g., Duong & Saphores, 2015; Harrington et al., 2023; Meehan et al., 2020). Instead, academic literature on potable reuse primarily frames these values in terms of technical performance and contaminant removal. Although acknowledged by some scholars (see e.g., de França Doria, 2010; Ross et al., 2014), the focus on technological optimization overshadows some of these society-level concerns. This suggests a disconnect where some values in research and society seem to align, but their overall *conceptualisation can* differ considerably. Therefore, one of the implications of our work is that actors should work simultaneously with technology-level and system-level values (conflicts) but also recognise and respond to value considerations raised by society.

Furthermore, the geographical representation of potable water reuse research hints that predominantly Western values are embedded in research since values and their conceptualisation are culturally and contextually bound. More broadly, existing studies on public perception and acceptance are also primarily conducted in Western regions (see, e.g., Distler et al., 2020; Khan & Anderson, 2018; Ormerod, 2019; Santos et al., 2022). We argue that current research is more likely to reflect Western values. Potable reuse systems are also applied in non-Western contexts such as Africa and Asia. Therefore, future research (see also Section 5.3) should actively incorporate diverse perspectives and non-Western values for a more equitable understanding of the potable reuse value landscape in those contexts.

Our research hints at the fragmented nature of the value landscape of potable water reuse. Although our comparison is not exhaustive, it illustrates possible neglected values and different understandings of research and society-level values. It marks a step toward understanding the values considered in current research versus those held by the affected publics. For example, the potential mismatch between technology-level, system-level and society-level values can lead to conflicting recommendations, which highlights the impact that different disciplinary perspectives and value interpretations can have on technology development. Policymakers influenced by technology-centric studies may favour immediate technical fixes, while those guided by system-level research might push for under-researched sustainable advancements. Socially-driven research, on the other hand, may advocate for more research into social aspects of safety. Addressing these mismatches requires transdisciplinary approaches to align research priorities across communities. Moreover, the context-dependent nature of public values necessitates value-sensitive approaches on a case-by-case basis. Van de Poel's (2013) VSD-informed Values Hierarchy can be the first step in bridging different values and conceptualisations and translating them into concrete design requirements.

2.5.2. Limitations and Future Outlook

For the use and interpretation of our work, it is important to point out some potential limitations. First, while topic modelling and thematic analysis have been used in other studies to aid the identification and conceptualisation of latent values, it remains important to stress that such results are value-laden constructs themselves. Epistemological limitations in empirical ethics generally stem from implicit interpretation and confirmation biases, as pre-existing conceptions may influence results. This research is likely no exception, but we have tried to mitigate biases by building upon a set of public values that have been used in various VSD studies (see, e.g., de Wildt et al., 2022; van de Poel et al., 2022; Wiarda et al., 2024), and by combining existing systematic, qualitative, and quantitative research methods engaging in reflexive multi-author discussions that aimed to enhance the inter-coder validity of this work. As also discussed in Section 2.2., we recognise that any conceptualisation of values is inherently prone to contestation.

Second, although the ValueMonitor tool has been validated in other contexts, it may introduce an 'anchor bias' by focusing on a pre-defined set of public values (see Appendix 1). While this allowed for a systematic analysis, it might have overlooked values unique to the potable water reuse context. More research is needed to deepen our understanding of values in water management and, specifically, for potable water reuse to enable a more comprehensive analysis.

Third, using the frequency of values as a proxy for their importance has its limitations. This approach allowed us to get a deeper understanding of the four most prevalent values, but other relevant values might be underrepresented in our analysis. Moreover, the frequency of mention may reflect scholarly trends or ease of operationalization, but it does not necessarily reflect the greatest significance in water management. Certain values might be less frequently discussed in academic literature due to their abstractness, their inherent complexity, or current research trends. Yet, they may hold substantial weight in the underlying research goal. Therefore, the four values highlighted in this study should indicate prevalent values in the literature which are not necessarily the most important or comprehensive set of values at play.

Lastly, it is important to acknowledge that our comparison between academic and society's values is preliminary due to the incompleteness of the full societal value landscape relevant to water management, specifically potable water reuse. While we have drawn upon existing literature to highlight key values in water management practices, especially with regard to engineering solutions, a comprehensive and empirically grounded assessment of societal values in this context is still lacking. Therefore, the identified misalignments should be interpreted as indicative and suggestive, requiring further research.

2.6. Conclusion

Water management research has been criticised for not sufficiently considering values relevant to society in the design of systems. While recent studies made valuable contributions to our understanding of values in specific technologies and water management at large, the value landscape of potable water reuse systems remains underdeveloped. This study investigated the alignment between society's values and those prioritised in academic research on potable water reuse. Employing a mixed-methods approach, combining large-scale topic modelling with thematic analysis, we identified and analysed latent values within a large corpus of scholarly literature.

Our study revealed that academic research predominantly focused on four key values: reliability, sustainability, health, and safety. The thematic analysis discovered diverse conceptualisations of these values. Here, we found that reliability is critical for safety considerations while safety, in turn, is instrumental to ensuring health. Moreover, sustainability showed an ambivalent relationship to the value of safety, which is either conflicting or complementary, depending on the research perspective.

While seemingly aligned with public concerns about health and safety, our analysis revealed critical differences. The academic literature primarily understands these values from a technology-level perspective, discussing contaminant removal and system performance. In contrast, studies addressing public perception highlight the importance of non-technical aspects, such as cultural-relativistic understandings of risk, justice, equity, and the cultural significance of water. These society-level values are often overlooked in the predominantly technocentric academic discourse. This misalignment between technology-driven academic research and the broader spectrum of society's values highlights the need for a more value-sensitive approach to potable water reuse. Although current research contributes to the technical feasibility of these systems, *responsible potable water reuse* requires a broader strategy. Building on our research approach, future research should contribute to a better understanding of the complexity, comprehensiveness and spatial distribution of values in potable water reuse systems to better develop solutions that are technically sound, ethically robust, and socially responsible.

3

Public Acceptance in Direct Potable Water Reuse: *A Call for Incorporating Responsible Research and Innovation*

3.1. Introduction

Increasing water demand due to growing populations and climate change has strained global water resources (Bates et al., 2008). The World Health Organization (2019) projects that by 2025, half the world's population will reside in water-stressed areas. In response, sustainable innovations and strategies to increase freshwater availability have gained substantial attention.

One such strategy is Direct Potable Water Reuse (DPR), a socio-technical system that utilizes advanced treatment technologies to reuse wastewater as a source of freshwater. DPR has the potential to contribute to sustainability by conserving freshwater sources, decreasing pollution, and reducing the carbon footprint (Burgess et al., 2015). However, despite these advantages, DPR remains a highly controversial water reuse system, primarily due to the explicit connection between wastewater and drinking water (Binz et al., 2016; Leverenz et al., 2011). This explicit link has resulted in low public acceptance, posing challenges to the successful implementation of DPR.

To address this issue, scholars have increasingly studied public acceptance in the context of DPR and proposed approaches to enhance it. Unfortunately, these approaches primarily rely on the information deficit model, assuming that the public lacks sufficient understanding of the benefits of a particular technology. The limitations of the information deficit model have been extensively discussed as inadequate in various domains (Rodhouse et al., 2021; Scruggs et al., 2020). Also, in DPR research, studies have demonstrated that simply providing information is insufficient to address the challenge of public rejection. Consequently, by relying on this model, DPR continues to face implementation failure.

This research advocates aligning DPR implementation approaches with Responsible Research and Innovation (RRI) principles. There appear to be only a few RRI studies of water reuse technologies, and only one, conducted by Dotson (2019), can be considered similar to this study. Dotson (2019) explored whether intelligent trial and error practices can help innovations such as recycled oil and gas wastewaters proceed more responsibly and has found significant gaps in RRI alignment. The authors highlighted substantial concerns, such as the dominance of dubious scientific data, the exclusion of specific stakeholders, and the omission of pivotal information. Our study resonates with these findings, further underscoring the need for incorporating RRI, especially within the context of DPR, which has yet to engage this discourse.

To move a step closer to DPR's alignment with RRI principles, we first conducted a literature review examining the concept of public acceptance in the context of DPR and identifying proposed approaches to enhance it. The identified strategies were subsequently evaluated to the extent they align with the principles of RRI discussed through the 'opening up', 'closing down' and 'leaving ajar' approach proposed by Russell et al. (2022).

The paper is structured into five sections. Following the *Introduction*, the *Methodology* section situates this study into the RRI literature and introduces the framework that will guide the analysis of the literature review findings. Furthermore, key concepts, literature research and coding strategy are outlined. The *Review Results* section presents the literature review findings, highlighting the current understanding of public acceptance of DPR and the proposed approaches to address it. Then, the *Discussion* section discusses the extent to which the proposed approaches align with the goals of RRI. Finally, the *Conclusion* section provides some concluding remarks on the review and suggests future research directions.

3.2. Methodology

This section serves to situate this research article within the RRI scholarship and introduces definitions of wastewater and water reuse concepts. Furthermore, it outlines the literature review process.

3.2.1. Responsible Research and Innovation

RRI offers guidelines to ensure that technological developments align with societal values and needs (Boenink & Kudina, 2020) and rests on the view that including diverse perspectives not only enhances democratic principles but also improves decision quality by incorporating a more comprehensive range of knowledge (Stirling, 2008).

RRI aims to prevent technological failures by providing pre-emptive measures to mitigate potential adverse effects of innovations that emerge from technology introduction (Von Schomberg, 2011). One of the most used frameworks within the RRI scholarship is the AIRR framework, which focuses on *Anticipation, Inclusion, Reflexivity,* and *Responsiveness.* These dimensions are designed to address emerging social and ethical concerns of technology innovation and serve as handholds in the innovation process. As such, the framework acknowledges the dynamic relationship between technology and society, recognizing that technology both shapes and is shaped by society (Bijker, 1994).

We will apply the AIRR principles by building upon the approach presented by Russell et al. (2022). The authors identify two primary extremes of public engagement in technological advancements: the 'opening up' and 'closing down' approach. In this, 'opening up' advocates widening the knowledge base in decisions related to new technologies by including the concerns and perspectives of non-experts and affected groups (Stirling, 2008). Consequently, the meaningful *inclusion* of new perspectives through 'opening up' engagement is the most fundamental aspect in this framework, enhancing the democratic level of decision-making and, as such, determining the success or failure of aligning with RRI principles.

Diversifying the knowledge base can better prepare innovation projects to navigate unforeseen challenges, thereby increasing its *anticipatory* capacity and providing a more comprehensive understanding of local societal contexts. Such a broad view allows for more informed decision-making, enabling the exploration of alternative paths and discovering previously unconsidered solutions (Cuppen & Pesch, 2021). As such, 'opening up' engagement encourages *reflecting* on the innovation process and equips decision-making parties to *respond* to the public's needs and concerns. It stands out that such 'opening up' engagement reaches beyond the deliberation of a single technology; it also questions the desirability and appropriateness of such technology.

Conversely, 'closing down' refers to resorting to traditional measures to convince the public of a technology's benefits through, for example: "emphasizing the severity and urgency of the problem, presenting [the technology in focus] as the best solution, avoiding more contentious applications" (Russell et al., 2022, p. 157).

Between the two extremes of 'opening up' and 'closing down', Russell et al. (2022) suggest a third approach to public engagement, called 'leaving ajar'. In this approach, engagement is utilized to make a particular technology innovation project socially acceptable by being "responsive to public views, but with a pragmatic focus on creating the conditions that might allow the technology to be successfully deployed" (Russell et al., 2022, p. 160).

3.2.2. Wastewater and Water Reuse

To avoid misunderstandings and increase the clarity of this research, this section provides some definitions of key concepts of the wastewater and water reuse domain.

Wastewater. Wastewater is commonly defined as water that domestic homes, industry or agriculture have used previously, containing human faeces, oils, soaps, chemicals and the like.

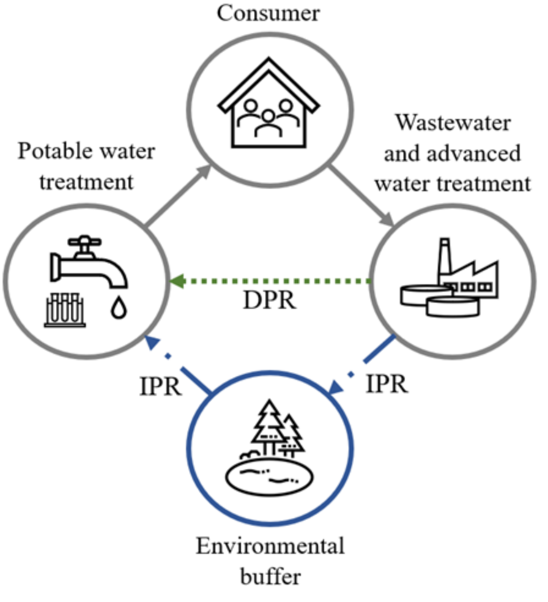

Figure 3.1: Schematic of the DPR and IPR treatment processes. Adapted from S. Eden, S. B. Megdal, and J. McLain (2016). "Potable water reuse of Water," Water Resources IMPACT, vol. 18, no. 4, pp. 10-11.

Types and purposes of water reuse. Traditional drinking water technologies use groundwater or surface water as a source. Water reuse technologies allow for alternative sources of drinking water, such as industrial and domestic wastewater[6]. Water reuse refers to the beneficial use of treated wastewater (Kayhanian &

[6] Saline water, which is mainly ocean water, is also an alternative water source, and desalination technology is increasing in popularity. However, because it is not wastewater or water that is "reused" in the strict sense, it will not be discussed further.

Tchobanoglous, 2016). Wastewater treatment varies in intensity depending on its purpose, especially whether it will be potable or non-potable. Although our research focuses on DPR, we briefly introduce two other types of water reuse – IPR and de facto reuse – as they are often mentioned alongside DPR technology.

Indirect potable water reuse. With IPR, treated water is discharged into an environmental buffer (Gerrity et al., 2013) into an environmental buffer can be a body of water (e.g., surface or groundwater). Currently, IPR is used in several locations around the world, fo remost in the US and Australia (Santos et al., 2022).

Direct potable water reuse. DPR does not use an environmental buffer between the wastewater treatment and the piping of the purified water to consumers (e.g., Boyer et al., 2017; Lahnsteiner et al., 2018; Moya-Fernández et al., 2021). This technology is, therefore, a viable option in regions where buffers are unavailable or inefficient due to high run-off or evaporation rates.

A schematic of DPR and IPR can be found in Figure 3.1. Both depend on similar rigorous technology that treats wastewater to meet the expected potable water norms. The main difference between them is the presence or absence of an environmental buffer (Gerrity et al., 2013).

De facto reuse. De facto reuse, also called unplanned reuse, refers to the involuntary reuse of treated wastewater from upstream settlements (Kayhanian & Tchobanoglous, 2016). Throughout the world, sources of potable water often already contain wastewater discharged by upstream settlements (Gerrity et al., 2013; Meeker & Tricas, 2015). This daily practice is often unacknowledged (Nagel, 2015).

3.2.3. Search Strategy

A review of the literature on the social impacts of DPR was conducted, following the process described by Moher (2010). The literature was assessed in three stages: search, screening and selection (see Figure 3.2). Each stage narrowed down the number of papers until a set of 67 papers remained. Of these, 55 papers were included as the remaining 10 contained relevant information already provided by the other papers, and 2 papers were literature reviews closely related to the topic at hand.

The literature collection was limited to three research platforms: Web of Science (WoS), JSTOR and Science Direct (SD). These platforms were chosen because they contain a large number of social studies. In addition, WoS was selected for its accuracy, high reproducibility and large number of databases, JSTOR for its wide range of popular research and SD for its large number of unique, relevant documents. We chose not to use the Scopus platform because it has many of the same articles as WoS, and many of its articles are inaccessible.

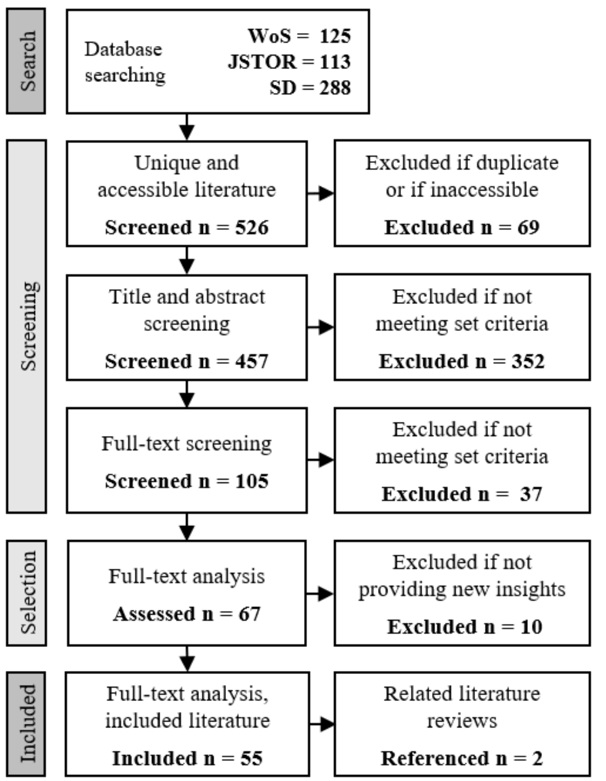

Figure 3.2: Literature selection process based on Moher (2010).

For the literature search, we used the query *"Direct Potable water reuse" OR "Direct Potable Water"* searching in the title, keyword and abstracts of all three databases:

WoS: ALL = ("Direct Potable water reuse" OR "Direct Potable Water") AND PY = 2009-2021

JSTOR: "Direct Potable water reuse" OR "Direct Potable Water". [Filter > 2009]

SD: TITLE-ABS-KEY ("Direct Potable water reuse" OR "Direct Potable Water") AND PUBYEAR > 2009

Since the focus is on relatively new water reuse technologies, we limited the publication year to 2010 and later. Before 2010, DPR did not receive much attention from scholars. The search phase resulted in 526 documents. Each title and author was collected in a single file and assessed manually; no data mining platforms were employed. This manual screening method was possible as a significant portion of the papers were on technical aspects and could be discarded early in the process through mere title screening. The initial sample could have been reduced by using stricter filter criteria, but beginning with a large sample minimized the chances of missing important literature.

The screening phase started with removing duplicates and inaccessible documents, leaving 457 documents. The abstracts, titles and keywords were then screened using the following exclusion criteria:

The focus is not on DPR or potable water reuse. Here, it must be noted that the selected literature focused predominantly on DPR to provide a clear picture of DPR's core research on social challenges. This means that this review may be missing some relatable insights from other technologies, such as Indirect Potable Water Reuse or Desalination.

1) The focus is not on societal aspects.
2) Many popular research articles did not provide an abstract and keywords. In these cases, we used cross-reading, which led to a lower rejection level and the need for closer inspection in the full-text screening phase. The abstract and title screening reduced the documents to 105.

The same exclusion criteria were applied in the full-text screening phase, leaving us with 67 relevant documents. These were again read closely. In this last phase, documents were excluded if they did not contain any new insights or were literature reviews themselves, which left a final number of 55 documents for this review.

Of these 55 articles included in this literature review, 40 (roughly 73%) were scientific, including transitional and social sciences studies. The remaining 14 papers (roughly 25%) were published in popular magazines and were often opinion pieces or of an educational nature, introducing DPR or wastewater reuse to a lay audience.

3.2.4. Literature Categorization and Coding

The literature analysis was conducted without predefined categories. Instead, the categories were deducted from the literature at hand. We found that public acceptance is generally understood as an overarching complex indicator of different public concerns. These factors, however, are not always agreed upon, which is often explained by its case dependency (Al-Saidi, 2021).

Table 3.1: Categorisation of Public Acceptance Factors.

Category	Technology-dependent factors	Context-dependent factors	
Codes	• Safety & Risk • The Yuck Factor	• Knowledge • Trust • Urgency	• Culture & Religion • Justice • Legitimacy

With the low number of papers regarding public acceptance and DPR, there is also a lack of acknowledged predefined categories. Hence, we chose to create categories during the review synchronously and refrained from making categories based on prior knowledge to avoid bias early on.

Table 3.2: Categorization of approaches to enhance public acceptance

Category	Educating	Public outreach
Codes	• Conventional education • Unconventional education • Pilot projects • Criticisms & inconsistencies	• Clear message & reframing • Enhancing trust • Public engagement
		Understanding & adapting

During the review process, we found that the different aspects of public acceptance can be sorted into two categories, technology and context-dependent factors, which is in line with the research of, for example, López-Ruiz et al. (2021) and Distler et al. (2020). Each of these two categories contains unique subcategories that we will call public acceptance factors, or factors in short, as seen in Table 3.2. This setup of categories and factors will be used as a general framework for the first part of literature review.

As a second step in the screening phase, we identified proposed approaches to increase public acceptance (hereafter: "approaches"). Again, the categories and subcategories emerged during the literature review process and were not predefined.

Some categories were further specified into subcategories (see Table 3.2).

3.3. Review Results – DPR's Public Acceptance as a Complex Phenomenon

In this review, a relatively large number of factors were considered to influence public acceptance of DPR. Their respective importance was highly case-dependent (cf. Al-Saidi, 2021). Factors of public acceptance were often split into two main categories: technology-dependent and context-dependent (e.g., Distler et al., 2020; López-Ruiz et al., 2021). For technology-dependent factors, the literature has a focus on two broad aspects: Safety and risk and the Yuck Factor. On the other hand, the context-dependent factors are more fine-grained and deal with trust, knowledge, urgency, culture and religion, justice and legitimacy. While some scholars have made a more detailed distinction between the contextual factors for this paper, the broader categorizations suffice because we aim to give a broad overview of current research rather than a detailed investigation of individual studies.

3.3.1. Technology-dependent Factors

Technology-dependent factors are those directly related to the working and aims of a technology. Two main factors were identified: safety and risk and the Yuck factor.

Safety and risk

The concerns for safety and risk associated with DPR and water reuse were one of the most mentioned challenges in the reviewed literature (e.g., Duong & Saphores, 2015; Fuenfschilling & Truffer, 2016; Ormerod et al., 2019). Safety and risk are related to the degree of human contact and to different risk perceptions.

Degree of human contact. The degree of human contact with treated wastewater was repeatedly seen as being of major importance for public acceptance (e.g., Adapa et al., 2016; Boyer et al., 2017; Ormerod et al., 2019). There seemed to be a negative correlation between the degree of human contact and public acceptance – the higher the degree of human contact, the lower the public acceptance (Moya-Fernández et al., 2021). This association, however, did not hold for all cases. A survey in South Africa resulted in the opposite finding – potable water reuse received more support than non-potable water reuse (Prins et al., 2022). Also, Kandiah et al. (2019) doubted whether the degree of human contact is closely related to public acceptance.

Risk perception. Researchers seemed to agree on the importance of this issue for technology acceptance and consequent adoption. Duong and Saphores (2015) distinguished between several types of risk: scientific-objective, cultural-relativist and realist, a combination of the other two types. According to these authors, the first two, in particular, are based on different premises and can, therefore, lead to conflict (Duong & Saphores, 2015).

The scientific-objective perspective is technical, describing potential risks derived from empirical evidence. Within wastewater management systems, including DPR, challenges such as microbiological pathogens, pharmaceuticals and personal care products in the effluent are increasing (Cotruvo, 2016; Voulvoulis, 2018). Pathogens are challenging to detect and remove during treatment (Duong & Saphores, 2015; Kandiah et al., 2019; Roccaro & Verlicchi, 2018). Additionally, the treatment process can create by-products that must be removed with additional treatment (Hummer & Eden, 2016). The high level of scientific uncertainty about the degree of contamination and its potential effects raises safety concerns (Hummer & Eden, 2016).

The cultural-relativist perspective refers to the experiences and emotions of those affected and is one of the main factors that dominate acceptance concerns (Duong & Saphores, 2015). According to Fielding and Roiko (2014), perceptions of risk in this view are subjective regarding the likelihood and magnitude of adverse outcomes. Cultural-relativist risk is interwoven with symbolic meanings such as "purity" and depends on the current social order (Duong & Saphores, 2015) and trust in authorities (Duong & Saphores, 2015; Voulvoulis, 2018).

The realist perspective combines the scientific-objective and cultural-relativist perspectives by using empirical evidence while acknowledging social considerations such as trust in authorities and fear (Duong & Saphores, 2015).

The Yuck Factor

The "Yuck factor" has been mentioned by various researchers as a primary impediment to public acceptance (e.g., Bichai et al., 2018; Moya-Fernández et al., 2021). Notably, water reuse projects have been halted or abandoned due to this factor (Askin, 2016; United Nations, 2017). Bioethicists first used the concept to reject human tampering with the natural order (Duong & Saphores, 2015). In the context of DPR, however, the concept is used with a somewhat different focus, highlighting three main notions: disgust, aversion to new technology, and violating social norms.

Disgust appears to be the most frequently referenced aspect, which Duong and Saphores (2015) characterized as "repugnance triggered by the idea of consuming the water that was once flushed down a toilet" (p. 200). Ormerod et al. (2019) expanded this definition by connecting it to social and cultural risk perceptions (see also Kandiah et al., 2019). Villarín and Merel (2020) propose that this factor involves "trust, subjective social norms, perceived control, and emotional aversion" (p. 16) and potable recycled water clashes explicitly with the social norm of separating drinking water and wastewater (Duong & Saphores, 2015).

Additional factors contributing to the Yuck factor include a lack of knowledge (Tennyson, Millan, and Metz 2015) and public squeamishness (Katz and Tennyson 2015; Bufe 2013a; Tennyson, Millan, and Metz 2015), with the latter prominently discussed in popular research articles. Despite elaborate research, overcoming the Yuck factor remains a challenge (Leong and Lebel 2020)

3.3.2. Context-dependent Factors

Despite technology-dependent factors, public acceptance is considered a highly context-dependent phenomenon (Al-Saidi, 2021). Five main factors that influence public acceptance were identified in this review: trust, knowledge, urgency, culture and religion, and justice.

Trust

In discussions on public acceptance of water reuse, scholars emphasize the pivotal role of trust. While trust is conventionally associated with interpersonal relationships (McLeod, 2006), in the DPR literature, it is multi-faceted, extending to authorities (Boyer et al., 2017; Fielding & Roiko, 2014; Voulvoulis, 2018) and institutions (Moya-Fernández et al., 2021; Mukherjee & Jensen, 2020).

According to Harris-Lovett et al. (2015), engineers and implementing authorities often link public trust to well-designed technologies and monitoring. For instance, the Long Angeles DPR project indicated general uncertainty about water sciences and the technology employed (Lejano & Leong, 2012). Moreover, trust in technology hinges on trust in its operators, as the technology's ability to function adequately "provides no assurances without an enforcement mechanism" (Martorana, 2016, p. 42). Therefore, the success of technology relies on trust in authorities and institutions, contingent on their risk-management capabilities and sound decision-making processes (Harris-Lovett et al., 2015). As such, trust, particularly in authorities, proves fragile and can rapidly erode during contamination (Mukherjee & Jensen, 2020).

The significance of trust in institutions, authorities and experts can vary regionally. In southern Spain, the relationship between trust and public acceptance was statistically insignificant (López-Ruiz et al., 2021), while in Africa, low trust in the government and in authorities' capabilities was a major factor (Prins et al., 2022).

Concerns about trusting authorities often stem from past experiences or opaque processes (Harris-Lovett et al., 2015). In an Australian pilot project, the public accused authorities of treating them as "guinea pigs", keeping them "in the dark regarding the negative impacts of drinking recycled water" (Fuenfschilling & Truffer, 2016, p. 305).

Knowledge

In this review, public rejection of DPR was often explained by a lack of knowledge (Lejano & Leong, 2012). In fact, Khan and Anderson (2018) suggested that a lack of familiarity with the technology was one of the main factors influencing public acceptance. In a study on the willingness to pay for recycled wastewater, the author explained the unexpected outcomes as being due to cognitive dissonance or the inability to comprehend technical information (Boyer et al., 2017). In South Africa, citizens were considered to have little to no knowledge about wastewater treatment and distribution (Burgess et al., 2015). As researchers have found, there seems to be a positive correlation between knowledge of the technology and acceptance (Adapa et al., 2016; Furlong et al., 2019; Kandiah et al., 2019).

Besides knowledge of the technology itself, several other kinds of knowledge were considered relevant by the scholars in this review. These included general knowledge about the hydrological cycle and knowledge about situational factors such as water availability and the quality and origin of the current water supply (e.g., Boyer et al., 2017).

Urgency

The feeling of urgency seems to have the capacity to both drive and impede DPR implementation. Some authors suggested that public acceptance is higher in times of drought (Bufe, 2013a; Wester & Broad, 2021) or in generally arid regions (Scruggs & Thomson, 2017). According to Landers (2015), this heightened awareness should be used to overcome negative public resistance to water reuse.

However, evidence suggests that urgency can vary in importance and stability. The former was shown in Australia, where DPR was rejected even though the area involved is highly arid and was experiencing extreme drought (Roccaro & Verlicchi, 2018). In this case, a local expert claimed the urgency led to lower acceptance because the public felt forced to implement a technology they did not support (Heffernan, 2014).

Katz and Tennyson (2015) warn that linking water reuse projects to drought is not a secure long-term strategy due to drought's unpredictability. This instability was found in Wichita Falls (Texas, US), where a DPR facility was built during a drought. However, the facility was not completed until after the drought ended, and public acceptance had decreased. The plant has been idle for many years (Bufe, 2013b).

Culture and Religion

The social challenges surrounding DPR vary by country, but they also show large differences within countries (Furlong et al., 2019; Ormerod et al., 2019). Public acceptance seems to differ in different cultural and religious contexts. Within Asian cultures, the use of faeces receives greater approval because it is often related to "traditions of frugality" (Kayhanian & Tchobanoglous, 2016, p. 1612). Such usage seems generally rejected in other regions, such as Western and African contexts (Kayhanian and Tchobanoglous 2016) and Latin America (Al-Saidi 2021). Moreover, in communities with large Islamic populations linger uncertainties about the appropriateness of DPR (Bichai et al., 2018; Kayhanian & Tchobanoglous, 2016) due to, for instance, the halal status of the purified water (Lee & Jepson, 2020). The stark differences in acceptance within countries indicate that religion and culture are essential factors, illustrating a region's unique context (Furlong et al., 2019).

Environmental attitude is another factor that can be attributed to a region's culture. Some authors mentioned that positive attitudes towards the environment play a significant role in accepting water recycling (Tchetchik et al., 2016). Reusing water is seen as a means of acting responsibly towards the environment because it puts less strain on natural resources (López-Ruiz et al., 2021). A discreet-choice experiment conducted in Israel indicated that a positive attitude towards the environment increases the likelihood of technology adoption (Tchetchik et al., 2016). However, a study involving university students in southern Spain could not replicate this finding (Moya-Fernández et al., 2021).

Justice

Justice entails, among other things, uneven exposure to risk (Ormerod et al., 2019). Questions of justice are, therefore, crucial in DPR. For example, in Los Angeles (California, US), public resistance against a DPR project in the San Fernando Valley was high because residents felt the municipal government was discriminating against them (Lejano & Leong, 2012).

One study in this review found that people who rejected stark inequalities were more supportive of DPR (López-Ruiz et al., 2021). This may stem from the "inherent positive relationship between notions of social justice and the concept of sustainable development" (López-Ruiz et al., 2021, p. 785). Similarly, the data of Moya-Fernández et al. (2021) showed that people living in a situation with great social injustice in southern Spain were less inclined to support DPR.

Legitimacy

Lastly, in studies of technological innovation systems, acceptance is closely related to the legitimacy of the technology. The legitimacy of new technology could be determined by its fit with current regimes (Harris-Lovett et al. 2015) or by its compatibility with collective action and widely held social norms and beliefs (Binz et al. 2016). Increased legitimacy can be obtained by continuously reshaping the system's practices and institutions. In the case of DPR, Binz et al. (2016) claim legitimacy can be acquired through continuous institutional adjustments, technology improvements and advocacy.

3.4. Increasing Public Acceptance

In the previous section, we showed many factors that may affect public acceptance issues. We now build on these findings by presenting the proposed approaches to overcome public acceptance issues we discovered in the current literature.

Along with the factors influencing public acceptance, this review also found various approaches to increase public acceptance. Such strategies included "increased education and coordinated public relations; increased consultation; different types of consultation; redesigning policy and infrastructure planning processes to become participatory; and avoiding consultation altogether" (Furlong et al., 2019, p. 57). Because public perceptions are slow to change, Mukherjee and Jensen (2020) advise that approaches to overcoming acceptance challenges should be implemented early in the process.

3.4.1. Educating

Education is seen as the most traditional way to increase public acceptance (Furlong et al., 2019). Scholars in this review suggested that citizens are more likely to accept DPR and other water reuse technologies when receiving more technical information about them (Boyer et al., 2017; Fielding & Roiko, 2014; Nagel, 2015). Even a small amount of information in the form of an educational video increased public acceptance in Australia (Law, 2016). Prins et al. (2022) suggested that, especially for people with little knowledge of alternative water sources, education can help increase general acceptance.

Education comprises conventional education methods such as information on technology and related subjects, unconventional education methods and pilot projects. Bufe (2013a) suggests that education should come from different sources to increase its reach rather than just from the government.

Conventional Education

This review found conventional education the most common method for increasing public acceptance. In this, Harris-Lovett et al. (2015) criticized that water authorities and other project planners often provide merely technical information to convince the public of the technology's benefits despite evidence that the public demands broader information such as social and environmental costs or risk considerations (Harris-Lovett et al., 2015). Other approaches suggested incorporating more types of information, such as safety risks (Fielding & Roiko, 2014), water scarcity and shortage (Duong & Saphores, 2015), the hydrological cycle (Burgess et al., 2015) and de facto reuse (Boyer et al., 2017; Furlong et al., 2019; Leverenz et al., 2011). Information on de facto reuse, in particular, was said to put "the risk of chemicals in the water in perspective" (Fielding & Roiko, 2014).

Unconventional Education

Unconventional education methods are those that go beyond simple information provision. Some scholars in this review suggested using the media, including social media, to increase reach and awareness (Scruggs et al., 2020). They also warned that media education and relationship-building should be started early in the process (Scruggs et al., 2020).

More creative forms of education can be found in the US. In Oregon and California, local brewers tried to increase awareness and public acceptance by producing beer with recycled water (Martorana, 2016; Stratton-Childers, 2015). At the University of San Diego, students worked with water utilities to enhance education on water reuse and its acceptance by younger generations (Eidson, 2015).

Pilot Projects

Another often-mentioned way to speed up DPR implementation is by increasing the number of pilot projects (Wilcox et al., 2016). Pilot projects are said to increase acceptance because they prove that the technology system works successfully with no adverse health impacts (Katz & Tennyson, 2015; Martorana, 2016). Wilcox et al. (2016) even claim that without an increase in pilot projects, public perceptions may not improve.

One example from this review is San Diego's (California, US) efforts towards implementing IPR. The IPR plant in the nearby region of Orange County is said to have significantly influenced public acceptance (Heffernan, 2014). Another inspirational example is the DPR system used in the International Space Station (Beutler, 2016).

Criticisms and Inconsistencies

Interestingly, not all information seems to influence public acceptance. A survey conducted in four cities across the US showed that providing information on drinking quality standards and regulations about drinking water and DPR did not have an impact on acceptance (Ishii et al., 2015). Moya-Fernández et al. (2021) argued that although there may be a relationship between information and acceptance, there is no statistical evidence of one when it comes to the potable use of recycled water in Spain. Also, in Australia, providing information did not increase acceptance (Mukherjee & Jensen, 2020). According to Furlong et al. (2019), these diverse study outcomes may be because education alone is insufficient to increase public acceptance.

3.4.2. Public Outreach

Burgess et al. (2015) argue that extensive outreach programs and campaigning have greatly increased public acceptance in the US. In fact, almost all the scholars in this review mention awareness and trust-raising campaigns as essential actions to increase public acceptance (e.g., Alspach et al., 2016; Katz & Tennyson, 2015; Voulvoulis, 2018).

Outreach is also often related to marketing strategies (Duong & Saphores, 2015; Ormerod et al., 2019) and can be structured as a communication plan. Such a plan can provide consistency, transparency and structure to communication efforts (Beutler, 2016). The communication plan can also be an overarching framework for implementing education efforts and building trust (Beutler, 2016). To ensure effectiveness, Alspach et al. (2016) advise that campaigning should start at the outset of projects to allow sufficient time for building trust, creating credibility and reputation and setting up communication channels.

Clear Message and Reframing

Several empirical studies have shown that clear and coherent communication can increase public acceptance (Katz & Tennyson, 2015; Villarín & Merel, 2020). A coherent narrative that appeals to a wide range of concerns can increase collaboration potential and public deliberation (Lejano & Leong, 2012). Approaches include using easy-to-understand vocabulary, establishing common terminology and reframing the debate. Additionally, communication should target the audience that needs to be reached (Distler et al., 2020; Harris-Lovett et al., 2015).

Common terminology. Terminology matters in the public debate about DPR. The terminology should be easy to understand, and overly technical terms should be avoided (Katz & Tennyson, 2015). A common terminology should be established to ensure clear and understandable communication (Kayhanian & Tchobanoglous, 2016).

The narrative "toilet-to-tap" seems to be a public acceptance killer (Al-Saidi, 2021). To avoid such framing, coherent use of positively inclined, reassuring vocabulary should be used. For example, scholars in this review suggested avoiding terms such as "treated wastewater" or "effluent" and instead using terms such as "recycled water" or "(advanced) purified water" because these words were successful in earlier projects (Villarín & Merel, 2020) and public opinion surveys indicate these terms are favoured (Tennyson et al., 2015). The word "treatment" is often related to sickness and disease and is therefore increasingly avoided by water agencies (Katz & Tennyson, 2015).

Reframing. Reframing the discourse on DPR offers a strategic approach to shift the narrative away from negative connotations. Generally, the public often perceives water extracted from the environment as natural, pure, and superior (Lohman, 1987) compared to recycled water, which is perceived as less pristine. This narrative is often seen as unhelpful in the DPR discourse. As such, reframing strategies are proposed.

Leverenz et al. (2011) challenge this perception, arguing that current wastewater discharging practices pollute traditional water sources. Others use the hydrological cycle to argue that essentially all water has been wastewater at some point in time (Katz & Tennyson, 2015). Similarly, it is suggested that communication should be based on the narrative that all water is essentially reused *de facto,* but its use is often overlooked or disregarded (Meeker & Tricas, 2015; Mercer, 2016).

Alternatively, some advocate for a more assertive frame by presenting DPR as the only viable option to increase a community's water availability (Dolnicar &

Hurlimann, 2010; Furlong et al., 2019; Wilcox et al., 2016). This framing was applied in the project in Wichita Falls (Wester & Broad, 2021), where public acceptance was volatile, leading the plant to stay idle for many years (Bufe, 2013b).

Enhancing Trust

Low trust poses a significant challenge to the public acceptance of DPR, as shown by the correlation between trust levels and acceptance (Khan & Anderson, 2018). Notably, elected officials and media are consistently viewed with scepticism, contributing to heightened distrust (Distler et al., 2020). To address this, proactive engagement and trust-building efforts are essential (Via & Tchobanoglous, 2016).

To bolster tryst, Harris-Lovett et al. (2015) proposed creating legitimacy around DPR through transparent processes, credible participation channels, effective communication of benefits, and comprehensive risk management (Harris-Lovett et al., 2015). Additionally, the communication messenger is crucial for gaining public trust. Here, scholars suggested regulators and experts are favoured compared to policymakers, developers or professional public relations consultants (Scruggs et al., 2020).

Public Engagement

Numerous authors posit that engaging stakeholders can enhance public acceptance by bolstering project legitimacy and trust in authorities (Boyer et al., 2017; Mukherjee & Jensen, 2020). Public engagement ranges from educational initiatives to involvement in the decision-making process. Tours and tryouts are frequently recommended as experiences contribute to public confidence (Katz & Tennyson, 2015). In California, 88% of survey respondents indicated feeling more comfortable using reclaimed water (Martorana, 2016). In Australia, public consultations via information days led to a higher public acceptance from the attendees than those who did not attend (Scruggs et al., 2020).

Involvement in the decision-making process is deemed crucial for building confidence in DPR projects (Matthews, 2015). Scholars advocate early and continuous stakeholder inclusion (Boyer et al., 2017; Exall & Vassos, 2012; Kayhanian & Tchobanoglous, 2016; Mukherjee & Jensen, 2020) to align the technology with societal needs (Wilcox et al., 2016). At the same time, it is important to manage stakeholders' expectations. Additionally, effective management of stakeholder expectations and incorporating values and emotions in decision-making processes are emphasized (Katz & Tennyson, 2015; Khan & Anderson, 2018). However, this may require a dramatic change in authorities' current practices (Harris-Lovett et al., 2015).

Not all of the literature we reviewed suggested using public engagement, and some also questioned the efficacy of public engagement. For example, evidence from Australia suggests higher acceptance when the public is not given a choice (Furlong et al., 2019). In other cases, engagement approaches did not seem to be used, such as in the DPR projects in Big Spring and Brownwood, Texas, where a large number of interviewees (40% and 45%, respectively) were not aware of the ongoing projects (Wester & Broad, 2021). Additionally, the often cited success stories, such as Windhoek, Namibia, and Tucson, Arizona (US), were established before public participation was considered crucial (Scruggs et al., 2020).

3.4.3. Understanding and Adapting

This review showed that while several recurring public acceptance issues have appeared worldwide, many are unique to a specific context (Scruggs & Heyne, 2021), and approaches to overcome them should be tailored to local circumstances (Al-Saidi, 2021). The local context must first be studied to understand its unique problems and the public's expectations and to identify relevant actors (Katz & Tennyson, 2015). A cultural approach grounded in sociology should be used to examine local practices and understand the conflicts between those practices and the use of treated wastewater (Duong & Saphores, 2015). Surveys can also be a powerful tool for gaining insight, as is done frequently in the US and Australia (Scruggs & Heyne, 2021).

3.5. Discussion – 'Closing Down', 'Opening Up' or 'Leaving Ajar'?

The literature review showed that most approaches to increase DPR's public acceptance appear to be geared towards educating and convincing the public about the technology's benefits (see Figure 3.3). One of the acceptance-enhancing approaches, educating, already shows many different methods, but also the public outreach category often involves educational elements. For example, public inclusion is often referred to as a participation method. Still, it can also be used instrumentally as another form of treating stakeholders as spectators rather than active participants. Additionally, trust-raising is essential to public outreach but predominantly relies on communication and education.

The strong focus on providing education has created a significant disparity between the current understanding of factors influencing public acceptance in DPR and those addressed in acceptance-enhancing strategies. While the current literature on public acceptance acknowledges its complexity and endeavours to untangle contributing factors, the suggested implementation approaches do not reflect this nuanced understanding but reduce the phenomenon to a lack of knowledge.

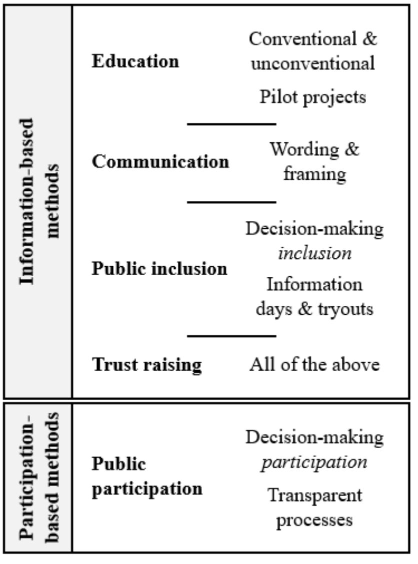

Figure 3.3: Main approaches to increase public acceptance

3.5.1. 'Closing Down'

The focus on providing information and education is a typical indicator of a 'closing down' approach. It indicates that the public is assumed to be unaware of the benefits of technology such as DPR. This assumption is also called the "information deficit model" and has been criticized for being ineffective and leading to implementation problems (Rodhouse et al., 2021; Scruggs et al., 2020).

Relying on the information deficit model is problematic for two reasons. Firstly, it prioritizes scientific, often quantitative information and overlooks other forms of knowledge, such as social and ethical perspectives or local experiences. Also, discussions in the DPR context often focus on technical risks, safety, and water quality standards rather than addressing social or ethical concerns. Such thinking can indicate misalignment with the RRI principles of *reflexivity* and *responsiveness* if relevant concerns are overlooked.

Second, this model assumes that the risks of the technology are acceptably low and outweighed by the benefits, which is not necessarily the case for DPR as there is still ongoing research on risk and safety aspects. Notably, the long-term impacts of emerging contaminants, their acceptable risk levels and the adequacy of water quality testing methods to detect these remain contested (Dotson, 2019; Duong & Saphores, 2015). Nevertheless, "DPR poses no risk" and "recycled water meets drinking water quality" are popular statements to raise trust in DPR, effectively closing the debate on these essential concerns and reducing the opportunity to *anticipate* potential challenges in this area.

Unfortunately, the current approaches to boost public acceptance in DPR show a strong preference for the information deficit model and scientific knowledge, both traditional 'closing down' techniques. Nevertheless, some scholars have emphasized the need to consider local circumstances and embrace a more nuanced understanding of public acceptance and the need for participation in DPR projects.

3.5.2. 'Opening Up'

In this literature review, we could identify some 'opening up' calls and proposals, for example, increasing calls towards more public involvement (e.g., Boyer et al., 2017; Matthews, 2015), which should begin at the early stages of the project (Mukherjee & Jensen, 2020) and continue throughout the entire life cycle (Kayhanian & Tchobanoglous, 2016). Other authors urged understanding the local context and tailoring technical solutions to the location's needs and concerns (e.g., Al-Saidi, 2021; Scruggs & Thomson, 2017). These aspects align with the endeavours to 'open up' public engagement, as Russell et al. (2022) suggested, and show that research on DPR increasingly recognizes that public participation is crucial for the success of technology implementation.

Yet, these calls remain far outweighed by literature that leans towards 'closing down' engagement. This persisting challenge may be due to the highly ideological nature of public participation endeavours such as those proposed in 'opening up' approaches. While essential for meaning and impactful public engagement in the future, the 'opening up' types of public engagement often face a lack of touch with real-world situations, high costs in terms of time and money and unaccounted-for power imbalances (see, e.g., De Hoop et al., 2016; Reynolds et al., 2023).

3.5.3. ‘Leaving Ajar’ as a Step Towards RRI for DPR?

Consequently, more moderate strategies, such as those proposed through ‘leaving ajar’ engagement options, might be an initial step for DPR projects to align more with the RRI principles. ‘Leaving ajar’ essentially aims to balance the ideals of ‘opening up’ approaches and the practical constraints in DPR projects. Technology choices are often severely constrained by financial and geographical factors. Hence, technologies seem to be frequently chosen before public introduction. The primary objective then becomes tailoring DPR solutions to address local concerns rather than liberating on ideal technology implementation processes. While this starting point is less than ideal, applying the AIRR principles can improve the implementation process.

As a first step, decision-makers in DPR projects should prioritize *reflexivity* and *responsiveness* towards public concerns. Here, addressing the misguided belief in "no risk" or "DPR as the only option" is crucial. The debate should shift towards openly discussing uncertainties, safety concerns, alternative technological options, and their societal implications. Moreover, it must be ensured that the deliberations extend beyond scientific aspects to include discussions on social impacts or cultural and religious considerations. With more deliberative discussions, unaddressed issues may emerge, which can also help improve the project’s *anticipation* capabilities.

Recognizing past missteps and a genuine commitment to improvement can also address a significant underlying issue: the erosion of trust. Mistrust in institutions and promises of government officials is especially lingering in many places; in terms of water reuse, this lack is also fuelled by past failures (e.g., the Flint Water Crisis; see also Masten et al., 2016).

The trust-building efforts in DPR projects should move beyond the selective information dissemination tactics to focus on the root problem of officials’ operational practices – lack of trust in operation, maintenance and monitoring processes. Some suggest incorporating external advisory panels for oversight and guidance (Cotruvo, 2016). However, assembling knowledgeable members may pose challenges with complex water systems.

Looking ahead, the insights from ‘leaving ajar’ engagement can be the foundational steps for more expansive ‘opening up’ strategies. Moreover, we think that identified issues and concerns of one community are often similar to other communities. Hence, collaborations between communities are another pragmatic way forward that can lead to knowledge exchange and a further ‘opening up’ of public engagement.

3.6. Conclusion

This review of the literature aimed to see how much public acceptance endeavours of DPR projects align with RRI principles. We achieved this by conducting a literature review on how public acceptance is understood in DPR and what approaches are suggested to increase it. The findings were subsequently assessed with the approach of 'opening up', 'closing down', and 'leaving ajar'. These have shown to be a practical framework for pinpointing current RRI alignment challenges and opportunities of DPR projects when trying to increase public acceptance. Our main finding is that the identified approaches to enhance public acceptance predominantly rely on the highly criticized information deficit model, which oversimplifies the issue and fails to address the multi-faceted factors influencing public acceptance, effectively 'closing down' any meaningful engagement.

This approach can also guide how to make the first steps towards becoming more responsible. Here, we urge to move away from strategies involving the information deficit model and towards embracing the principles of RRI. More particularly, future efforts to enhance public acceptance should prioritize fostering an open dialogue that does not seek to convince the public of the technology's benefits and where risks and uncertainties are not downplayed but are communicated clearly and deliberated on.

Theory Development

4

Uncharted Waters: *How Large-Scale Water Infrastructure Projects Manage Public Acceptance*

4.1. Introduction

Sustainability transitions are currently underway across a wide range of large-scale infrastructure, including energy and water systems. Transitions within such systems are, by default, immense, spanning cities and even entire countries. However, if they work as intended, these systems usually go unnoticed and are often "hidden in plain sight" (Star, 1999). Infrastructure often functions as background architecture (Larkin, 2008). With the new demands of ever-increasing resource scarcity and climate change, however, these long-established systems require change, essentially moving them back into view due to, for example, the need to build facilities in new locations, opening streets for pipelines, or altering the physical landscape of communities.

The sustainability transition in the drinking water sector seems to follow this pattern of moving into view. For decades, the water sector has functioned as a largely invisible system, sustained by deliberate concealment and 'habituation,' which is the public's unconscious reliance on established, working infrastructure (Edwards, 2017). Until recently, drinking water systems have continued on trajectories laid out during the nineteenth and early twentieth centuries (Melosi, 2008). The changes utilities have undertaken have had few direct consequences for the everyday user, enabling utilities to implement projects with minimal public engagement. However, the search for 'new' water sources, such as treated wastewater, has generated much greater public interest than before, due in part to the decoupling of long-held values around what constitutes an acceptable water source (Spackman et al., 2025).

Water reuse, treating wastewater for beneficial purposes, is increasingly proposed as a technological solution for agricultural irrigation and augmenting the drinking water supply. A specific, though more challenging, application is potable reuse, which involves treating wastewater to drinking water standards. Although technically viable, several projects, such as Toowoomba's and San Diego's attempts in the 1990s, have failed (Hartley, 2006; Hurlimann & Dolnicar, 2010), while others have operated only until water shortages eased (Wester & Broad, 2021). What they are claimed to have in common is public opposition, which is usually framed as a 'social acceptance' problem. Research demonstrates this is a complex phenomenon influenced by multifaceted challenges. Here, the 'Yuck factor' is frequently claimed to be highly impactful, which describes the psychological disgust associated with the perceived 'contamination' of drinking water (Leong & Lebel, 2020; Tennyson et al., 2015). Moreover, safety and risk perceptions, often fuelled by a lack of trust in the authorities, add further complexity (Ormerod & Scott, 2013; Scruggs et al., 2020). While alternatives such as desalination or water import exist, their high energy intensity and ecological impacts often make potable reuse the more cost-effective option, especially in inland areas (Herman et al., 2017; Khan, 2013; Leverenz et al., 2011). However, potable reuse remains more controversial than many of these alternatives, dragging a once-hidden system into view as citizens demand a more active stake in the decision-making process.

Despite these challenges, initiatives deploying potable reuse systems are increasing, especially in the arid Western United States (e.g., Binz et al., 2016; Distler et al., 2020; Harris-Lovett et al., 2015), although Eastern states such as Florida have adopted reuse guidelines, and South Carolina is exploring reuse guidelines. This regional acceleration in the Southwest U.S. is driven by several systemic pressures: the structural over-allocation of the Colorado River, multi-decadal droughts, and rapid urban population growth in desert metropolises (Hirt et al., 2017). Potable reuse projects often employ various strategies to enhance social acceptance, including education campaigns, community outreach, and participatory approaches. However, such methods are often critiqued for prioritizing persuasion over genuinely addressing underlying public concerns, potentially leading to fragile support misaligned with broader societal values (Moesker et al., 2024b; Taebi, 2017; Ibo van de Poel, 2016).

This study aims to investigate how public concerns are addressed in planning for large-scale water infrastructure projects in these uncharted waters, where large-scale sustainability transitions alter infrastructure in ways that violate long-held social norms about what is − and is not − considered an acceptable water source. We explore how three prominent potable reuse projects in San Diego, Phoenix, and Scottsdale engage with the public by examining the extent to which their engagement strategies align with RRI principles. Drawing on interviews with experts and project stakeholders alongside publicly available documents, we utilize the 'Leaving Ajar' framework as proposed by Russell et al. (2022), modified to enhance application clarity, to evaluate how each project facilitates public engagement in their potable reuse projects. By examining these case studies, this research aims to better understand the practical challenges and opportunities of implementing more inclusive and responsive engagement strategies within the complex context of infrastructure projects.

4.2. Theory

4.2.1. Responsible Innovation

RRI aims to increase the social and ethical desirability of technological innovations by providing guidelines that ensure technological developments are aligned with societal values and needs (Boenink & Kudina, 2020; Von Schomberg, 2011). Public participation, specifically, is a primary means of collecting those values and needs and integrating them into the innovation trajectory. However, in practice, participation is frequently poorly executed, frequently prioritizing instrumental goals like conflict reduction over substantive democratic input (Fiorino, 1990).

One highly influential approach in categorizing the desirability of public participation approaches in technology development is shaped by the work of Stirling (2008): Opening Up and Closing Down. In this, Opening Up rests on the view that including diverse perspectives not only enhances democratic principles but also improves decision quality by incorporating a more comprehensive range of knowledge, thereby acknowledging the dynamic way that technology shapes and is shaped by society (Bijker, 1994; Stirling, 2008). To do so, starting participation early or 'upstream' in the project lifecycle before key decisions are made is critical for public input to have a meaningful impact (Rowe & Frewer, 2000; Wilsdon, 2004).

Conversely, Closing Down refers to traditional measures aimed primarily at convincing the public of a technology's benefits. According to Russell et al. (2022), this often involves tactics such as emphasizing the severity and urgency of the problem the technology addresses, presenting it as the best available solution, and avoiding more contentious discussions. Stirling (2008) further notes that such engagement processes often limit questions about the wider context, resulting primarily in a narrow focus on achieving public acceptance for a predetermined solution.

Although often promoted as the RRI ideal, the practical feasibility of Opening Up engagement is questioned by several scholars. Critics highlight real-world constraints, such as private sector limitations, considering confidentiality, power imbalances, and institutional barriers (Blok & Lemmens, 2015; Reyes-Galindo et al., 2019; Scholten & Blok, 2015) demanding a "radical departure from business as usual" (Tempels & Van den Belt, 2016, p. 11). Instead, Van Mierlo et al. (2020)

argue that Opening Up and Closing Down occur in tandem and are an inherent part of the innovation process. These opening and closing dynamics can also be understood as "phenomena that simultaneously shape agency within individual settings along the innovation stream" (Fuchs, 2024, p. 51).

Building on the idea of intertwining approaches, Russell et al. (2022) propose 'Leaving Ajar' as an in-between the extremes of Opening Up and Closing Down. They posit that Leaving Ajar approaches aim for social acceptance by *being* "responsive to public views, but with a pragmatic focus on creating the conditions that might allow the technology to be successfully deployed" (p. 160). While oriented towards deployment, unlike Opening Up, Leaving Ajar differs from Closing Down by emphasizing responsiveness over mere persuasion.

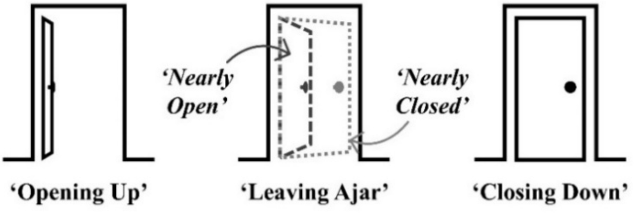

Figure 4.1: Schematic representation of Opening Up, Closing Down and different stages of Leaving Ajar.

We extend Russell et al.'s concept by viewing Leaving Ajar not as a single point but as a spectrum of approaches. This perspective allows for analyzing diverse engagement practices that leave varying degrees of opportunity for public feedback to shape technology implementation, with some strategies leaning closer to Opening Up and others towards Closing Down. Figure 4.1 illustrates this spectrum using a door metaphor: a closed door represents Closing Down (narrow engagement focused on deployment), an open door symbolizes Opening Up (vast possibilities), and a partially open door depicts Leaving Ajar, representing variability within this middle ground.

Nevertheless, the RRI scholarship, more generally, and Opening Up, specifically, were primarily developed with small-scale technologies in mind. Large-scale infrastructure projects face fundamentally different participatory requirements due to their physical scale, long-term lifecycles, and massive capital investments.

4.2.2. Large-Scale Infrastructures and Potable Reuse

The development of infrastructure operates at a systemic scale, frequently creating friction between the system's requirements and the localized impacts on the communities it is intended to serve. As such, infrastructures differ fundamentally from small-scale technologies. They are deeply embedded within society, extending far beyond a single locality and into distant temporalities, while often being taken for granted (Star, 1999). In many developed countries, infrastructures appear most often to the general public during breakdown or, as in our case, during fundamental transitions (although Anand (2011, 2017) highlights the unevenness of who gets to take for granted infrastructures).

Deploying potable water reuse represents a fundamental transition in water infrastructure, forcing this traditionally 'invisible' system into the public light due to its controversial nature and potential costs. Generally, water reuse involves using treated wastewater from diverse sources like rainwater and stormwater, as well as intentionally collected household wastewater (Kayhanian & Tchobanoglous, 2016). Indirect potable reuse (IPR) and direct potable reuse (DPR) are two increasingly popular systems. Both use advanced technology to ensure compliance with potable water standards, differing primarily in the presence or absence of an environmental buffer (Gerrity et al., 2013). IPR releases treated water into an environmental buffer, like natural water bodies or artificial storage, with notable adoption in the United States and Australia (Santos et al., 2022). In contrast, DPR skips the environmental buffer, directly integrating treated water into the drinking water system (Voulvoulis, 2018).

By removing the physical and temporal distance traditionally provided by natural water bodies, DPR forces the once-hidden water supply and waste systems into view. This transition is frequently characterized by controversy, prompting scholars and management experts to seek strategies to increase acceptance. However, due to high context dependency (Al-Saidi, 2021), developing a comprehensive picture of factors affecting public acceptance remains elusive. Nevertheless, scholars attempting to map critical factors suggest that public acceptance depends on technological aspects such as safety and risk (e.g. Duong & Saphores, 2015; Ormerod et al., 2019) or the Yuck factor (e.g. Leong & Lebel, 2020; Villarín & Merel, 2020). Others highlight the importance of context, where trust in authorities (Boyer et al., 2017), knowledge about the technology (Khan & Anderson, 2018), and perceived urgency (Bufe, 2013a) are frequently mentioned. Lastly, Moesker and Wiarda (2025) point out that current potable reuse research show fundamental value misalignment, leading to conflict.

Various approaches to increase public acceptance have been proposed, such as educating the public (Nagel, 2015), pilot projects (Wilcox et al., 2016), reframing the technology (Katz & Tennyson, 2015; Villarín & Merel, 2020) and tastings to gain insights about the participants' embodied reactions or memories (see, Manheim, 2024; Manheim & Spackman, 2022; Spackman et al., 2022). Other approaches acknowledge the need for holistic public engagement (Distler et al., 2020; Duong & Saphores, 2015; Scruggs et al., 2020). Yet, many of those proposed processes remain stuck in a 'deficit model' that often functions as an educational campaign to persuade the public rather than consult them (Manheim, 2024; Moesker & Pesch, 2025; Moesker et al., 2024b).

While participation is seen as essential for sustainable water governance, this body of literature is only emerging with a lingering disconnect between theory and execution, often resulting in tokenistic participation (Antwi et al., 2021; Ruiz-Villaverde & García-Rubio, 2017). Other challenges include overcoming practical barriers, such as lacking practical experiences with participation processes, unclear stakeholder roles and their decision-making impact, the difficulty of balancing conflicting stakeholder interests, and unbalanced representation (Huitema et al., 2009; Mostert et al., 2007). Yet, when successfully implemented, participation in water governance can help incorporate local expertise and reduce long-term friction (Graversgaard et al., 2017).

4.2.3. Learnings from the Energy Transition Scholarship

To move beyond the limitations of current scholarship on water governance around responsible participation in infrastructure transitions, we look to the more mature discourse of energy transition scholarship to highlight the unique participatory challenges inherent in large-scale infrastructure systems. Water and energy infrastructures are inherently comparable; both are critical systemic utilities that require massive capital investment, involve long-term 'lock-in' of technological choices, and are currently undergoing transitions driven by resource scarcity and climate change.

Historically, the energy sector also relied on top-down approaches used instrumentally to secure acceptance for pre-determined choices and reproduce existing power structures (see, e.g., Cuppen & Pesch, 2021; Rodhouse et al., 2021). However, energy scholarship has since matured, offering several critical learnings for infrastructure governance. Specifically, this literature highlights that participation must be reconceived as a system-wide effort, is inherently in tension with the urgency of sustainability transitions and must shift toward addressing justice-related impacts rather than merely increasing acceptance.

First, participation is increasingly conceived as a system-wide effort (Smolka & Böschen, 2023). This 'ecology of participation' recognizes that meaningful engagement occurs in both local, emergent spaces, such as grassroots activism, and systemic, top-down efforts, which co-evolve and inform one another (Chilvers & Longhurst, 2016; Chilvers et al., 2018). However, merely implementing any participation process is insufficient. Only transparently designed objectives of the engagement can be evaluated on their 'success' (Reynolds et al., 2023). Yet, there is currently a lack of agreement in the timing as well as what constitutes adequate participation approaches (Bice et al., 2019).

Second, a persistent challenge within participation efforts is a tension with the perceived urgency to move towards more sustainable systems. Changing infrastructure is a long-term endeavour, often requiring years of planning and construction. As such, there is a tension between the increased political urgency to act and the slow, iterative nature of meaningful participation (Boyle et al., 2024). At the same time, this perceived urgency risks technological lock-in, where institutional and economic frameworks reinforce initial technical choices (Arthur, 1989). The drive for rapid decarbonization risks entrenching dominant power structures (Hoffmann, 2025; Lenhart & Fox, 2021; Sovacool & Brisbois, 2019) and limits the space for diverse innovation, as experimenting is often discouraged in favour of faster transitions (van der Loos et al., 2020).

Lastly, energy transition scholarship offers an expansive body of research on social acceptance, evolving from reductionist frameworks like the deficit model toward sophisticated participatory processes (reviewed in Moesker et al., 2024a). Recently, a shift from a narrow focus on gaining social acceptance toward impacts on justice can be noticed, especially (Ayllón & Jenkins, 2023; McCauley & Heffron, 2018; Sovacool et al., 2021). These justice perspectives reject reductionistic views about public concerns, such as the NIMBY (Not-in-my-backyard) myth. Instead, the field increasingly acknowledges that public resistance arises not merely due to egoism or a lack of knowledge but often stems from valid concerns regarding distributive justice, local identity, and place attachment (Wolsink, 2000, 2006).

4.3. Methodology

This study employed a semi-structured interview methodology and focused on participants' attitudes toward public participation, their valuation of public outreach activities, their expectations regarding outreach outcomes, and their perceptions of the impact on public views concerning potable water reuse. This research has received approval from the Human Research Ethics Committee of TU Delft (ID no.

3973). To identify potential interviewees, we used five methods: reviewing water utility content, researching governmental decision-makers, leveraging existing networks, recruiting at the AZ Water Conference, and using the snowball effect.

We interviewed 17 key stakeholders to evaluate how each city navigates public acceptance. Given the specialized nature of potable reuse and it only recently becoming more popular the pool of individuals responsible for high level strategy is limited. Participants were selected through purposeful sampling to capture diverse perspectives from those involved in the strategic design and observation of these projects. Because of the close geographic proximity and technical collaboration between Phoenix and Scottsdale, several stakeholders provided expertise for both cities and are counted accordingly in Table 4.1.

Table 4.1: Overview of interview participants

Stakeholder Category	San Diego	Phoenix	Scottsdale
Project Managers / City Officials	1	3	2
Academic Experts & Consultants	2	2	3
NGO / Community Representatives	3	3	2

Moesker systematically organized, coded, and evaluated the interviews using a hybrid coding approach, combining both deductive and inductive strategies. Spackman then reviewed the coding. A hybrid approach is especially suitable as it allows for goal-oriented coding through deductive starting points in an area with little preexisting research. The coding scheme of this study is based on Russel et al.'s (2022) Leaving Ajar framework (see Table 2). We refined these categories to facilitate coding by removing duplicate aspects and providing a clear set of subcategorizations.

For example, "Prime the public for [technology] release" does not differ significantly from "sell the technology," as both aim at the same thing – implementing the technology. Moreover, "engage early" previously appeared under multiple approaches but has now been made explicit under the single "Engagement Timing" category of Opening Up. We introduced new categories to provide an overarching coding structure, replacing the "Strategy (how)" category with the following (A summary of the revised framework can be found in Table 4.3):

Engagement Timing assesses the temporal dimension, highlighting when public engagement occurs relative to the decision-making process. For this study, 'the decision' refers primarily to the formal commitment to proceed with implementing a potable reuse project. Opening Up approaches focus on engaging long before the technology is needed, Leaving Ajar emphasizes engagement at the decision-making stage, and Closing Down limits engagement to post-decision phases.

Table 4.2: Leaving Ajar Approach Framework Indicators as proposed by Russell et al. (2022)*

	Closing Down	**Opening Up**	**Leaving Ajar**
Implicit Goal (Why)	• Sell [the] technology • Build public acceptance • 'Prime' publics for [technology] release	• Explore [the technology] • Seek public input to decision-making • Deliberate about [the technology] as a solution	• Make [the technology] acceptable • Seek social license • Respond to public concerns
Strategy (How)	• Emphasize the severity and urgency of the challenge • Present [the technology] as the best solution • Tell morally compelling stories • Disassociate with [related disputed technology] & contentious applications	• Engage early • Discuss pros and cons and context, case by case • Go beyond risk, consider broader issues • Learn from the debate [of related technologies], understand and respect diverse public reactions • Be open to not using [the technology]	• Engage early • Attend to local communities and their needs • Focus on problems • Compare [the technology] with alternative solutions • Reframe the [technology] debate • Emphasize non-profit, public good applications

Note: The technology in focus, Gene Drive, has been changed to a more abstract form, [the technology], to make this framework suitable as an assessment tool for other technologies.

The *Problem Space* explores the specific challenges addressed by public engagement strategies for potable reuse. Opening Up looks beyond immediate risks to explore more systemic issues, Leaving Ajar centres on context-specific concerns, and Closing Down narrows those concerns to those justifying the technology. During the interviewing process, we inductively identified four *overarching problem areas* that were to be addressed in engagement strategies:

- **Societal Responses:** Communication addresses public attitudes, beliefs, and reactions to potable reuse, including understanding, acceptance, cultural norms, and the "yuck factor."
- **Environmental Context:** Communication focuses on ecological conditions and constraints, such as water availability, urgency, and dependence on external sources.
- **Long-Term Impacts:** Communication elaborates on anticipated future societal consequences of potable reuse, including sustainability, climate change, business impacts, and city growth.
- **Technological Impacts:** Communication highlights technological attributes and their potential consequences, such as safety, water quality, affordability, and equity.

Table 4.3: Leaving Ajar as a Spectrum

	Opening Up	**Leaving Ajar**	**Closing Down**
Implicit Goal	Seek public input: Explore and deliberate about [the technology] as a solution	Make [the technology] acceptable Respond to public concerns	Sell [the] technology
Engagement Timing	Engage long before [a technology] is needed	Engage when a decision for [a technology] is needed	Engage after deciding on [the technology]
Problem Space	Go beyond risk, consider broader issues Understand and respect diverse public reactions	Focus on problems Attend to local communities and their needs	Emphasize the severity and urgency of the challenge
Debate Framing	Discuss pros and cons and context, case by case Learn from the debate of [related technologies]	Reframe the [technology] debate Emphasize non-profit, public good applications	Tell morally compelling stories Disassociate with [related disputed technology] & contentious applications
Addressing Alternatives	Be open to not using [the technology]	Compare [the technology] with alternative solutions	Present [the technology] as the best solution

Addressing Alternatives highlights how potable water reuse alternatives are addressed in potable reuse engagement. Here, Opening Up approaches are characterized as open to not adopting the technology; Leaving Ajar aims to compare alternatives directly; while Closing Down approaches present the chosen solution as the only viable option.

Debate Framing expands on how a city presents potable reuse in the public discourse. Opening Up strategies present balanced views by openly discussing the system's risks and benefits. Leaving Ajar approaches strategically manage the narrative, often using branding or specific wording to guide perceptions towards acceptance. Closing Down employs tightly controlled, persuasive communication that emphasizes benefits and downplays risks to secure acceptance.

These overarching code groups served as a deductive starting point, providing a set of a priori categories for analyzing the interview transcripts, except for the "Implicit Goals" category. As implicit goals are not directly articulated but inferred from the interplay of other expressed ideas and actions, we did not explicitly code for them during the initial coding phase; instead, we used this category to synthesize and discuss the emergent themes and patterns identified.

Following this, we employed an inductive approach, following Vears and Gillam (2022), thereby populating each overarching coding group with specific codes that emerged from the data through iterative coding. This inductive process involved creating new codes and modifying existing ones based on a detailed examination of the transcripts, ensuring that the final coding scheme was theoretically grounded and empirically informed. For instance, the coding group "Debate Framing" was initially defined as encompassing how information about the project was presented to the public. Through the inductive coding process, this group was populated with specific codes, such as "Branding," "Wording and Phrasing," and the "Water is Water" frame, as these codes emerged from the interview data. Table 4.4 briefly defines each code group and some example codes.

The analysis was conducted using the qualitative data analysis software Atlas.ti, with coding performed at the level of discrete ideas within the transcripts. The relatively small number of interviewees and the heterogeneity make quantitative claims based solely on code frequency potentially misleading. Instead, each city's position on the Leaving Ajar spectrum was determined through a qualitative assessment of the coded data. This involved examining the presence, prevalence, and notable absence of indicators associated with Opening Up, Leaving Ajar, and Closing Down in each city, with emphasis on identifying patterns and recurring themes in the interview data. To enhance the study's validity and ensure coding consistency, the authors held regular discussions.

Table 4.4: Code group definition with example codes and quotes.

Definition	Example Code	Example Quote
Engagement Timing: Point in time public engagement activities are taken up in relation to the decision-making process.	Long Before Decision	"The conversation has been out there long before anyone was actually talking about putting this in taps."
	When Decision Needed	"As soon as you have a dominant design and an industry with its own interest, that's probably where the public should have a close look"
	After Decision	"Phoenix has kind of come in here more recently... because they have realized that... we really are just going to have to find additional sources of water."
Problem Space: How the problem that the project addresses is defined and understood. This can involve defining the scope of the problem, identifying its root causes, and determining which issues are considered relevant.	Understanding public needs	"They did a public opinion poll just to try to understand how people felt about recycled water."
	Affordability	"It doesn't matter how much it costs because it's cheaper than if we had to do a whole other thing."
	Urgency to find solution	"We do have issues with water. Everybody knows that. People know that we're going to have to find additional supplies"
Debate Framing: The way in which information about the project is presented to the public, including the choice of language, the emphasis on certain aspects, and the overall narrative that is constructed.	Wording & phrasing	"In focus groups people hear the word treatment and they think of cancer treatment, radiation treatment. It sounds super scary."
	Water is water	"What people are really trying to emphasize now is, it's water, it's water like any other"
	Inevitability	"Geographically, it's not like we have an alternative"

Addressing Alternatives: Whether and how alternative solutions to the problem are considered and discussed with the public.	Desalination	“We have also talked about desalination. Very expensive and very energy intensive.”
	Diversifying	“[DPR] is one egg in our basket”
	Conservation	“You can't conserve your way out of a drought.”

4.4. Results

This article assesses three cities at various stages of implementing potable reuse systems in the arid U.S. Southwest: Scottsdale, AZ; Phoenix, AZ; and San Diego, CA. These locations share similar geographic backgrounds and challenges related to water scarcity but are in different stages of implementation (see Figure 4.2), and in the case of San Diego, under a different state regulatory framework.

The following analysis is organized by city and is structured according to five key engagement dimensions: engagement timing, problem space definition, the addressing of alternatives, debate framing, and the implicit goals of the communication strategy. This approach allows us to compare and evaluate how each city addresses public concerns toward controversial water technologies.

Figure 4.2: Schematic representation of the projects’ deployment stages

4.4.1. City Analysis

Case 1: Direct Potable Reuse in Scottsdale, Arizona

Scottsdale faces severe water scarcity due to a combination of factors, including prolonged droughts, climate change, and population growth. With its hot desert climate and average summer temperatures frequently exceeding 100°F (38°C), Scottsdale relies heavily on limited external water sources, particularly from the Colorado River and groundwater reserves (Scottsdale Water, 2021). For over 20 years, Scottsdale has implemented IPR primarily for landscape irrigation, facilitated mainly by financial partnerships with the city's numerous golf courses (Tenney, 2018).

In 2018, Arizona relaxed its ban on producing recycled water for human consumption, allowing cities to negotiate terms for DPR permits. Scottsdale actively partnered with the Arizona Department of Environmental Quality (ADEQ) to draw up criteria for monitoring and regulating direct potable reuse within Arizona, becoming the first city in the state to operate such a demonstration plant (Biesemeyer, 2019). The city's strategy emphasizes proactive community engagement and educational initiatives to foster public trust and support for the DPR initiative, recognizing the importance of public acceptance for the project's success. Various public education methods are being utilized, including facilitating tasting events at local festivals (Spackman et al., 2022) and collaborations with local breweries (Manheim & Spackman, 2022; McNamara, 2023).

When considering ***Engagement Timing***, the city's stakeholders understand the project to be taking a proactive approach. Three of the interviewees the city and its utility strongly emphasized engagement long before the decision to move towards DPR was made. Engagement efforts remained continuous, intensifying in the late 2010s with the pilot plant's operation and as the likelihood of pursuing full-scale DPR increased. One interviewee highlighted: "We started this process, thinking it was likely, … but not certain, that we'd have to do it" (Person_N). This early engagement was made possible by leveraging the infrastructure and expertise of the already existing IPR plant. Building the DPR demonstration component onto this existing infrastructure offered a less cost-intensive pathway to explore the system compared to a standalone DPR project. This demonstration has been intended to be a form of public engagement, to *"start getting this technology and the idea about having potable reuse water out there to people,"* as another interviewee noted. This willingness to receive public responses indicates an openness to discuss the project's implications for the communities.

Moreover, the DPR facility in Scottsdale served as a significant form of engagement with *policymakers and regulators.* This interaction focused on collaboratively drafting the necessary regulations for DPR to be permitted in Arizona in close partnership with Scottsdale's utility (Manheim, 2024). This type of engagement can be seen as Leaving Ajar as regulators and policymakers, whose role involves creating a workable and safe framework, arguably have a vested interest in ensuring project success, thereby facilitating its path towards potential implementation.

The city's ***Problem Space*** focuses predominantly on understanding and managing societal responses. Initially, the city focused on understanding those responses, as one interviewee highlights: "They did a public opinion poll just to try to understand how people felt about recycled water" (Person_A). An interviewee with decision-making capacity indicated that this exploratory outreach was prompted by the system's anticipated controversy and the need to understand its roots. This awareness suggests an initial openness to exploring the problem space with the public, yet confined within the potable reuse realm.

The focus later shifted to managing the identified societal responses that led to non-acceptance. This involved addressing specific concerns that emerged, including potential negative business impacts, as one interviewee noted: "Everyone has friends and family out there … So I know some of them have some concerns that [DPR] may be hindering the business" (Person_D). To counter such worries and build support, outreach strategies actively communicated the benefits of DPR by presenting potable reuse as crucial for the community's future prosperity: "We are doing it for the good of the community, we're also doing it for the good of our environment. We're doing it for the good of our economy and helping us grow and be attractive to other businesses." (Person_M). This shift in priorities from initially understanding public concerns towards later presenting DPR in a positive light indicates Leaving Ajar tendencies.

However, Scottsdale ***Addresses Alternatives*** such as desalination or groundwater recharge and considers additional water import and the possibility of continuing solely with IPR. Desalination is dismissed as too costly compared to DPR due to the city's landlocked nature: "When you consider the cost of desalination … in Mexico or California and pumping water to us and the tremendous investment of that, … compare that to what we can do directly. It's a viable economic investment" (Person_N). Importing more water is also deemed unfeasible due to the current state of the Colorado River: "All the lower Basin States, Nevada, New Mexico, Arizona, California have agreed to drastically cut our take from the Colorado River until we can figure out what the hell is going on and if this is going to be the new normal" (Person_P). Therefore, it appears the city strategically dismisses competing technologies, effectively highlighting its project as the most viable solution, aligning with Closing Down tendencies.

DPR and water conservation, on the other hand, are seen as insufficient on their own: "We have put in place a lot of conservation measures … there is room for improvement... . But there will obviously be a threshold" (Person_F). Instead, interviewees point out that other measures must be taken, where one interviewee underscored that it is not about choosing an alternative but seeing potable reuse as: "One egg in our basket that's going to help us conserve. It's going to help us sustain.

It's going to help us move forward." (Person_M). Portraying potable reuse as a necessary addition to the current water portfolio is another indicator for a Closing Down approach, as it frames the technology as indispensable, thereby limiting the scope of public deliberation to *how* it should be integrated rather than *if* it should be adopted.

Further, we found that Scottsdale has put significant effort into developing ***Debate Framing*** strategies. The decision to rebrand their recycled water "Advanced Purified Recycled Water" (APRW) from the earlier Advanced Water Treatment approach, reflecting an attempt to balance transparency with a positive, framing: "We add the 'recycled' in because we want make people to understand it really is recycled" (Person_N). Other elements that play a significant role in their communication strategy suggest a Closing Down approach. For example, debate frames such as "all water is recycled" (e.g., "I hate to tell you, but you're already drinking dinosaur poo" (Person_B)) and "water is water" (e.g., "what people are really trying to emphasize now is, it's water, it's water like any other" (Person_A)) aim to normalize the working of potable reuse by comparing it with the workings of the hydrological cycle. This dual approach, trying to increase transparency while managing potential negative perceptions, places Scottsdale's framing strategy predominantly within the Leaving Ajar category.

Overall, Scottsdale's engagement appears driven by an ***Implicit Goal*** of ensuring long-term public 'buy-in' and acceptance through proactive, continuous engagement. Their strategy was initiated with a Nearly Open exploration of the problem space, gauging public opinion and understanding potential controversies and intensified engagement as DPR became more likely. While they discuss and dismiss several alternatives in a Closing Down manner, their transparency in branding (Advanced Purified Recycled Water) and early, sustained engagement point towards a commitment to address public concerns, rendering it a Leaving Ajar approach.

Case 2: Potable Reuse in Phoenix, Arizona

Phoenix shares geographic challenges with its neighbouring city, Scottsdale, and experiences significant water supply pressures due to climate change and population growth. In response to these challenges, Phoenix's water management strategy includes the use of reclaimed water for non-potable purposes, such as irrigation, industrial cooling, and aquifer recharge (City of Phoenix, 2021b).

More recently, the city has been evaluating the feasibility of DPR as part of its long-term water sustainability efforts. In 2023, the city committed $30 million to convert the previously closed Cave Creek Reclamation Plant into a DPR plant, although Arizona's regulation frameworks for such a system had not yet been finalized (Cahill, 2023). Another project planned for conversion into a DPR facility is the 91st Avenue Wastewater Treatment Plant, a collaboration with neighbouring cities of Tempe, Mesa, and Scottsdale, which is expected to be finalized by 2030. The public outreach campaign for Phoenix's DPR project is still in its early stages. Officials have acknowledged the importance of engaging the public to build support for the project and recently partnered with the local news agency *The Arizona Republic*, but concrete outreach strategies are still being developed.

As Phoenix is only ramping up its engagement strategy, its Engagement Timing began much later than its neighbour, Scottsdale. Phoenix's more recent engagement must be contextualized within Arizona's regional watershed – the city has, for example, engaged with the public in the past around the building of an indirect reuse treatment facility, the Tres Rios wetland (Brown et al., 2011; Elkins, 2011). One interviewee who has decision-making capacity noted a desire to have a "demonstration trailer and facility … then you could go into that micro kind of education where our customers can come in and interact with the technology and touch and feel the product and really get a sense of what they think this is of, of what we're going to be putting out as advanced purified water versus what the reality of it is" (Person_I). This anticipatory timeline, coupled with the fact that Phoenix is in the planning process for converting its 91st Ave waste treatment facility (which currently collects waste from Glendale, Mesa, Phoenix, Scottsdale, and Tempe (Sheth, 2023)), suggests that Phoenix is navigating engaging the public as parts of the decision are being made, and after other decisions have been made, indicating a Nearly Closed approach.

Phoenix's current approach eschews a long ***Problem Space*** exploration, perhaps due to its late entry to DPR. Instead, the city is focusing heavily on the belief that opposition arises from misconceptions, as one interviewee articulated: "I think that's a lot of the misconceptions that you're trying to overcome of what individuals may think this is versus the reality of what it is" (Person_I). As such, public outreach is used as a means of education "so that they understand the need for it and the technology behind it and so that they understand that it's safe and an important water resource" (Person_K). This is done, for example, by highlighting the role DPR can play in addressing water scarcity: "Especially in Phoenix, we all understand that we live in a desert city – yeah, we do have issues with water" (Person_A). As a result, the problem space of Phoenix is drawn up to manage expected societal responses strategically, rather than to address public concerns, indicating a Closing Down approach.

Phoenix, although sharing the same geographical characteristics as Scottsdale, ***Addresses Alternatives*** differently. Unlike Scottsdale interviewees who saw technical alternatives such as desalination and groundwater recharge as more costly than DPR, and thus outside of feasibility, an interviewee from Phoenix highlights that various measures are needed to ensure future water availability: "We're doing everything everywhere, all sources we're getting. We're adding new water resources on top as well as conservation efforts to reduce the demands that we do have" (Person_I). On the surface, Phoenix appears to be more open to alternatives than other cities that have already committed to a specific type of potable reuse.

The same interviewee also indicated room for flexibility in the choice of moving towards DPR or IPR: "Initially, we have to do IPR because the rules are not in place to do anything about that. I think as we move forward, advanced purification – putting that product into the distribution system – will be the primary. And then depending on what's going on with the raw water constituents, they may get put back into the ground depending on certain scenarios" (Person_I). While this emphasis on diversification and the flexibility between IPR and DPR points to some degree of openness regarding future pathways, Phoenix ultimately appears to view potable reuse as a necessary component of its long-term water portfolio, indicating a Closing Down approach to alternatives.

Within the category of ***Debate Framing***, Phoenix employs frames comparable to Scottsdale, such as "all water is water" and "all water is recycled" in its public engagement approach. While also adopting the Arizona-wide term "Advanced Water Purification" (AWP), Phoenix is not opting to include the term 'recycled'. Instead, the city considers a more consumer-friendly brand like "Arizona Pure". Communication experts articulated the intent behind this branding: "Ideally, the general public would be able to associate Arizona Pure with advanced water purification and know immediately that we're talking about a new water resource for the benefit of the community: economic growth, population growth, sustainability, protecting the environment" (Person_K). This strategic use of branding and marketing techniques reveals a clear intention to shape public perception positively, suggesting Closing Down Tendencies.

Actively managing terminology when speaking to the public is also considered to avoid undesirable reactions: "We had an unfortunate circumstance where one of our subject matter experts, just in speaking conversationally with the journalist, used a very common term in the industry and referred to water coming out of the back end of a plant. And that was not the best choice of words and we spent a week or two just sort of dealing with that." (Person_K). Treating potentially negative terminology as a threat to public acceptance further highlights the city's attempt to shape public perceptions and induce a positive bias towards potable reuse, further indicating a Closing Down approach.

In sum, Phoenix seems to be guided by the ***Implicit Goal*** of securing acceptance within a short timeframe. Their reactive engagement timing, combined with a problem space definition focused on correcting perceived public misunderstandings and emphasizing urgency, points towards a Closing Down approach. These tendencies also recur in framing the debate with normalizing language and positive branding. This reinforces the idea that managing perceptions and persuading the public of DPR's necessity and safety are key objectives. As a result, although the cities have shown some openness and responsiveness, for example, by highlighting that DPR is not seen as a stand-alone solution but a combination of other efforts, this city's approach should be considered Nearly Closing Down because the city seems committed to moving forward with the project.

Case 3: Indirect Potable Reuse in San Diego, California

San Diego, facing persistent water scarcity in its semi-desert location, has historically relied on imported water sources (90%), leading to concerns about reliability and cost, exacerbated by past mistrust of the regional water importer, Metropolitan Water District of Southern California (MWD) (Bridgeman, 2004; Dennis & Brondizio, 2020). To reduce dependency on external sources, city officials proposed introducing IPR into the potable water supply. Initially, the idea gained support from technical experts and various community groups. However, by 1999, political debates and public resistance began to surface, leading to cancellation due to public health, equity, and cost concerns (Hartley, 2006; Po et al., 2003).

Despite this failed attempt, San Diego revived the concept in the early 2000s, strategically incorporating an extensive Public Outreach Program (starting in 2010) and a demonstration project specifically designed to build public support and address previous shortcomings (City of San Diego, 2013). Now known as Pure Water San Diego, the program has advanced significantly in recent years. Being unanimously approved by the city council in 2014, the building phase started in 2021, with the first phase expected to be completed by 2025 (City of San Diego, 2023). Once operational, Pure Water is to produce up to 30 million gallons of purified water daily, with plans to supply one-third of San Diego's water by 2035.

San Diego's ***Engagement Timing*** for potable reuse primarily focused on the decision-making phase. Unlike Scottsdale and Phoenix, San Diego has previously failed to implement potable reuse. One interviewee recounted the initial IPR efforts in California, where "until the 90s, early 2000s, this was all happening below the radar of the public. ... It was a pure expert circle that experimented with this very idea early on" (Person_B). In response, the city's proponents of IPR built a very robust network in advance of their second effort to promote the system: "And so we started having meetings with getting stakeholders: 'Listen, get people on your side. Work with them. Private meetings. Get the Chamber on your side. Get them listening. Get the organization so that when you when you start having the public meetings, you have trusted partners'" (Person_G).

The earlier focus on experts alone in the decision-making process during the 90s and early 00's was subsequently replaced by an outreach campaign to thought leaders and influencers. In this, San Diego's current efforts could be seen as a Nearly Closed approach: despite the early involvement in the second round of stakeholders, the stakeholders chosen were "big" players rather than the everyday community: as such, there was seemingly little opportunity for more than a handful of people to influence the decision to pursue IPR a second time. One interviewee recounted a previous IPR project that was put on hold in 1999, only to be revived in the mid-2000s with efforts to garner political support. This seems to suggest a pattern where decisions regarding potable reuse preceded substantial public engagement.

Like the other cities, San Diego's ***Problem Space*** focuses heavily on managing societal responses. However, next to addressing safety and knowledge concerns, their approach encompasses other previously encountered challenges, emphasizing past impacts of and attempts to alleviate water scarcity. For example, the desalination plant in Carlsbad and the increasing dependence on volatile and costly imported water have increased water prices in the past decade: "There's a lot of things that are driving the water costs up. Pure Water plays a role in there. I don't think it's as significant as one of the bigger ones as the seawater desalination plant in Carlsbad, and some of the other things" (Person_L). There also seems to be a general desire to become independent of imported water sources, where past impacts of water rationing have been repeatedly highlighted: "I mean that to me, that's the biggest selling point: Wow. We're not dependent!" (Person_G). Moreover, equity has been a primary societal concern, and is now integrated as a key component in engagement strategies: "And we also learned from 'effluent from the affluent' that we really wanted to bring multicultural consultants in to talk to certain communities" (Person_P). Hence, San Diego appears aware of relevant public concerns and attempts to address them, suggesting responsiveness to context. However, this effort seems strategically linked to promoting the redesigned IPR project as part of the solution to water dependence, affordability, and equity concerns. This aligns with a Leaving Ajar approach: genuine concerns are addressed, but it is designed to make the pre-selected potable reuse strategy more acceptable.

In ***Addressing Alternatives***, San Diego acknowledges IPR as part of a larger water portfolio and reinforces its selection by strategically dismissing other options. Like Scottsdale, it dismisses several competing alternatives; however, the reasoning extends beyond cost. For example, groundwater recharge is deemed inadequate as the city has no aquifer in the vicinity, and importing water is deemed unreliable based on past supply issues: “There were communities in California … they had to have water trucked in. They didn’t have enough water to have people have water out of their taps” (Person_P). In contrast to the other cities, desalination seems more viable given its proximity to the ocean and the existing Carlsbad plant. However, building more of those is communicated as too expensive and energy-intensive: “We have also talked about desalination. Very expensive and very energy intensive. So it didn't seem like that was a really good solution” (Person_C). As such, it appears that just as Scottsdale, San Diego downplays directly competing technological alternatives, indicating a strategic narrowing of potential solutions to be discussed in public, which aligns with the Closing Down approach.

For ***Debate Framing***, San Diego initially used the term common in scholarly literature, ‘Indirect Potable Reuse,’ to describe the system. However, in the past years, they simplified it to “potable reuse” to avoid confusion: “We were getting phone calls: ‘Well is one better than the other?’” (Person_P). The city also branded its water as "Pure Water", which connotes the same highly positive bias towards the system as done in Phoenix. Other Closing Down frames are also recurring in this city, such as the systems ‘inevitability’ (e.g., “geographically, it's not like we have an alternative.” (Person_H) ‘all water is recycled’ (e.g., they were saying all water has been here for a billion years. It's not like we have new water and old water” (Person_C), and avoiding the ‘toilet to tap’ frame. Uniquely, they leverage the aspect of ‘not being first’ in the vicinity to employ such a system: “I think it benefited from the fact that Orange County Water District had moved forward with theirs and progressed, and it was going online. And so they would take people up there … . You could tour the facility, you could drink the water” (Person_L). Hence, just as Scottsdale and Phoenix do, San Diego strategically employs terminology and framing that aim to normalize the system's workings and induce a positive bias towards it, rendering its approach one of Closing Down.

Not surprisingly, San Diego's ***Implicit Goal*** of rebuilding trust and achieving acceptance through carefully managed communication appears deeply influenced by its history of past project failures. We found Leaving Ajar approaches in the Problem Space, reflected in the city's efforts to address context-dependent concerns. However, their engagement timing, focused on the decision-making phase, and their handling of alternatives point towards managing the narrative to ensure project success this time around. As such, San Diego seems to follow a Nearly Closed approach.

4.5. Discussion – The Opportunities and Limitations of Opening Up

This study investigated the degree of openness of three public engagement approaches for potable water reuse infrastructure projects in Scottsdale, Phoenix, and San Diego. The analysis revealed that these projects predominantly employed Leaving Ajar strategies, with varying degrees of Closing Down and minimal evidence of Opening Up. In this discussion, we highlight several noteworthy study implications based on the similarities and differences in the cities' approaches, address the overall feasibility of the RRI ideal of Opening Up public engagement in the context of 'hidden' infrastructure, and conclude with this study's limitations.

4.5.1. Implications of the Leaving Ajar Approaches

While the three cities employ unique engagement strategies within the Leaving Ajar spectrum, significant similarities emerge, particularly in how they Address Alternatives and Debate Framing, both of which employ approaches primarily associated with Closing Down. Regarding Addressing Alternatives, all cities strategically reinforce the narrative that potable reuse is a necessary addition to the water portfolio, narrowing public discussion from whether the system should be utilized to how it can be done, with a lesser focus on whether indirect or direct reuse is a better fit. Similarly, the use of Debate Framing tactics, such as normalizing language and highlighting the system's benefits, actively induces a positive bias towards potable reuse and therefore aligns with Closing Down approaches.

The prevalence of a Closing Down approach in Addressing Alternatives and Debate Framing suggests that these tactics are considered highly successful at achieving acceptance by utilities, communications officers, and some public officials.

While seemingly less foundational than Engagement Timing or Problem Space, because they focus on communication, addressing alternatives, and debate framing carry significant implications as they set boundaries around what can be discussed. By limiting the scope of engagement (e.g., emphasizing benefits over risks) and strategically dismissing alternatives (such as desalination, or further afield, composting toilets (Ormerod, 2019)). Closing Down strategies actively steer the debate towards predetermined outcomes. This raises questions about the legitimacy and representativeness of engagement results when critical information or perspectives may be omitted or downplayed.

Significant differences emerged in Engagement Timing and Problem Space definition. Scottsdale, one of the major pioneers of DPR in Arizona, demonstrated an evolution toward semi-continuous participation. While they did not implement systemic participation from the project's conceptual phase, their expanded timeline allowed for a sustained engagement period during planning and deployment. This represents a significant advancement over traditional 'one-off' participation events. By maintaining a presence for an extended duration, Scottsdale could transition from merely identifying concerns to actively managing them as the project co-evolved with regulatory frameworks. Only after this exploration period did the city shift its broader public engagement strategy more clearly towards a Leaving Ajar approach by managing identified concerns to ensure project progress while maintaining responsiveness.

This contrasts with Phoenix, where the lack of systemic participation with inhabitants is more evident. Lacking Scottsdale's early start, the city's compressed timeline precludes a similar exploratory phase, but it does benefit from work done by Scottsdale and others. Instead, Phoenix's Problem Space focuses on correcting perceived public misunderstandings about DPR and highlighting the urgency driven by water scarcity. In some ways, Phoenix's approach resembles a classic deficit model, although its public collaboration with Scottsdale and a local news agency to promote the production of local beer made with DPR, and its openness to water tastings as outreach, demonstrate an approach open to public feedback (Manheim, 2024). Given the city's desert location, history of prolonged drought, and proximity to Scottsdale, it is difficult to attribute its relatively late engagement to a failure to recognize water scarcity in time. Instead, Phoenix's proximity and ongoing collaboration with Scottsdale, Mesa, and Tempe in outreach efforts, as well as its position within the sub-regional operating group (see, Tenney, 2019) as a receiver of many other cities' wastewater suggests that the city's decision-makers have let Scottsdale 'test' public opinion, and then, based on observing Scottsdale's success, allowed Phoenix decision-makers to feel confident and sufficiently informed for moving forward with a compressed timeline rather than following a more deliberative Leaving Ajar approach.

While collaboration between cities can increase efficiency, as seen in the Scottsdale-Phoenix partnership, solely relying on another city's experience, even within a similar environmental context, may lead to overlooking critical public concerns unique to their community. Engagement strategies leaning towards Closing Down, potentially adopted due to time pressures, may sidestep the slower work of participatory processes needed to uncover local nuances. For example, despite already active reuse projects, in August 2025 residents of Tucson (located ~100 miles south of the Phoenix metropolitan region) rejected plans to build a data center to be cooled by reclaimed water. Despite technical promises of minimal water impact, the project faced unprecedented backlash from residents anxious over the Colorado River crisis, such that the Tucson City Council unanimously rejected the project's water agreement, leading Amazon to abandon the site in late 2025 (Gilger, 2025) (City of Tucson, 2025).

The case of Tucson highlights a fundamental tension in infrastructure development: the conflict between the drive for efficient, timely decision-making and the RRI commitment to genuinely addressing diverse public concerns, recognizing that even neighboring municipalities facing similar environmental challenges may hold differing values.

For San Diego, the opportunity for genuinely 'early' engagement regarding the fundamental decision for potable reuse passed decades ago due to a previous project failure. San Diego's current strategy also reflects an advancement from virtually no participation in the 1990s towards semi-continuous participation efforts. However, rather than engaging 'early on', their current engagement timing focuses primarily on when decisions are needed, reflecting a Leaving Ajar that is less proactive than one like Scottsdale's. Unlike the other cities, San Diego's engagement strategy is heavily influenced by its past experiences, explicitly addressing specific local concerns. While this demonstrates responsiveness to past shortcomings, strategically addressing these particular concerns strengthens the case for using IPR. As such, the city exemplifies the part-way Leaving Ajar approach to the Problem Space: genuinely addressing specific public concerns while facilitating acceptance of the city's chosen path.

It appears that Engagement Timing and Problem Space categories critically depend on context, reflecting city-specific needs and histories. The variation between the cities in these context-driven aspects highlights a key requirement for effective engagement: sufficient time. As such, potable reuse projects should move beyond quick project development by managing immediate acceptance issues or assumed knowledge deficits and towards understanding the context-specific public concerns of their region.

4.5.2. Infrastructure as a Constraint on RRI and Future Research

Our findings suggest that applying RRI principles, especially the Opening Up ideal, is particularly challenging within large-scale infrastructure projects such as potable reuse. To evaluate the feasibility of RRI in this context, we return to the three participation challenges identified in energy transition scholarship: temporal longevity and lock-in, high capital investments, and the shift toward transition justice.

First, potable reuse projects are subject to significant path dependencies and the emergence of dominant designs. Early technological choices, substantial financial investments, and the development of specialized industries have already created momentum that makes it increasingly challenging to deviate from the chosen path over time. As technologies mature and industries develop vested interests, the space for substantial public influence on fundamental project aspects diminishes. For all three cities, the most fundamental question – whether to pursue potable reuse – was already decided when public visibility was lowest. As such, robust consideration of and debate about alternative pathways has effectively been closed off, seemingly regardless of public opinion. San Diego exemplifies this phenomenon: despite the failure of its potable reuse attempt in the 1990s, the city is once again pursuing the same technological trajectory but with a more sophisticated public participation process to better address public concerns.

From our perspective, we acknowledge the difficulties associated with applying RRI principles to address the ways in which temporal longevity and lock-in, as well as high capital investments, shape infrastructure decision-making. The sheer duration of the initial stages of infrastructure development can span decades and may involve government-level seeding of specific technological paths. Regarding potable water reuse, system concepts were developed in the U.S. in the 1970s, with the U.S. EPA convening an expert group in 1980 to evaluate potable reuse (Spackman et al., 2025; U.S. EPA, 1982), creating an environment where experts and technocrats primarily shaped the debate. However, development and implementation took many years as one interviewee from California questioned the project lifecycle: "It really takes 60 years from the first idea to a full-scale solution that can diffuse without any problems. It is two generations … And so, when would you include the public? What could they contribute in the first 30 years?" (Person_B). The upstream starting point remains a site of significant contestation: while some practitioners caution that premature engagement risks stoking unnecessary public anxiety, others argue that early transparency is essential to enhance trust and pre-empt opposition (Bice et al., 2019). The time required for technology development and adoption, as well as the costs associated with developing and testing new technologies, complicate efforts to engage the public during pre-adoption periods and further highlight the 'invisibility' challenge of infrastructure. The extended timelines associated with infrastructure development pose a fundamental challenge for RRI scholars advocating Opening Up approaches. This tension represents a critical area for future research into the governance of infrastructure transitions.

Second, the lengthy timelines go hand in hand with high capital investments associated with these projects, which seem to necessitate a degree of Closing Down to ensure project stability. While we observed progress toward semi-continuous participation, all cities clearly chose Closing Down approaches to some degree, presumably to secure their investments. After all, radically Opening Up decision-making across the drinking water system as a whole risks delays and cancellations of projects with billion-dollar consequences, especially when associated with shifting administrative priorities and limited funding opportunities

Finally, while energy scholarship has shifted toward considering justice concerns, our analysis reveals that the water sector remains largely stuck in the social acceptance paradigm. In all three cities, Leaving Ajar strategies were designed to facilitate project deployment rather than to explore the system's social and ethical impacts, although recently implemented practices such as water tastings do open the door for conversations based on everyday expertise, undoing the power imbalance between consumer and water provider (Manheim & Spackman, 2026). Justice issues, such as equitable cost distribution or the impact on marginalised communities, remain low on the agenda and are addressed only when seen as hurdles to acceptance. More research is necessary for both areas: first, to better understand the justice-related impacts of potable reuse projects, and second, to better understand the opportunities and challenges of participation in water infrastructure projects.

4.5.3. Limitations

This qualitative, multi-case study design entails several limitations. First, generalizability is constrained as findings are based on only three cities within the specific socio-political and environmental context of the arid Southwestern U.S., limiting direct applicability to potable reuse projects elsewhere. Secondly, reliance on a limited number of interviews with decision-makers, stakeholders, and academics may not fully capture the full spectrum of relevant views, potentially affecting representativeness. Thirdly, researcher subjectivity inherently shapes the qualitative analytical process, including coding, statement interpretation, and categorization within the Leaving Ajar framework. Although consistency was sought through author discussions, this interpretive dimension is intrinsic to this research approach.

4.6. Conclusion

This study evaluated how engineers, regulators, and policymakers understand and address public concerns across potable reuse projects in Scottsdale, Phoenix, and San Diego. Drawing on interviews with project stakeholders and analyzing publicly available documents, we found a predominance of Leaving Ajar approaches, in which cities aim to balance responsiveness to public concerns with the pragmatic goal of securing acceptance. All cases exhibited significant Closing Down tendencies, particularly in dismissing alternatives to battle water scarcity and strategically framing the debate through positive branding and normalizing language. The *engagement timing and the problems addressed in the public debate* reflected city-specific contexts: Scottsdale showed proactive evolution allowed by an early start, Phoenix adopted a compressed timeline, benefitting from Scottsdale's pioneering groundwork, and San Diego's approach was shaped by addressing historical concerns. However, genuine Opening Up strategies that facilitated reflective deliberation and joint decision-making with the option for project termination were minimal across all sites. The low uptake of Opening Up in current projects and the unique challenges to infrastructure project innovation, such as long timelines, path dependencies, and massive investments, highlight a significant tension between the participatory ideals of RRI and the inherent practical constraints of large-scale water infrastructure development. As the water sector navigates these uncharted waters, the transition from an invisible system to one under the spotlight remains difficult. Moving forward, this transition demands new engagement frameworks, possibly informed by the more mature energy transition scholarship, that are specifically designed to address the unique political and technical complexities of large-scale water infrastructure projects.

5

Making Sense of Acceptance and Acceptability: *Mapping Concept Use in Energy Technologies Research*

5.1. Acceptance & Acceptability – A Source of Misunderstandings

As societies grapple with the challenges of transitioning to more environmentally friendly and socially responsible technologies, the concepts of acceptance and acceptability have gained increasing importance. Yet, there is no unequivocal understanding of these concepts. Instead, research often utilises either of the concepts without defining them (Wüstenhagen et al., 2007) or uses them interchangeably together with the concept of adoption (Batel et al., 2013; Milchram et al., 2018).

Terms like acceptance and acceptability have been subjected to significant variations in interpretation based in part on the research field and objectives. Consequently, misinterpretations and ambiguity concerning research outcomes persist. This lack of consistent and clear definitions may hamper effective communication, impede the comparison of research findings across different studies, and complicate the development of cohesive strategies for technology implementation and societal integration. As such, clarity should be pursued when using the fundamental concepts of acceptance and acceptability in the interdisciplinary context of technology implementation strategies.

In support of this pursuit, we will provide an overview of the dominant interpretations of acceptance and acceptability that have arisen in social studies, ethics of technology, and innovation studies in the last decade, where especially research on energy transitions has contributed to concept development. With this overarching picture, we developed a scheme – the funnel of acceptance and acceptability – to illustrate that different understandings address different research perspectives and levels of abstraction. The funnel aims to help differentiate the various meanings of acceptance and acceptability more independently of the research fields, emphasising the interconnectedness and complementary nature of all definition types. Moreover, it prompts scholars to clarify their intent with these concepts, facilitating effective communication and fostering interdisciplinary dialogue within and across research areas.

5.2. Methodology

Before diving into the different understandings of acceptance and acceptability, a note on this perspective's methodology is needed: This theoretical synthesis attempts to integrate the different conceptualisations of acceptance and acceptability in energy technologies in a structuring framework. The need to do so emerged from another study of ours, which aimed at understanding narratives surrounding acceptance in another large-scale infrastructure context (Moesker et al., 2024b). We found that the fields of social studies, ethics of technology and innovation sciences contributed most to the debate. As ethics of technology scholars, we see these fields often come together when researching the societal impacts of implementing technology into society, making it difficult to make watertight distinctions between them.

To determine which understandings of the concepts of acceptance and acceptability dominate the current debates, we sought out widely cited papers that deal with these concepts, recognising their significant contributions to contemporary debates. We conducted a loose narrative review with the following title-abstract-keywords queries in the Web of Science database:

- (energy AND acceptance AND (social OR societal))
- (energy AND acceptability AND (social OR societal))
- (energy AND acceptance AND (ethic* OR normative*))
- (energy AND acceptability AND (ethic* OR normative*))
- (energy AND acceptance AND (adopti* OR innovati*) AND (user OR consumer OR market))
- (energy AND acceptability AND (adopti* OR innovati*) AND (user OR consumer OR market))

We deliberately separated the queries of acceptance and acceptability because their number of citations is appreciably different. The importance of acceptance in energy technologies has increased dramatically in the last two decades, leading to a range of highly cited literature debating this notion. The idea of acceptability, though emerging as early as the 1990s, seems much less developed, leaving ambiguity about which conceptualisation dominates the field. Although some papers seem increasingly impactful, it remains uncertain which definition will ultimately become dominant. Therefore, instead of setting a threshold, we decided to look at the ten most cited papers per query, excluding those not focusing on energy technologies or adequately discussing these concepts.

The identified literature comprised conceptual and empirical papers, where social studies have contributed most notably to the development of acceptance and acceptability conceptualisations. In the other domains, these seem to be mostly lacking. Instead, empirical evidence that emphasises the conflation of different terms was dominant. To obtain additional conceptualisations in these domains, our own expertise and the snowballing effect from identified literature facilitated finding conceptual papers that go deeper into the meaning of these concepts in their respective field.

5.3. Different Concept Interpretations per Research Field

This section provides an overview of dominant definitions of acceptance and acceptability encountered within the research fields of social studies, ethics of technology, and innovation studies.

5.3.1. Social Studies

Social studies have played a prominent role in acceptance and acceptability research, where scholars from the renewable energy domain, particularly Wüstenhagen et al. (2007), have greatly influenced the conceptualisation of acceptance beyond their research field. Social acceptance is commonly understood as "the positive response to, or tolerance of a technical or socio-technical transition project by members of a given social unit" (Klok et al., 2023, p. 2), critical for technology implementation success. Public opposition, on the other hand, is seen as a barrier that needs to be understood and overcome, which is predominantly done by unpacking and delineating impacting factors (e.g., Jobert et al., 2007; Zoellner et al., 2008). While being a dominant interpretation of public opposition, it is also increasingly criticised for its uncritical underpinnings (Aitken, 2010), such as its "unreflective positivist research frame" (Ellis et al., 2007, p. 520)

In response, a shift in the understanding of the concept has occurred in recent years, moving from an outcome-oriented to a process-oriented perspective where social acceptance is defined as "complex, multi-level and polycentric processes of escaping our institutionally locked-in energy systems" (Wolsink, 2018, p. 287). Rather than aiming for securing acceptance, this more recent 'third social acceptance wave' assesses energy technologies more critically and questions whether overcoming public opposition is a desirable pathway (Batel, 2020).

In addition to different understandings of acceptance, there is also an increasing uptake of the concept of acceptability, increasing conceptual ambiguity even further. Fournis and Fortin (2017) define acceptability as "the collective process of evaluation of a socio-technical project" (p. 15), which seems to overlap with the third wave of social acceptance.

However, Huijts et al. (2012) propose a different account and define acceptability on the individual level as "an attitude […] towards new technologies and attitude towards possible behaviours in response to the technology" (p. 526). This type of understanding seems to be driven by a relatively small but highly influential cluster of scholars who attempt to delineate factors influencing public attitudes and behaviour (see Perlaviciute & Steg, 2014; Steg et al., 2005; Steg et al., 2015).

While some scholars treat acceptance and acceptability as separate entities, as seen above, others use them interchangeably, albeit with a preference for one over the other (Carattini et al., 2018; Demski et al., 2019). The diversity of these concept interpretations highlights the need for more clarity in their use. Yet, the third wave of acceptance and the introduction of acceptability as a stand-alone concept especially indicate a general paradigm change towards becoming more process-oriented. To a certain extent, this development produces a 'systemic' approach to questions about acceptance and acceptability in which the successful implementation of a new technology results from the interplay between decisions being taken within different institutional settings and the responses of societal groups. However, earlier definitions of the concepts continue to be used, contributing to ambiguity and confusion.

5.3.2. Ethics of Technology

Ethics of technology is a research field addressing ethical concerns arising from technology development. A prominent goal of this field is judging the moral desirability of particular technologies and their implementation. The use and discussion of acceptance and acceptability concepts are relatively recent.

The concept of acceptance is often seen as an empirical matter, describing a "state-of-affairs" (Ibo; van de Poel, 2016) or a factual situation referring to "the fact that a new technology is accepted – or merely tolerated – by a community" (Taebi, 2017, p. p. 1818). Here, considerable importance is placed on moral values and their impacts on acceptance (see, e.g. de Wildt et al., 2022). For example, Oosterlaken (2015) found that distributive justice and sustainability are critical for increasing acceptance of wind park projects. In the Groningen gas controversy, Mouter et al. (2018) identified the procedural justice-related values of trust and honesty as critical and noted that these remain under-addressed. Overall, the value of justice seems to be increasingly prominent for many energy technologies (also see Cowell et al., 2011; Sovacool et al., 2023).

Also, the concept itself is subject to criticism. For example, Milchram et al. (2018) criticise that most research on acceptance considers many contributing factors but neglects the importance of moral values. Moreover, Batel et al. (2013) cautioned against the uncritical use of the term acceptance and pointed to the risk of conflating two distinct stances towards technology: acceptance and support. Cowell et al. (2011), on the other hand, highlight that *ex-post* acceptance should not be confused with *ex-ante* acceptability as "people accept all sorts of unwanted outcomes" (p. 553) once the technology has been implemented.

Instead, institutions and technology should be designed for values such as justice *a priori* technology implementation to ensure acceptability (also see Oosterlaken, 2015). As such, ethical acceptability is a morally evaluative term, judging how something ought to be. Although the evaluative standard could range from moral or public values, a code of ethics, or adherence to moral standards found in the law (Ibo; van de Poel, 2016), moral value judgements seem to be dominant for energy technologies. For example, Künneke et al. (2015) define social acceptability as a reflection of "moral and societal values that are shared by all members of society" (p. 118-119) and Taebi et al. (2012) connect acceptability with distributive justice in nuclear power considerations.

Even with some definitions in place, ambiguity persists within technology ethics, as both acceptance and acceptability are frequently defined in terms of values relevant to technology and institutional frameworks. Yet, there seems to be a consensus that moral values must be incorporated better to ensure the desirability of technology implementation, brought out by the acceptance and acceptability concerns.

5.3.3. Innovation Studies

Innovation studies encompass various research fields, including innovation, economy, and market studies. This extensive domain primarily revolves around facilitating successful tool adoption and has long recognised the critical nature of acceptance. A cornerstone of this domain is the incorporation of marketing strategies and innovation diffusion theory, explaining how consumers adopt new products through interactions between individual adopters and their environment (Wüstenhagen et al., 2007).

One of the earlier and most impactful contributions to this debate is the Technology Acceptance Model (TAM) (Davis, 1985), which centres on the user with the objective of augmenting tool adoption by influencing specific criteria. Over time, this model has evolved to address new challenges, incorporate advancements in knowledge, and assess diverse technologies, including electric vehicles (Li et al., 2017; Zhang et al., 2019). More recent models, such as extended TAM or the Unified Theory of Acceptance and Use of Technology (UTAUT), have emerged, encompassing the user environment and social influences (Taherdoost, 2018).

Innovation studies often concentrate on the individual's behaviour and attitudes, where acceptance can be defined as an individual's tangible, measurable technology use or technology adoption (Alexandre et al., 2018; Rezvani et al., 2015). Ruiz-Mercado et al. (2011) make a more fine-grained distinction where tool adoption does not equal acceptance. Instead, *initial* acceptance refers to the choice to purchase, which is one phase of the adoption process.

Acceptability, on the other hand, refers to the extent to which these innovations are perceived as appropriate and desirable by stakeholders, such as end-users, consumers, businesses, or policymakers (Alexandre et al., 2018). Hence, acceptability differs from acceptance as acceptance relates to the individual's actual use of the technology, while acceptability is the anticipated willingness or "a positive attitude toward adoption" (Noppers et al., 2015, p. 57).

Nevertheless, the use of the two concepts is not always explicitly maintained throughout the innovation studies. A large number of influential empirical researchers use the terms acceptance and acceptability interchangeably, often paired with a lack of definition of the concept (e.g., Fell et al., 2015; Fetcenko et al., 2007). Moreover, both concepts are often described through criteria deemed relevant for tool adoption. For example, (Elghali et al., 2007) claims that the social acceptability of biomass systems is ensured "when the benefits of using biomass [are] recognised as outweighing any negative social impacts" (p. 6076). In the case of new energy vehicles in China, Du et al. (2018) claim that the acceptability of government policy can be determined by awareness and knowledge about these policies.

Consequently, although some clear definitions of acceptance and acceptability exist, they are not always used distinctively in practice and are often defined through criteria or factors to be met. Nevertheless, there is common ground between the studies: the overall aim of acceptance and acceptability studies is to understand which design criteria are most impactful for consumers to buy or (be willing to) use a particular technology.

5.4. Overview of Concept Interpretations and Categorisation

The diverse interpretations of acceptability and acceptance across research fields have arisen from each field's unique demands and research needs. Consequently, no single understanding can be deemed superior to the others. Instead, these perspectives are all crucial and complementary, serving distinct purposes within their respective fields. Figure 5.1 shows an overview of the different understandings. Together, they offer valuable insights into the multifaceted nature of acceptance in the context of technology implementation.

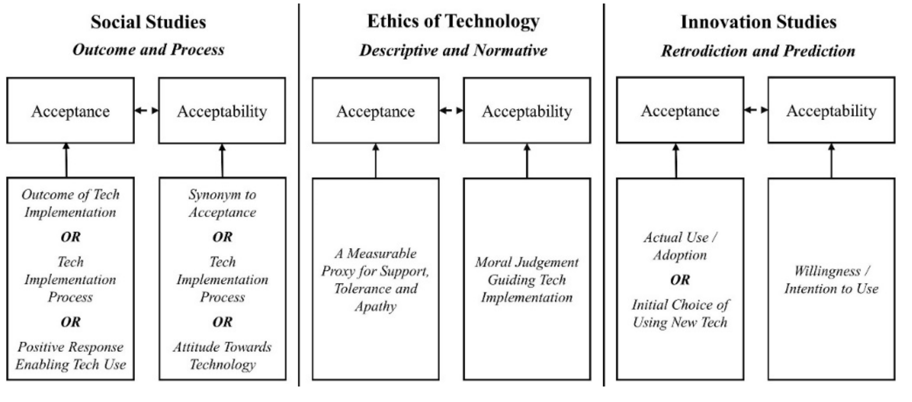

Figure 5.1: Overview of Acceptance and Acceptability Interpretations by Research Field.

Nevertheless, it is a valuable endeavour to construct an overview of the diverse interpretations of acceptability and acceptance. Establishing a framework can help researchers from different domains engage in discussions and exchange insights more effectively while at the same time reducing miscommunications. Here, we propose that the various understandings of acceptance and acceptability can be visualised as a funnel, where the chosen research level – systemic, societal, or individual – dictates the relevant interpretation of these concepts (see Figure 5.2).

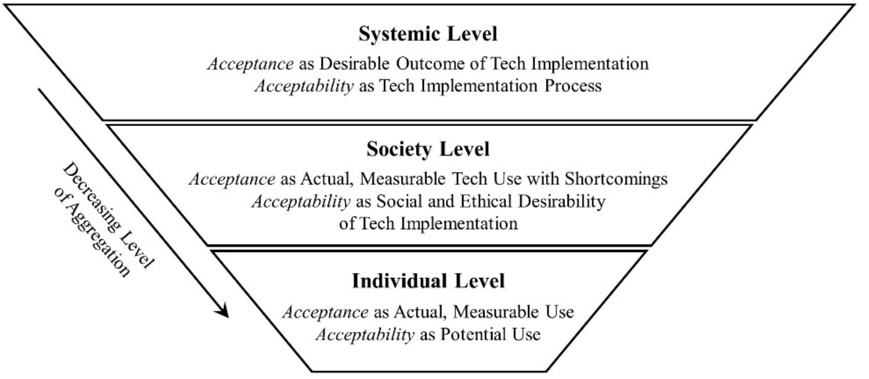

Figure 5.2: Funnel of Acceptance and Acceptability – Concept Definitions Based on Abstraction Level.

At the *systemic level*, acceptance and acceptability provide a general perspective on technology desirability within a socio-technical system. Acceptance is the desired outcome of technology implementation encompassing the interactions between institutions of state and market, as well as societal groups, including the consideration of ethical, legal, political, and market aspects to ensure effective integration within the institution. The concept of acceptance is traditionally emphasised, whereas acceptability only emerges on the systemic level. It is referred to as the desirability of the technology implementation process, encompassing all steps and considerations involved in successfully introducing the technology within society. The contributions of Batel (2020), Wolsink (2018) and Fournis and Fortin (2017) can be seen as representatives for the systemic level.

Moving to the *societal level*, the focus shifts to the groups and communities that form society and that are affected by technology implementation. Discussions here predominantly revolve around the ethical and social impacts of the technology. In this, acceptance often refers to a generally positive attitude towards technology and a desirable outcome of the implementation process, even though it may come with certain shortcomings or limitations. Typical representatives of this research level are Jobert et al. (2007) for the social focus and Milchram et al. (2018) for the ethical considerations on this research level. Acceptability, on the other hand, encompasses both the social and ethical desirability aspects of technology implementation, often operationalised through values, as found in the works of (Künneke et al., 2015).

Lastly, the *individual level* considers acceptance and acceptability indicators of individual tool adoption. Acceptance is characterised as individuals' actual and measurable use of technology, reflecting their tangible engagement with technology in practice. Representatives for this research level can be found in innovation studies (e.g. Li et al., 2017) but also in social studies which focus on the individual (e.g. Huijts et al., 2012). In contrast, acceptability indicates an individual's willingness and readiness to adopt and integrate technology into their daily lives, as represented by the works of Noppers et al. (2015) and Steg et al. (2005).

Starting from the institutional entanglements at the macro-level of society, the funnel contracts to the meso-level of groups to arrive at the micro-level of individuals. What can be observed is that within these different levels is that the question of what is being accepted pertains to the process of implementing a socio-technical system in which a broad spectrum of considerations play a role, ranging from political, technology, societal and individual factors, to the assessment of the desirability of a particular technology, to the use of a concrete tool respectively. With that, the levels of the funnel present varying degrees of aggregation, with the scale and object of acceptance becoming more specific and less aggregated moving down the funnel. Hence, with increasing object specificity, the concepts of acceptance and acceptability become also more specific.

As such, the funnel adds insight to the triangle of social acceptance by Wüstenhagen et al. (2007), by which it is inspired. Yet, the funnel of acceptance and acceptability not only reveals the varying interpretations of these concepts but also that the uptake of new technology in society is a phenomenon that has multiple dimensions. Researchers using these concepts could usefully be mindful of the level of analysis they are adopting, as reflected in the funnel diagram, and use this in their definitions of the concepts. Doing so may help social scientists, in particular, contribute to further developing our understanding of acceptance and acceptability, reducing confusion. With such additional clarity, other researchers can build on the findings more easily, avoid misinterpretations and facilitate collaborations. At the same time, acknowledging multiple layers allows for a more comprehensive understanding of the complex phenomena of acceptance and acceptability.

5.5. Discussion

It became evident that all research fields contribute to understanding the persisting challenges of technology implementation but are not addressed equally. Moreover, silo thinking seems to be a recurring issue in technology development and implementation, thereby prioritising one research level over the others.

Large-scale technologies such as energy technology infrastructures are often understood on the systemic level, thereby marginalising societal and individual considerations. For example, we can look at the development of PV as a decarbonised energy source. At the systemic level, this development pertains to various aspects, including establishing regulations, innovation policies, subsidies, and interconnections with the existing energy grid. The questions for acceptance and acceptability involve the interplay between all these aspects, including the societal responses to any of these. Yet, several studies show that the systemic levels are considered in isolation, ultimately lacking to provide a holistic view of acceptance. For instance, the commonly used systemic attempt to move towards renewable energy by incentivising PV adoption through tax benefits and subsidies has disproportionately favoured affluent neighbourhoods, leading to distributive injustice as all residents, including non-owners, bear the costs leading to limited adoption (Brugger & Henry, 2019), consequently decreasing acceptance on the societal and individual level.

Yet, there is a wide range of studies on the social and individual level. At the social level, the question of acceptance and acceptability primarily concerns the desirability of PV panels themselves, particularly in contexts like large solar (and wind) parks, where local impacts are significant but often overlooked in regulatory processes (Kraaijvanger et al., 2023; Schram et al., 2024). At the individual level, attention goes to households and understanding what individual aspects impact the decision to purchase PV panels, which go beyond affordability and include altruism and socio-democratic factors such as gender and age (e.g., Huang et al., 2009).

These examples show that the isolation of the different levels fails to provide a holistic view of acceptance, potentially leading to technology implementation problems. For instance, we might not connect the decision of households to buy PV with broader discussions about compensation schemes nor with the justice implications of non-owners contributing to the well-being of PV owners. If we fail to see these regulatory issues as codetermining the ethical desirability of PV, we miss out on the whole picture.

5.6. Limitations & Future Research

Finally, we want to stress the importance of validity, considering both the comprehensiveness of this concept analysis and the generalizability of the resulting framework. We recognise that this investigation is not exhaustive, acknowledging that the notions of acceptance and acceptability go beyond the boundaries of the specific research fields we discussed. Since this study has not been conducted as a systematic literature review, there is the possibility that other significant literature distinguishes between both concepts well. However, such a review remains essential given that we found many highly influential empirical studies that conflate different meanings. Moreover, the focus on acceptance conceptualisations in energy technologies might unintentionally limit its generalizability to other technologies. Yet, its leading role in addressing issues of acceptance and acceptability can still serve as a starting point for other areas of technology development, providing foundational knowledge and methods that can be adjusted for different sectors. Finally, we want to highlight the ontological challenges of the concepts of acceptance and acceptability. While our research focused on their current usage in the literature, it's crucial to gain deeper insights into the social concerns these concepts aim to draw out. Exploring these underlying issues could provide fresh perspectives for distinguishing between acceptance and acceptability and formulating clearer definitions.

5.7. Concluding Remarks

Acceptance and acceptability are critical in shaping the discourse and understanding of technology implementation in several research fields. Yet, the interpretations of the concepts show significant differences. This research aimed to provide some structure in the diverse variations of acceptance and acceptability within social studies, ethics of technology, and innovation studies. It revealed disparities between and within the fields and frequent occurrences of silo thinking. To foster a more interdisciplinary dialogue, we propose the "funnel of acceptance and acceptability." The funnel metaphor illustrates how distinct research levels impact the interpretation of these concepts and emphasises their interconnectedness. Moreover, it underscores the importance of moving away from silo thinking and towards simultaneously addressing the systemic, societal, and individual levels to move towards responsible technology implementation.

Ethical Assessment

6

Beyond Social Acceptance in Wicked Problems: *A Socio-Ethical Assessment Framework for Technology Governance*

6.1. Introduction

Problems can be seen as 'wicked' if there is no consensus about the problem definition and the appropriate solution (Rittel & Webber, 1973), and solutions are prone to raising controversy. For instance, in the wicked problem of water scarcity (Quentin Grafton, 2017; Sanya, 2020), the introduction of biotechnology or water recycling has met with public resistance. This resistance is typically framed as a barrier to project development and further technological innovation, where technology developers appear to believe that social acceptance is achieved if the public can be convinced to abstain from such resistance (Ibo van de Poel, 2016).

As a case in point, opposition to direct potable water reuse is usually represented as a lack of knowledge by the general public, which is believed to be solved by better informing the public or by having pilot projects that enable members of society to learn about the benefits of the technology (Moesker et al., 2024b). However, by seeing learning as an activity that only comes from the side of the public, this framing reduces the public to passive recipients of technology rather than recognizing them as active participants in a co-evolutionary process (Stirling, 2008). Numerous scholars have argued that genuine public participation enhances decision-making, increases legitimacy, and enables the development of more socially desirable technologies (Fiorino, 1990; Harris-Lovett et al., 2015; Wynne, 2006). As such, social participation can (and perhaps should) be seen as a *method* that allows for developing acceptable and more desirable technologies.

Nevertheless, achieving social acceptance through participation processes does not necessarily lead to the creation of more desirable technologies. An approach that exclusively relies on the input of participants invited to speak out on the desirability of technology development might foster problems such as bias, myopia, and groupthink (Solomon, 2006; Wynne, 2007; Young, 2016). Moreover, the question as to whether a technology can be regarded as desirable is intrinsically normative and as such, we believe that attending to the social acceptance concerns alone is insufficient for responsible technology governance, especially in the case of wicked problems characterized by complexity, conflicting values, and a lack of definitive solutions (Quentin Grafton, 2017; Rittel & Webber, 1973).

This paper argues that a more comprehensive assessment of the desirability of technology requires integrating ethical considerations alongside social acceptance. As such, the research question that is studied in this paper is whether technology governance frameworks can go beyond mere social acceptance issues and incorporate ethical considerations. To address this question, we will look at the controversial technological advance of potable water reuse, a technological system increasingly proposed to address escalating water scarcity (see, e.g., Gerrity et al., 2013; Leverenz et al., 2011). Despite its potential, potable water reuse faces significant social acceptance hurdles rooted in various context-specific concerns regarding, among others, safety, trust and the 'yuck factor' (López-Ruiz et al., 2021; Ormerod & Scott, 2013; Scruggs et al., 2020). With three currently ongoing potable water reuse projects in Phoenix, Scottsdale, and San Diego, serving as illustrative cases, this paper identifies the shortcomings of existing public participation practices and demonstrates how a 'socio-ethical framework' can provide new insights into the desirability of this technology.

This paper has the following novel aspects. First, we will show the importance of taking ethical considerations into account in matters of technology governance, and second, we will propose a socio-ethical assessment framework as a more robust alternative to enhance the quality of participation strategies. To do so, the paper will have the following structure. Section 2 introduces the socio-ethical assessment framework, which provides the conceptual foundation and overarching narrative for our analysis. Section 3 provides essential background information on potable water reuse technology and the three case studies in the U.S. cities of Phoenix, Scottsdale, and San Diego. Section 4 examines existing approaches to social acceptance in these projects, highlighting their limitations. Section 5 then explores the ethical dimensions of potable water reuse and introduces the concept of ethical acceptability. Finally, Section 6 presents our conclusions and discusses the implications of our findings for responsible innovation and governance in water management.

6.2. A Framework for Socio-Ethical Assessment

Building upon the limitations of solely pursuing social acceptance, as outlined in the introduction, this section introduces the theoretical considerations that allow us to develop the *socio-ethical assessment framework*. This framework offers a more comprehensive approach to evaluating and guiding the governance of new technologies by integrating both social acceptance and ethical acceptability considerations.

This framework is connected to the findings from the literature on technology development from innovation theory (Garud & Rappa, 1994; Nelson & Winter, 1977) and science and technology studies(Bijker, 1994; Rip, 1995) that counter the dominant approach to technology development in which technologies are fully developed before they are implemented in society. This 'linear' model of technology development fails to acknowledge that technologies will evolve further with the existing sociotechnical contexts in which they are implemented. New social practices and interdependencies will emerge after the societal introduction of a technology, which implies that the development of a technology is best seen as an ongoing process in which the input of users and affected parties is used to further advance the technology (Owen et al., 2020; Te Kulve & Rip, 2011). The socio-ethical assessment framework can be seen as an approach that allows for improving the quality of that input. The structure of this paper follows the framework outlined in Table 6.1.

Table 6.1: Socio-Ethical Assessment – Connecting social acceptance and ethical acceptability

	Procedural	**Substantive**
Social Acceptance	Common participation: Aims to address expected social concerns / implementation challenges.	Opening Up participation: Aims to identify overlooked yet socially relevant concerns.
Ethical Acceptability	Ethical participation: Aims to ensure the moral desirability of the public participation process.	Opening Up the problem space: Aims to identify additional morally relevant concerns.

We start by critically examining the social acceptance component, focusing on *common public participation* processes used in potable water reuse projects. Despite the diverse range of approaches to social acceptance (Moesker et al., 2024a; Wüstenhagen et al., 2007), our analysis highlights a critical weakness prevalent in these practices: the frequent failure to capture a holistic set of socially relevant concerns.

To address this weakness, many potable water reuse scholars suggest *Opening Up participation* strategies, drawing upon Stirling's (Stirling, 2008) concept of 'Opening Up,' expanding decision-making processes to include a broader range of perspectives (e.g., Binz et al., 2016; Harris-Lovett et al., 2015; Katz & Tennyson, 2015). Opening up pertains to accounting for a wider variety of norms, values, beliefs and knowledge claims, for instance, by deploying participatory forms of decision-making in which societal members are invited to articulate their views and considerations (lso see, Ruiten et al., 2023). By including a wider range of perspectives, the decision-making process becomes enriched, leading to more robust outcomes. However, Opening Up participation can be undermined by manipulative practices, such as inducing an overly optimistic bias towards the technology and a strategic problem framing that narrows the public debate to discussing an acute symptom rather than the underlying systemic problem of water scarcity itself.

We propose incorporating *ethical participation* as a complementary lens to mitigate these shortcomings, focusing on the moral desirability of the participation strategies themselves. This includes considering the impacts on entities beyond the immediate stakeholders, such as future generations and non-human entities, who are often excluded from common participation processes. However, even ethical participation can lead to undesirable technology implementation because the problem space itself can be too narrowly pre-defined by decision-makers to favor a particular technological solution. A caveat here is that wicked problems typically bring about 'normative uncertainties' (Taebi et al., 2020), questions about which no decisive normative answers can be given. Conventional ethical theories, such as utilitarianism and deontology, are ill-suited to deal with such uncertainties, as these are based on moral norms and outcomes that are fixed (Hofbauer, 2024). It is precisely the quality of wicked problems that we do not know which norms and outcomes will become pertinent (cf. van de Poel & Taebi, 2022). This shortcoming of conventional ethical theories implies that we have to introduce an alternative approach to ethics, which we will do below.

Following up on this point, we introduce a last assessment aspect to overcome a problem space that is too narrowly defined, which is *Opening Up the problem space.* The relevance of this aspect is essential in technological solutions to 'wicked problems' (cf. Rittel & Webber, 1973), where there is no agreement on the epistemic and normative nature of the problem. As such, any technology-based solution will raise objections about its feasibility and desirability. While authors working with the notion of social acceptance rely on social research methods to find out what people consider to be desirable, authors who focus on ethical acceptability have approaches from moral philosophy as their point of departure. As such, this aspect explores the problem of water scarcity more deeply by addressing alternative framings and proposed solutions. It also highlights the implications of a problem space that is too narrow on the desirability of technology development and the role public participation can play in shaping more responsible governance. With these concerns at hand, we urge technology implementation projects to move beyond a narrow focus on social acceptance towards a more holistic socio-ethical assessment to ensure social and ethical desirability.

Before we investigate the social acceptance and ethical acceptability strategies in depth, we will briefly introduce the general working of the technological system, potable water reuse, and the chosen case studies that are currently underway implementing such a system: the cities of San Diego, Scottsdale and Phoenix.

6.3. Background: Potable Water Reuse and Current Case Studies

To provide context for the subsequent analysis of social and ethical acceptability, this section introduces the technology of potable water reuse. Potable water reuse involves treating wastewater to meet drinking water standards using advanced technologies. Unlike traditional reuse methods, which return treated water to natural systems or use it for non-potable purposes, potable water reuse integrates treated wastewater into water supply systems (United Nations, 2017). Indirect potable reuse (IPR) utilizes environmental buffers like reservoirs or aquifers for storage, while direct potable reuse (DPR) bypasses these buffers entirely (Gerrity et al., 2013; Voulvoulis, 2018). While IPR has been widely adopted in places like the U.S. and Australia, DPR is only gaining traction as a solution to water scarcity (Santos et al., 2022).

As such, the population of suitable of suitable cases is relatively limited, and we have taken an explorative research design. The selected cases, Phoenix, Scottsdale, and San Diego, have been found to provide variety in terms of their maturity. The cities of San Diego, Scottsdale, and Phoenix represent different stages of implementing potable water reuse to address water scarcity challenges. San Diego is in its construction phase, Scottsdale is in its demonstration phase, and Phoenix is in the planning phase. San Diego, heavily reliant on imported water (90% from northern

California and the Colorado River), faced public and political resistance to potable water reuse in their first introduction attempt in the late 1990s (Bridgeman, 2004; Hartley, 2006). Through initiatives like the 2010 Water Purification Demonstration Project, stakeholder interviews, city hall meetings and news coverage, public trust was rebuilt, leading to the creation of the Pure Water Program. Approved in 2014, this program aims to meet a third of the city's needs by 2035 (City of San Diego, 2023).

Scottsdale and Phoenix are neighboring central Arizona cities, facing increasing water scarcity due to prolonged droughts and population growth (City of Phoenix, 2021a). Here, Scottsdale has taken the lead in potable water reuse and has transitioned from IPR for irrigation to launching Arizona's first DPR demonstration facility. This shift was enabled by regulatory changes in 2018, allowing DPR permits. Public outreach strategies, such as tasting events and collaborations with breweries, aim to foster trust and acceptance (McNamara, 2023; Schneider, 2022). Phoenix, on the other hand, is still in the feasibility stage of DPR implementation. Yet, the city has long utilized reclaimed water for non-potable uses. Recently, it allocated $30 million to retrofit the Cave Creek Reclamation Plant for DPR despite incomplete regulatory frameworks (Cahill, 2023). Collaborative projects with neighboring cities and public engagement efforts are underway, but remain in the early development stages.

Data collection took place during a research visit of the lead author in Phoenix and San Diego in the Spring of 2023. The used data sources include an extensive review of documents, reports, videos and online materials available through official water utility channels. Individuals prominently featured in this content, especially policymakers and practitioners actively engaged in water reuse initiatives, were identified as potential participants. Furthermore, a semi-structured interview methodology has been employed to gain insights from decision-makers, stakeholders, and academics involved with potable reuse projects. The interviews focused on participants' attitudes toward public participation, their valuation of public outreach activities, their expectations regarding outreach outcomes, and their perceptions of the impact on public views concerning potable water reuse. To identify potential interviewees, five methods have been used: reviewing water utility content, researching governmental decision-makers, leveraging existing networks, recruiting at the AZ Water Conference, and using the snowball effect.

We have aimed to safeguard research ethical standards by obtaining informed consent from participants, offering research transparency, and ensuring data security. Before conducting the interview, each interviewee has been given an informed consent form and ample time for questions. Participation was voluntary, and no compensation was offered. Post-interview and transcription, we enhanced transparency and accuracy by sending interview summaries to participants for member checks. This iterative process provided an opportunity for clarification or revision of our interpretations. In our dedication to preserving participant confidentiality, we implemented secure and anonymous data processing methods, including anonymizing transcripts and aggregating information when anonymization alone may not sufficiently protect privacy. All data was securely stored on institutional cloud services, with personal details kept separate from interview transcripts, and upon completion of the study, all personal data was permanently destroyed.

6.4. Social Acceptance

This section examines how the challenge of gaining social acceptance has been approached in potable water reuse projects. It explores the methods used, their underlying assumptions, their strengths and weaknesses, and ultimately argues that a focus on social acceptance alone is insufficient for responsible technology implementation. We will analyze two distinct approaches to social acceptance in the context of potable water reuse: *Common participation approaches*, as exemplified by the city of Phoenix, and *Opening Up participation*, as demonstrated by the efforts of Scottsdale.

6.4.1. Common Participation – A Starting Point

Public participation, in its ideal form, is a process that empowers the public to engage in meaningful dialogue and decision-making regarding issues that affect their lives. Generally, participation is an ambiguous concept which can encompass a range of activities, from information sharing to collaborative problem-solving (Arnstein, 1969; Cornwall, 2008). However, in developing and implementing new technologies, participation has often been shown to take on a more limited form, frequently presented as an educational effort to inform the public about a chosen technology's benefits (Wynne, 1992). As such, participation can be strategically deployed to legitimize pre-existing power structures, with 'invited' spaces for engagement ultimately serving the interests of those who initiated them (Cornwall, 2008; Pesch, 2019). Participation then quickly becomes a strategy to secure public acceptance for a pre-selected technological choice rather than a genuine exploration of alternatives or a mechanism to incorporate public concerns into the design process (Irwin, 2006; Rowe & Frewer, 2000; Stirling, 2008). We will illustrate this common participation approach with the Phoenix case study.

Phoenix has formally approved a DPR project on the Cave Creek Plant at 91st Avenue, signaling a commitment to this technological solution (Seely, 2024). This initiative involves collaboration with neighboring cities of Tempe, Mesa, and Scottsdale. The public outreach campaign for Phoenix's DPR project is still in its early stages. Officials have acknowledged the importance of engaging the public to build support for the project, but concrete outreach strategies are still being developed. The absence of a dedicated potable water reuse outreach website, documents on stakeholder involvement and social media channels indicates a centralized, top-down approach to implementing DPR. Instead, current information on the project focuses on DPR's safety, technical processes, and necessity, emphasizing the region's water scarcity due to prolonged drought and low Colorado River levels (see, e.g., City of Phoenix, 2021b, n.d.).

To increase social acceptance, public participation strategies are mostly based on education efforts (Harris-Lovett et al., 2015; Moesker et al., 2024a). Phoenix seems to be approaching its communication regarding water scarcity and potable water reuse similarly (City of Phoenix, 2021a; Fischer, 2024), pointing to assumptions that might be embedded in Phoenix's approach. Communicating safety is a high priority for the city, and it is addressed through an expansive education strategy utilizing various channels such as websites, social media, and events where residents can taste the water and interact with important decision-makers. For tasting events, however, the assumption is that positive sensory experiences will build trust and address safety concerns without fully engaging with residents' deeper questions about potable reuse. These activities indicate that it is believed that misinformation or ignorance is the source of resistance, which can be resolved by targeted communication. Such an approach, also called the knowledge-deficit model, implicitly assumes that public acceptance can be achieved by 'correcting' these knowledge gaps. While evidence of potable water reuse studies indeed suggests that additional information can increase acceptance (see, e.g., Fielding et al., 2019; Fielding & Roiko, 2014; Prins et al., 2022), there is also evidence that suggests that this effect is overly emphasized concerning other factors (see, e.g., De Koster & Achterberg, 2015; Leong & Lebel, 2020). Extensive literature outside the potable water reuse field has shown that the knowledge-deficit model alone is rarely sufficient to represent technology-related social concerns (Blake, 1999; Wynne, 1992). Such concerns about potable water reuse often extend beyond technical safety to encompass broader issues such as trust, equity, and the ‘Yuck factor’ (Moesker et al., 2024b; Ormerod & Scott, 2013). Critically, Phoenix’s reliance on an educational approach reflects broader patterns seen in common participation methods that aim to close down on a predetermined solution (Stirling, 2008). These methods tend to engage only established stakeholders, who represent expected societal concerns, while excluding marginalized groups or emerging movements that may raise new values or issues (Pesch, 2019).

The shortcomings of Phoenix’s strategy are emblematic of what Batel et al. (2013) describe as a conflation of passive acceptance with active support. By prioritizing the project’s advancement over inclusive dialogue, the city risks neglecting the broader societal implications of potable water reuse. This approach aligns with van de Poel’s observation that acceptance garners attention only when it is assumed to become a barrier (Van de Poel, 2016). This tendency can be traced back to Phoenix’s underlying reason for collecting the needs and concerns of the public – they are used to improve engagement materials to better convey the safety and future benefits of the technology to the public.

The decision to use public participation instrumentally to secure acceptance reflects a broader reluctance to adopt more inclusive engagement strategies. The motivation for this appears to be the belief that more inclusive approaches require too much time and may contribute to unintended outcomes such as project delay or the non-use of the system. As a result, common public participation methods are often top-down, one-way communication exercises aimed at managing public perception rather than a genuine effort to understand and address diverse public concerns about the technological solution. With that, public engagement is used to build superficial acceptance to quickly move the project toward the implementation phase because, once a technology has been implemented, “people accept all sorts of unwanted outcomes” (Cowell et al., 2011).

6.4.2. Opening Up Participation

Opening Up participation offers a more inclusive and deliberative model for engaging the public in technological decision-making (Fiorino, 1990). This approach directly addresses the shortcomings of common participation strategies, which often prioritize securing acceptance over genuine dialogue and marginalizing dissenting voices. It deliberately expands decision-making processes to include a broader range of perspectives, values, and knowledge sources, where public concerns and ideas shape the project’s trajectory (Stirling, 2008). Here, starting participation early or ‘upstream’ in the project lifecycle, ideally before key decisions are made, allows public input to have a more meaningful impact (Rowe & Frewer, 2000; Wilsdon, 2004).

The city of Scottsdale provides an example of attempting to incorporate more inclusive and deliberative engagement strategies in its potable water reuse project. Scottsdale obtained a permit for a demonstration facility after Arizona relaxed its ban on producing recycled water for human consumption in 2018 (Scottsdale Water, 2023a). The city's strategy emphasizes proactive community engagement and educational initiatives to foster public trust and support for the DPR initiative. Recognizing the potential hesitancy towards potable reuse, the city built a pilot plant to raise awareness and overcome the 'yuck factor', stressing that there were no immediate plans to connect it to the water supply (Brodie, 2019). With this, the city's participation efforts started almost a decade earlier than Phoenix by hosting community forums, focus groups, and stakeholder workshops (Schneider, 2022; Tenney, 2018). Moreover, tasting events have been facilitated, such as Canal Convergence (see, e.g., Schneider, 2022) and collaborations with local breweries (McNamara, 2023).

These initiatives reflect a growing awareness that public participation must go beyond education to uncover latent societal concerns and priorities. However, while these participatory initiatives can potentially broaden the decision-making process substantively, they remain susceptible to being captured by dominant power structures and political objectives. This dynamic can be traced back to the way Scottsdale representatives frame the discussion of potable water reuse in the media, highlighting positive outcomes like water security, high water quality, and progress in overcoming the 'Yuck factor' (see, e.g., Backer, 2022; Brodie, 2019; Scottsdale Independent, 2019)but giving less attention to potential risks and costs. This approach suggests that the primary goal of this public communication is to gain acceptance rather than to provide a balanced assessment of potable water reuse's costs and benefits.

This critique highlights a broader issue within social acceptance frameworks: the absence of tools to evaluate the moral desirability of participatory approaches in practice. Current frameworks are primarily descriptive, focusing on goals and processes (see, e.g., Fielding et al., 2019; Katz & Tennyson, 2015) rather than interrogating the ethical dimensions of participation methods. As a result, social acceptance methods run the risk of resorting to morally questionable practices to achieve their pre-defined aims. In Scottsdale's case, while the opening-up efforts may provide a platform for a broader range of societal concerns and perspectives, the induced positive bias may hide important problems such as rising water prices and remaining concerns regarding the environmental impact of treatment plants (see, e.g., Ahmad & Baddour, 2014; Gerrity et al., 2013). With that, even when orienting at Opening Up participation, a strong emphasis on increasing social acceptance can risk the implementation of technologies that may ultimately be unsuitable for a particular society.

6.5. Ethical Acceptability

To determine the desirability of technological development, it may not suffice to invite members of society to speak out. In the case of a wicked problem, there is normative uncertainty, meaning that there are different ideas about what is 'good', but also different approaches to disclosing the question about what is 'good'. The exclusive reliance on the input of invited participants, who are confined by concrete spatial and temporal boundaries, disregards the heterogeneity of approaches to address normative questions, among which are the methods developed in the field of ethics. This reliance testifies to the reluctance to deploy approaches from ethics to deal with wicked problems (Pesch & van Uffelen, 2024).

Ethical analyses of controversial technologies such as nuclear energy (Taebi et al., 2024) and nanotechnology (van de Poel, 2009a) have shown that the assessment of a technological system's ethical acceptability can be seen as complementary to the evaluation of its societal acceptance (Moesker et al., 2024a). In this, ethical acceptability can be defined as a "reflection on a new technology that takes into account the moral issues that emerge from its introduction" (Taebi, 2017). Despite its recognized importance, ethical acceptability remains relatively under-researched compared to the extensive body of work on technology acceptance (Gauttier, 2019).

It is difficult to find an explicit 'method of ethics' in the literature, and the question about the ethical acceptability of new technologies has, as yet, only received scattered attention. So, while we fully embrace the need to attend to these matters, we can only outline some explorative starting points about the integration of ethical concerns in discussions on the acceptability of new technologies at this moment.

In this, we can start with the observation that the implicit method of ethics is based on the pursuit of eradicating contingent factors from our reasoning (Pesch, 2024). While acknowledging that a genuinely impartial perspective is an ideal that can never be effectuated, one may see a range of approaches developed that allow the normative assessment of real-life phenomena from an outsider's perspective.

With that, ethical approaches help us to overcome the blind spots of social acceptance approaches.

It is important to emphasize that ethical approaches do not rule out the participation of societal actors. In fact, the involvement of such actors can be seen as a suitable approach to pursuing an impartial position: the exchange of perspectives of diverse actors helps to reduce bias. The key difference with conventional participatory approaches to social acceptance is that the outcome of a participatory process is not to be seen as a final result but as a stepping stone towards a 'more impartial' position (Roeser & Pesch, 2016; Swierstra et al., 2009).

6.5.1. Ethical Participation

As said above, the ideal of ethics is to arrive at a point of view that is independent from any particularistic interest. Though this ideal seems to be unattainable, we may converge to it by acknowledging a range of perspectives, values and concerns that is as broad as practically feasible. Based on this consideration, we introduce the notion of 'ethical participation', which extends the principles of Opening Up participation by explicitly incorporating a broader set of societal values. Participatory methods are based on the involvement of agents who are able to speak out, while future generations or nonhuman agents have no voice (yet). Such exclusion of such agents is not a mere matter of lacking representation; it also means that it misses out on perspectives and concerns that are relevant. As such, ethical participation acknowledges that participation of the many is not a panacea to technology development, but emphasizes that the methods used to engage stakeholders must be ethically sound.

No method for ethical participation appears to exist as of yet. As such, the remainder of this section explores how ethical considerations can be integrated into decision-making processes, starting with ethical participation and closing with Opening Up the problem space. From our cases, we try to derive participatory activities that appear to either converge towards or diverge from the inclusion of ethical concerns in determining the acceptability of new technologies.

San Diego has made notable strides in incorporating a wide range of stakeholders in its potable water reuse program called Pure Water. The city has proactively contacted various participants, including environmental organizations, community leaders, governmental bodies, and the general public (City of San Diego, 2025; Rea & Parker Research, 2011). Organizations such as the Surfrider Foundation, which advocated for more stringent environmental safeguards, have been actively involved in the project's progress, showing the city's awareness of potable water reuse's environmental concerns (see, Occiano & Strayer, 2012). Including non-human entities – through representative environmental stakeholders such as Surfrider – has been critical to San Diego's approach, making its strategy an example of how ecosystem concerns can be better represented alongside human interests.

Already in the 1990s, city officials proposed introducing reclaimed water into the potable water supply, which led to political debates and public resistance. Concerns about public health risks, socio-economic disparities, and the project's costs led to its cancellation (Hartley, 2006; Po et al., 2003). Nevertheless, San Diego reintroduced a project for water reuse in 2002, which was accompanied by the Long-range Water Resource Plan included an extensive Public Outreach Program plan that started in 2010. This effort was paired with the Water Purification Demonstration Project and numerous initiatives, including public opinion polls, interviews, and surveys, to ensure a broad and inclusive engagement approach (City of San Diego, 2013). San Diego's potable reuse project, known as Pure Water San Diego, has advanced significantly in recent years. Being unanimously approved by the city council in 2014, the building phase started in 2021, with the first phase expected to be completed by 2025 (City of San Diego, 2023).

Despite these efforts, San Diego's approach to participation still faces limitations. One challenge is the reliance on community leaders to represent entire communities, which may not always be a true reflection of the diverse perspectives within those communities (Pesch, 2019; Wynne, 2007). Additionally, stakeholders chosen through this method are often those who are already more likely to support the technology or have vested interests, which could lead to biased input and the exclusion of voices that may express opposition or concerns about technology-induced impacts (Stirling, 2008). This highlights the critique that stakeholder lists, like those in San Diego, are static and may not fully account for emerging societal concerns or marginalized groups who have not been actively included in the process (Moesker & Pesch, 2022).

Moreover, while San Diego has worked to include a broad range of stakeholders, the concept of 'affected' parties remains challenging to define. The boundaries set by service areas or geographic limits can exclude people who may be indirectly impacted by the technology. This limitation is especially significant when considering the potential global impacts of potable water reuse systems. For example, sourcing materials for these systems or the long-term effects of their operation on water cycles could affect communities far beyond San Diego's borders. Furthermore, future generations, human and non-human, are typically underrepresented in these processes, raising questions about intergenerational justice and the rights of those not yet born. While commendable in its attempt to incorporate some aspects of ethical participation, such as the attempt to incorporate non-human entities, San Diego's approach can be critiqued for failing to address concerns outside its geographic and temporal boundaries.

While ethical participation represents a significant improvement over traditional and Opening Up approaches by broadening the *range of stakeholders* considered, it typically still operates within a *pre-defined problem space*. This problem space often reflects existing power structures and assumptions about the public's concerns and needs, potentially limiting the underlying roots of the challenge at hand and its associated implications. Therefore, a more holistic socio-ethical assessment also requires addressing *what* is being discussed in the public debate. We argue that these concerns necessitate an Opening Up of the problem space.

6.5.2. Opening Up the Problem Space

While ethical participation aims to broaden the range of stakeholders to incorporate often overlooked considerations into the decision-making process, it often operates within a pre-defined problem space. In the case of potable water reuse, the problem to be solved is frequently framed as regional 'water shortage,' aligning with the traditional, supply-focused approach of water planners, who have historically prioritized identifying and meeting growing human demands for water (Gleick, 2003). This problem framing rests on the premise that the core problem at hand is a lack of available water within that region. Hence, increasing supply through a new water source – recycled water – appears to be an inherently logical solution.

We argue that 'water shortage' cannot be equated with 'water scarcity' as it overlooks the inherent 'wickedness' of water scarcity. This oversimplification of the problem becomes more apparent when looking at Quentin Grafton's (2017) definition of water scarcity as "water misallocation where [...], multiple pathways to water reallocation and substantial uncertainty over the consequences of business as usual and alternative futures" (p.3025) exist. As such, the 'wickedness' of water scarcity necessitates a shift of the problem frame from simply needing to *find more water* to examining *how water is currently used, managed, and distributed*.

Nevertheless, current public engagement strategies in potable water reuse projects often resort to the simplistic problem space of 'water shortage'. For example, public engagement strategies surrounding potable water reuse in the Phoenix region (including Scottsdale) narrow the problem further down to '*drinking water* shortages'. The framing that is employed here obscures alternative strategies, such as saving water from other water-consuming sectors, particularly agriculture and landscaping. Although these sectors have shown increased efficiency in water use and more sustainable innovations, they continue to consume significant amounts of water, often justified by claiming to use 'non-potable' sources (Kelley, 2018; Scottsdale Water, 2023b), which do not compete with drinking water demands. This framing is problematic because the distinction between potable and non-potable water sources creates a boundary where the excess use of some 'non-potable' water sources seems to remain largely unquestioned. Yet, the increasing uptake of potable water reuse systems highlights that this distinction is merely artificial, but helps reinforce the status quo of water-intensive, partially non-essential practices like golf course irrigation, large-scale landscaping and water-intensive agriculture such as citrus fruits.

Moreover, the narrow focus on water shortage risks overlooking crucial ethical concerns and uncertainties inherent in our current water management systems concerning *how water is currently used, managed, and distributed*. Potable water reuse systems have been developed to be compatible with the current Western water management system. Hence, potable water reuse represents an incremental innovation that supports our current water management system, which perpetuates critical sustainability concerns such as using highly treated, potable water for watering lawns, flushing toilets, showering, and washing clothes – activities that do not require drinking water quality yet cost significant amounts of resources and energy due to the high water quality. The wastefulness of our current water management system remains frequently unacknowledged. Particularly in Western societies, there is a pervasive, often unquestioned, assumption that our centralized, infrastructure-heavy approach to water management is inherently 'good' or 'advanced' (Meehan et al., 2020), masking the sustainability issues of these systems.

The increased circularity of potable water reuse systems offers a seemingly more sustainable solution. However, they risk perpetuating the unsustainable aspects of current water management. By allowing the continuation of current consumption patterns (e.g., overconsumption or using potable water for non-potable purposes) and failing to address infrastructure issues (e.g., leakages), the costs of our current water management systems appear to remain largely unchallenged. The substantial investments in new pipelines and advanced treatment technologies (e.g., reverse osmosis) for potable water reuse could further entrench path dependency, making it more difficult and costly to transition to alternative water management strategies.

Hence, it can be argued that potable water reuse, as an incremental innovation, only deepens the technological lock-in of these unsustainable water management systems. Here, technological lock-in describes the situation where a technological system stays dominant not necessarily due to its superiority but because of established infrastructure and interdependent systems that make alternatives less viable (Arthur, 1989; Callon, 1990). Infrastructures are prone to lock-ins because of their large-scale, long-term investments, deeply embedded social practices and institutional arrangements, creating a self-enforcing system (Helmrich et al., 2023). Especially, techno-centric strategies help reinforce current water infrastructure systems, thereby risking the exacerbation of ecological and social vulnerabilities (Markolf et al., 2018).

Yet, the ecological and social vulnerabilities may be significant. Regarding ecological vulnerabilities, discussions about potable water reuse often overlook the potential impacts and uncertainties associated with the *new waste streams* generated by these advanced treatment processes. The concentrated brine, a byproduct of technologies like reverse osmosis, contains high levels of salts, minerals, and potentially harmful contaminants. Current disposal methods in Arizona, such as evaporation ponds and discharge into the sewer system (Hummer & Eden, 2016), have limited capacity and pose significant environmental risks; evaporation ponds consume large areas of land and can pollute soil and air (Amoatey et al., 2021), while sewer discharge will become increasingly problematic as potable water reuse scales up (Hummer & Eden, 2016). Moreover, the discharge into oceans or rivers, another common method, can severely harm aquatic ecosystems (Ahmad & Baddour, 2014). Therefore, the long-term environmental sustainability of potable water reuse's generated waste stream remains a critical and unresolved concern.

Regarding social vulnerabilities, the narrow focus on potable water reuse as a technological solution can exacerbate existing inequalities or introduce new ones. A typically mentioned concern of current centralized water management systems is the issue of affordability. While water affordability has long been a concern of the United Nations, particularly in less developed countries, developed nations also face affordability challenges, especially for low-income households (se, e.g., Mack & Wrase, 2017; Vanhille et al., 2018), which are likely to exacerbate in the future (Teodoro & Saywitz, 2020). The large-scale adjustments in infrastructure and technologies needed for potable water reuse and its high energy consumption when in operation induce high costs (Gerrity et al., 2013; Lee & Jepson, 2020), impacting low-income households and communities the most. However, research on affordability is lacking due to the low number of operational plants. Moreover, there is a hot debate about the cost of alternatives, such as desalination, being claimed as significantly more costly than potable water reuse (Expósito et al., 2024; Mattingly et al., 2015).

Hence, the dominant reduction of the problem of water scarcity to water shortage narrows the problem space towards focusing on technological solutions that increase supply, such as potable water reuse. This narrow framing aligns with traditional water planning and obscures the 'wickedness' of water scarcity and its corresponding social and environmental concerns. Without Opening Up the problem space, these aspects often do not come to light when considering potable water reuse as a technological solution. As a result, pursuing social acceptance within this limited problem space risks perpetuating unsustainable practices and hindering the development of more desirable solutions.

6.6. Conclusion

This paper has contended that achieving social acceptance, while often considered the primary goal for the governance of new technologies, is insufficient to determine the desirability of technological developments. Especially for 'wicked problems' like water scarcity, current governance approaches that focus solely on social acceptance risk overlooking crucial ethical considerations, thereby potentially reinforcing unsustainable practices. By using potable water reuse projects in Phoenix, Scottsdale, and San Diego as illustrative cases, we could explore how even Opening Up participation strategies are susceptible to manipulation and risk neglecting the needs of marginalized groups, future generations, and non-human entities. To address these deficiencies, we proposed a socio-ethical assessment framework as a tool for more responsible governance that integrates social acceptance measures with considerations of ethical acceptability. This framework emphasizes the importance of ethical participation, prioritizing the moral quality of engagement processes and broadening the stakeholder scope. Additionally, it calls for Opening Up the problem space by challenging the initial framing of the problem to be solved and acknowledging the inherent complexities and uncertainties associated with wicked problems like water scarcity, as well as social and environmental uncertainties. With this socio-ethical assessment approach, we hope to support technology developers and policymakers in guiding the development of technologies that are socially accepted by the public and ethically desirable for society and the environment.

We need to emphasize the novelty of our framework; its main goal is to set the agenda for future research. Currently, studies that systematically bridge participatory decision-making and ethics appear to be lacking. The goal of our work has been mainly explorative, and detailed governance implications cannot yet be given. As such, the most important lesson that we want to convey for now is one of raising awareness. It needs to be acknowledged that for most governmental actors, the appeal for opening up opposes their inclination to close down decision-making processes. Likewise, the institutional context in which they work can be seen as 'closing down' machines (Ruiten et al., 2023). Moreover, participatory methods are often used in an instrumental fashion, and ethical concerns tend to be reduced to stakeholder opinions. However, decision-makers are also increasingly aware of the 'wickedness' that characterizes the introduction of new technologies, and become more receptive to include a broader range of concerns, even if that means that they have to step out of their comfort zone (cf. Melnyk et al., 2025). Researchers should use this receptiveness to implement new approaches and show their potential and efficacy. At the same time, governance actors should realize that participatory methods do not guarantee the legitimacy of decisions regarding wicked problems, and quick fixes are not to be expected. We invite researchers and decision-makers to collaborate to create and test different frameworks and methods for such assessment. With such a co-creative approach, we can move towards the development and refinement of practical methodologies to integrate ethical acceptability into technology governance processes and systems, such as potable water reuse. Concrete tools and guidelines for conducting ethical participation and facilitating deliberative processes need to be developed that effectively Open Up the problem space surrounding wicked problems like water scarcity. This could include developing normative methods for evaluating the long-term social and environmental impacts of different technological pathways to inform governance and decision-making better, incorporating a broader range of ethical considerations and uncertainties.

Conclusion

7

Conclusion

To conclude this dissertation, I now return to the previously identified research gap in potable water reuse research – a lack of normative evaluation of the system and its implementation process – addressed with the following research question:

(RQ) How can potable water reuse be implemented to ensure social and ethical desirability?

This final chapter answers this overall question and ties together my research journey, as introduced in Chapter 1 and re-illustrated in Figure 7.1. First, I briefly recap my intermittent research outcomes, starting with the *Problem Space Exploration*, moving towards *Theory Development* and finishing in providing a first *Ethical Assessment* of potable water reuse.

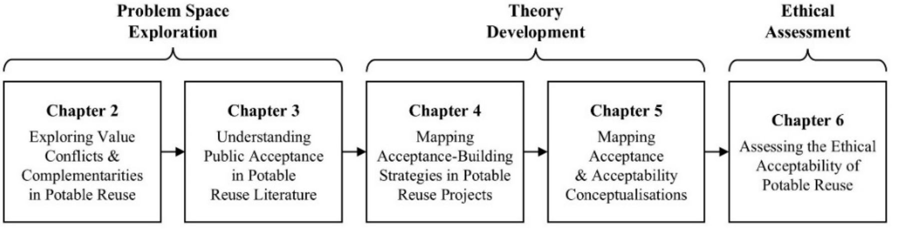

Figure 7.1: Dissertation Outline

To do so, I would like to begin by recapping the tension identified at the beginning of this dissertation: on the one hand, potable water reuse is increasingly seen as a *technically* viable solution to growing water scarcity, while on the other, the controversial nature of this system continues to challenge its *social* viability. To gain an understanding of the challenges and concerns that may influence this viability, I first analysed the overall *Problem Space* of these systems as addressed in current literature.

7.1.1. Problem Space Exploration

My research in this phase was dedicated to understanding existing challenges and identifying the key factors influencing the implementation of potable water reuse systems. This involved mapping out the value landscape and examining how the controversial nature surrounding potable water reuse is framed in the current literature.

Chapter 2 focused on identifying the core values prevalent in all types of potable water reuse research, including engineering, policy and social studies, with the first sub-question: *Which values are pertinent to potable water reuse in current literature, and how are they related?* With the help of the topic modelling software ValueMonitor, I found reliability, sustainability, health, and safety to be the four dominant values, though their conceptualisations showed overlaps and contradictions. Broadly, these values seemed to overlap with frequently raised societal concerns, but deeper investigation showed that these values are primarily understood in terms of technical performance and characteristics. Crucial social dimensions related to these values, such as justice, equity, and culturally diverse understandings of risk, were largely neglected within the academic research on potable water reuse.

The prioritisation of technical viability over addressing social concerns provides first insights into the tension of viability. The relative lack of research into social aspects may impede the understanding and, consequently, the adequate addressing of underlying reasons critical for achieving social viability.

With the relative underrepresentation of studies regarding the social concerns of potable water reuse in the field, Chapter 3 presents a more detailed understanding of how these concerns are currently approached, with the second sub-question: *How does the current literature frame the opposition towards potable water reuse?* I found that the controversial nature of potable water reuse is predominantly framed as a problem of social acceptance, which is seen as a significant barrier to implementation. A growing body of research attempts to unpack the factors contributing to social acceptance, revealing it to be a multifaceted and context-dependent phenomenon that requires a case-by-case approach. In contrast to these findings, however, many implementation methods proposed to enhance acceptance do not attempt to address this complexity but focus on education. The underlying assumption here seems to be that the main factor contributing to non-acceptance is a lack of knowledge about the system and the urgency of addressing water scarcity. This assumption is based on the 'information deficit model', which suggests that non-acceptance can be 'educated away' – an approach widely criticised for its ineffectiveness and for oversimplifying public responses towards technological innovations.

These results suggest that the complex phenomenon of social acceptance is increasingly understood by potable water reuse scholars, but the approaches to enhance acceptance do not reflect this sophistication. Instead, overly simplistic approaches are suggested that do not genuinely address all social concerns, which is another indicator potentially contributing to the opposition toward potable water reuse.

7.1.2. Theory Development

Concluding the previous phase, I hypothesised that ongoing potable water reuse projects are likely shaped by the current literature on acceptance-enhancing strategies, which do not address all societal concerns adequately. However, this assumption needs empirical underpinnings as theoretical insights do not always align with real-world practices. As such, Chapter 4 answered the third sub-question: *What types of acceptance-building strategies are applied in potable water reuse projects?* Investigating the public engagement strategies of three ongoing projects, San Diego (California), Phoenix and Scottsdale (Arizona), this research revealed that the 'information deficit model', as found in the literature, is also dominant in real-world contexts. Moreover, approaches such as educational campaigns and facility tours often highlight the system's benefits rather than provide an overview of both its benefits and potential shortcomings. Although all cities showed attempts to understand public concerns and address those, the most employed engagement strategies remain within the educational spectrum. The beneficial framing of potable water reuse in public outreach materials further suggests that advancing project implementation is often prioritised over meaningfully addressing public concerns.

Chapter 5 scrutinised the concept of social acceptance in itself, as it seems to be subject to ambiguity. Successful progress in potable water reuse projects has shown to be frequently equated with achieving social acceptance. However, this interpretation appears to contradict the academic emphasis on thoroughly addressing public concerns. Upon closer examination, the concept of social acceptance seemed to encompass various meanings, influencing variables, and related synonyms, making it highly ambiguous. However, concept clarity is critical to build a strong foundation for an ethical assessment. Therefore, I developed a theoretical framework to establish a more robust and interdisciplinary understanding of these concepts with the fourth sub-question: *How is the concept of acceptance understood in large-infrastructure technology development?* Because the research field of potable water reuse is only emerging, I turned to another more mature field that assesses controversial technologies – the field of energy technologies – where the challenges of social acceptance are more widely researched, and the ambiguity surrounding this concept is acknowledged.

This study revealed significant interdisciplinary differences and silo thinking across fields like Social Studies, Ethics of Technology, and Innovation Studies. To structure these different interpretations, I proposed the *funnel of acceptance and acceptability* metaphor and advocated moving away from isolated perspectives towards a simultaneous consideration of systemic, societal, and individual levels. Most notably, the concept of ethical acceptability has been found to be critical to the desirability of technology development and implementation in energy research. In potable water reuse studies, however, there has been no assessment of ethical acceptability to date.

7.1.3. Ethical assessment

Despite its importance in other fields researching controversial technologies, ethical acceptability remains underdeveloped in potable water reuse research. Considering the ongoing implementation of potable water reuse projects, the lingering issues with social acceptance, morally undesirable methods to increase it, and a record of past failed potable water reuse projects, an ethical assessment has proven essential. Hence, Chapter 6 answers the fifth sub-question: *How can the ethical acceptability of potable water reuse be assessed?*

This paper identified the ethical shortcomings of current acceptance-enhancing approaches and expanded the analysis to encompass ethical concerns that have not yet been addressed. This assessment is built upon the preceding *Problem Space* exploration and *Theory Development.* From currently suggested and applied acceptance-enhancing strategies, I synthesised three overarching approaches, highlighting each of its strengths and weaknesses. The insights gained by the scholarship of responsible research and innovation and the concepts of ethical acceptability guided the assessment of these acceptance-enhancing approaches.

This last sub-question highlighted the importance of ethical participation, including the representation of marginalised voices, future generations, and non-human entities. I further argued that the primary focus of achieving acceptance, even if designed with ethical desirability in mind, is insufficient to assess the overall ethical desirability of potable water reuse. We also need to ask questions about which problem potable water reuse intends to solve and which issues it may raise or entrench.

7.2. Answering the Main Research Question

After looking at the research journey, let us now turn to the main research question of this dissertation:

(RQ) How can potable water reuse be implemented in a way that ensures social and ethical desirability?

To answer this final question, each of the chapters provided critical insights. First, Chapter 2 highlighted that a first step towards implementing potable water reuse more desirably is to recognise that it is not a purely technological system but a socio-technical one where technology shapes and is shaped by society. Hence, social concerns are critical for technology success and must be taken seriously and addressed adequately.

For this, assessing the often-raised issue of low social acceptance of potable water reuse is critical. Chapter 3 pointed out that social acceptance is a technology and context-dependent phenomenon that must be addressed on a case-by-case basis. Current literature provides a wealth of starting points of typically found factors influencing social acceptance and sophisticated methods to uncover those. Yet, Chapters 3 and 4 showed that care must be taken when designing acceptance-enhancing strategies as there is a risk of a disconnect between the concerns found relevant and the ones actually addressed in practice. The dominant paradigm of spreading information to combat lacking knowledge, as embodied by the archetype 'Common Participation' of Chapter 6, is insufficient and must give way to other approaches that aim to address *all* relevant public concerns. Approaches that fit the archetype of 'Opening Up' are better equipped to understand and address public concerns surrounding potable water reuse.

However, even those approaches can be victims of a problem space that is too narrow or manipulative. To overcome these drawbacks, ethical acceptability is necessary. Chapter 5 illuminated that ethical acceptability can help draw out potential implications of controversial technologies that are not considered in social acceptance strategies, as these often exceed the spatial and temporal boundaries of the project. The archetype 'Ethical Participation' of Chapter 6 provides first handholds of overcoming the shortcomings of social-acceptance enhancing strategies, such as the deliberate inclusion of future, non-human and marginalised voices.

Moreover, ethical acceptability offers more than the assessment of social-acceptance approaches. It draws attention to the 'wickedness' of the problem of *water scarcity,* which Quentin Grafton (2017, p. 3025) describes as "water misallocation where [...], multiple pathways to water reallocation and substantial uncertainty over the consequences of business as usual and alternative futures" exist. This quote highlights the question of which problem potable water reuse intends to solve. Chapters 3, 4 and 6 suggest that in potable water reuse research and projects, water scarcity is often reduced to water *shortage*, rendering potable water reuse an ideal option. However, in Chapter 6 I suggested several possible future implications, such as a deeper lock-in in inherently wasteful decentralised systems, remaining contamination risks, and social and environmental equity concerns that are getting overlooked in this view. Hence, a first step to better ensure the ethical desirability of potable water reuse, the complexity and uncertainty of water scarcity must be better acknowledged and addressed in the public debate so that society can make informed decisions that are responsible and sustainable.

As a result, to ensure the social and ethical desirability of potable water reuse, social acceptance *and* ethical acceptability should be treated in tandem, as both are vital for the success of technology. Addressing social acceptance concerns helps resolve latent social problems in the temporal local sphere. On the other hand, ethical acceptability reflections ensure that processes to increase social acceptance are morally desirable and help determine additional systemic and future implications of the chosen technological system.

7.3. Contributions and Implications

This dissertation makes several theoretical contributions to understanding the controversial nature surrounding potable water reuse. By adapting existing and developing novel frameworks, this work helps advance the field of Ethics of Technology. First, Chapter 4 contributes to the Responsible Research and Innovation scholarship by adapting the 'Leaving Ajar' framework, which helps to categorise different approaches to enhance technology or system acceptance. These adaptations streamlined the framework for case study analysis and demonstrated its broader applicability beyond its initial focus on gene drive technologies. Furthermore, this research established the 'Leaving Ajar' framework's potential as a foundation for ethically assessing chosen case studies, as seen in the discussion of Chapter 5 and throughout Chapter 6.

Second, Chapter 5 enhances the conceptual clarity of acceptability and acceptance, two concepts that show divergent meanings depending on the research field and topic of study. The 'funnel of acceptance and acceptability' aimed to structure these different understandings to increase concept clarity, reduce misunderstandings and enhance interdisciplinary collaboration. This framework may also be helpful in other fields researching controversial technologies and systems.

More prominently, however, are the contributions made to the field of potable water reuse, which range from uncovering research gaps, undesirable ethical assumptions and a first ethical assessment of the system itself. This dissertation highlights a significant mismatch between the complex theoretical understanding of social acceptance of potable water reuse and the simplistic, practical approaches found in literature and practice used to address it. While academic literature increasingly recognises social acceptance's nuanced and context-dependent nature, real-world projects often employ overly simplistic strategies, reducing non-acceptance to a knowledge problem. This finding can be used as a starting point to close this gap between theory and practice.

Moreover, I challenge the prevalent and often implicit assumption that potable water reuse is seen as inherently 'good'. Chapters 3, 4 and 6 identified a strong positive bias towards this technological system, particularly in empirically focused studies, where the perceived benefits of increased water availability often overshadow a balanced debate about risks and ethical concerns. This bias can (and has) lead to skewed public engagement strategies that highlight benefits while minimising potential drawbacks. Yet, besides the frequently mentioned concerns of technological safety and reliability, other risks and concerns that are not immediately linked to technological performance exist. Chapter 6 addresses some of those concerns that have been largely neglected or overlooked. These drawbacks include the potential marginalisation of various non-vocal publics (such as future generations, non-humans or affected groups outside the spatial boundary of a project), future impacts of entrenching technological lock-in with unsustainable decentralised infrastructure, unresolved challenges with managing concentrated waste streams as systems scale up, and fundamental equity issues, particularly concerning affordability and fair access to high-quality drinking water.

While I acknowledge that this is only a starting point, my work aims to highlight the importance of considering the moral dimensions of reclaiming wastewater for human consumption, an aspect that has been largely overlooked in the past.

7.4. Future Research

This dissertation offers a first exploration of the ethical implications that the increasing implementation of potable water reuse can have on communities and broader society. However, this investigation represents only a preliminary step and is, by itself, insufficient to comprehensively assess the overall moral desirability of these systems. Since potable water reuse is still in a relatively early phase of adoption, now is the time to proactively assess these ethical dimensions. Engaging in robust ethical analysis *before* systems become deeply entrenched in society is critical as it can help anticipate and mitigate potential negative consequences. Future research can build upon this initial ethical assessment through more in-depth investigations, using different research perspectives such as different ethical lenses, zooming in or out of spatial or temporal boundaries or even a more detailed analysis of specific system setups.

My research has highlighted a critical mismatch within the field of potable water reuse and the literature on social acceptance in general. While academic literature increasingly recognises social acceptance's complex and context-dependent nature, approaches to enhance it remain predominantly simplistic, often reducing non-acceptance to a knowledge problem. As such, a significant avenue for future research lies in developing new methods and approaches to better address *all* relevant public concerns. While some scholars have made significant contributions in, for example, addressing the issue of trust (Ormerod & Scott, 2013) or legitimacy (Binz et al., 2016; Harris-Lovett et al., 2015), there is much more to be done. For example, the current Western-dominated research landscape might overlook concerns which are highly relevant, yet less visible. Here, more research is needed on how different social and cultural norms affect acceptance of potable water reuse to make this field more sensitive to heterogenous concerns and needs.

Moreover, future studies should prioritise developing and testing engagement strategies based on ethical participation approaches to better represent the public's concerns, including those of the marginalised groups. This necessitates moving beyond one-way information dissemination towards genuine dialogue, deliberation, and processes that actively incorporate diverse values and perspectives in decision-making. Research fields such as Science and Technology Studies as well as Ethics of Technology offer extensive research on designing public engagement approaches across various technological and environmental domains. Here, especially in the technological domain of energy technologies, significant progress has been made in including and engaging the public in technology development and implementation. Due to similarities between energy and water infrastructure projects, the insights and methodologies developed within energy engagement research can serve as valuable starting points for designing more effective and inclusive engagement strategies tailored explicitly for potable water reuse initiatives.

7.5. Limitations and Reflections

While this dissertation offers insights into the ethical dimensions of potable water reuse and the complexities of social acceptance, it is important to acknowledge certain limitations inherent in its scope and methodology. While each research chapter has pointed out its specific limitations, I will highlight several that pertain to this dissertation as a whole.

A significant limitation of this dissertation stems from the limited empirical evidence available to ground its analysis, a constraint evident throughout the preceding chapters. As highlighted in Chapters 2 and 3, potable water reuse remains an emerging and relatively small field of study. Consequently, the findings presented herein should be viewed as a snapshot of current interpretations rather than a definitive and holistic analysis, as the field's progression over time will likely yield further insights and potentially shift these observations. Moreover, the analysis in Chapters 4 and 6 primarily relied on three cases, which in itself constitutes a modest empirical foundation for drawing broad generalisations. This limited case base, while providing valuable initial insights, necessitates further investigation across a wider range of contexts to strengthen the robustness and transferability of the findings to other contexts.

A second notable limitation stems from my own situatedness as a researcher. Educated within a Western European context, my cultural embeddedness has undoubtedly shaped the way I understand and address the desirability of potable water reuse. Moreover, Chapter 2 highlighted that most research on potable water reuse, including engineering, social sciences and policy research, stems from European or North American research institutions. My Western-European background, coupled with primarily Western-led literature on potable water reuse, presents a considerable constraint as it may inadvertently overlook or underemphasise alternative cultural values, non-Western understandings of water and technology, and the specific ethical considerations that may arise in different societal contexts. Recognising this, there is a need for future research that actively incorporates diverse global perspectives to achieve a more culturally sensitive understanding of the ethical and social landscape of potable water reuse.

7.6. Reflection

Being an engineer by training has made writing this dissertation and conducting research in the field of Ethics of Technology a challenging experience. During my engineering studies, I was taught that technology development was an objective, straightforward task, often coupled with certain requirements which were, if boiled down, matters of cost (maximum fuel use, maximum weight, aerodynamics, etc.). Engineering approaches often rely on calculations that function as idealised approximations of complex real-world contexts. They have been created through frequent empirical testing, often using trial and error, and typically depend on clearly established system boundaries.

Assessing the ethical and social impacts of emerging technologies, however, operates under fundamentally different premises. Although during my Masters in Management of Technology, I already realised that technology incorporates much more than pure numbers and the finding of the 'ideal solution' to a clearly bound mathematical problem, it remained challenging to articulate *why* this was the case. It meant learning a new way of thinking and talking about what kind of impacts technology can have on society and the environment – a 'zooming out' from the design details of a specific technology towards the implications of the system as a whole. But at the same time, these nitty-gritty details can also significantly impact this whole system, making the assessment process a back-and-forth, a zooming out of and into technological systems.

I first experienced this rather messy reality of understanding and assessing technological systems as immensely frustrating. It seemed to go against my being an engineer who always aims to efficiently find the 'ideal solution' to a problem. At the same time, precisely this messiness and the difficulty of finding satisfying solutions to an immense, complex real-world(!) problem is what made this quest so interesting.

With this mindset, I set out to explore the field of Ethics of Technology, expecting to find frameworks or principles that, at least partially, provide the effective and efficient tools that I was looking for to help me analyse potable water reuse. However, it became increasingly clear when exploring the field that ethics assessments do not operate that way. Instead of providing universally applicable guidelines or principles for ethical analysis, the field offers diverse perspectives, conceptual tools, and critical approaches that nearly always require their own interpretations and contextual application. I had to step outside my comfort zone and really get a better feel for how the field of Ethics of Technology operates. For me, this meant becoming more comfortable with answers that weren't definitive and accepting that a particular technology often cannot generally be judged 'good' or 'bad'. Instead, creativity and out-of-the-box thinking seemed to be essential skills.

Still, I kept looking for frameworks of potentially comparable technologies or systems that I could at least be inspired by but realised that potable water reuse is rather special due to it being a centralised, very large infrastructure. The system's sheer size made it impossible to draw clear boundaries of what exactly comprises potable water reuse. The different potential setups (e.g., indirect or direct), different requirements of communities, and all the different impacts that certain sub-systems can have on society and the environment made it difficult to clearly map the problems encountered by these systems. And that makes sense, of course, because as I (and other scholars) repeat over and over again throughout this dissertation, the social and ethical implications of a specific technology are context and technology-dependent!

However, the uncertainty from all sides left me swimming, and the newness of these systems and the resulting lack of empirical evidence did not help in this matter. With all these unknowns in mind, I realised that I needed to take a step back from my aim of comprehensively assessing the social and ethical desirability of potable water reuse and moving towards paving the way to do so. As such, I chose to address all the challenges that I encountered when I first attempted an ethical acceptance of potable water reuse, early on in the trajectory: exploring the wealth of challenges that a potable water reuse project might encounter, collecting empirical evidence, exploring system boundaries and only then move on to providing first thoughts on how social and ethical desirability can be assessed for potable water reuse projects.

The mix of needing to be creative like a scholar in Ethics of Technology and the engineering drive for empirical grounding, clear boundaries and a sprinkle of 'trial and error' is what made this research what it is now. This meant many frustrations and many 'kill your darlings', but I think it led to a way of looking at the ethics of potable water reuse that is analytical and intuitive while always considering the real-world complexities these systems come with.

In the end, this whole experience has not only shaped my dissertation but also helped me find my place in the field of Ethics of Technology. Towards the final stages of this trajectory it has been especially rewarding to hear that my research, perhaps because of the journey described, is considered a useful foundation for others. The feedback suggests that my intuitive and approachable research style makes the work accessible even to those not deeply familiar with ethics, which, considering my own learning process, is something I particularly value.

Back Matter

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About the Author

Karen Moesker was born on October 6, 1992, in Germany. The doctoral research presented in this dissertation was conducted by Ms. Moesker at Delft University of Technology, The Netherlands, within the Faculty of Technology, Policy and Management, commencing in September 2021. Her dissertation investigates the social and ethical complexities of implementing water recycling systems, drawing from Ethics of Technology and Science and Technology Studies, and is part of the ESDiT (Ethics of Socially Disruptive Technologies) consortium.

Her career journey has cultivated a distinct interdisciplinary profile, blending engineering, management, and ethics. Prior to her doctoral studies, Karen completed a Master's degree in Management of Technology at TU Delft (MSc, July 2021), where her thesis focused on justice in sustainable transitions. With this degree, she graduated *cum laude* and received a special annotation for Entrepreneurship and Technology in Sustainable Development. Before, she completed a Bachelor's in Aerospace Engineering from TU Delft (BSc, July 2017), featuring an exchange semester at the Beijing Institute of Technology, China. Before undertaking her Master's degree, Karen gained professional experience as a Project Management Intern at the BMW Group in Munich, Germany and as a Business Analyst and Testing Engineer at Accenture in Zurich, Switzerland.

Karen actively engaged in several academic and professional development activities during her doctoral trajectory. She participated in the Doctoral Certificate in Responsible Innovation Program, a specialized training initiative involving Arizona State University (US), Karlsruhe Institute of Technology (DE), and TU Delft, which included a three-month research stay at Arizona State University in Phoenix, Arizona. Her research has led to publications in high-ranking academic journals such as *Energy Research & Social Science* and the *Journal of Responsible Research and Innovation*. Alongside her research, she contributed to engineering education by teaching engineering ethics courses across various faculties at TU Delft and completed the University Teaching Qualification (UTQ) program.

The Simon Stevin Series in Ethics of Technology is an initiative of the 4TU Centre for Ethics and Technology. 4TU.Ethics is a collaboration between Delft University of Technology, Eindhoven University of Technology, University of Twente, and Wageningen University & Research. Contact: info@ethicsandtechnology.eu

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Simon Stevin (1548-1620)

'Wonder en is gheen Wonder'

This series in the philosophy and ethics of technology is named after the Dutch / Flemish natural philosopher, scientist and engineer Simon Stevin. He was an extraordinarily versatile person. He published, among other things, on arithmetic, accounting, geometry, mechanics, hydrostatics, astronomy, theory of measurement, civil engineering, the theory of music, and civil citizenship. He wrote the very first treatise on logic in Dutch, which he considered to be a superior language for scientific purposes. The relation between theory and practice is a main topic in his work. In addition to his theoretical publications, he held a large number of patents, and was actively involved as an engineer in the building of windmills, harbours, and fortifications for the Dutch prince Maurits. He is famous for having constructed large sailing carriages.

Little is known about his personal life. He was probably born in 1548 in Bruges (Flanders) and went to Leiden in 1581, where he took up his studies at the university two years later. His work was published between 1581 and 1617. He was an early defender of the Copernican worldview. He died in 1620, but the exact date and the place of his burial are unknown. Philosophically he was a pragmatic rationalist. For him, wonder about a phenomenon, however mysterious, should be the starting point for seeking understanding or even ultimate explanation through human reasoning. Hence the dictum 'Wonder is no Wonder' that he used on the cover of several of his books.

As global water scarcity intensifies, potable water reuse, the process of treating wastewater to a quality suitable for drinking water, offers a path toward sustaina-ble water management. However, despite its growing technical viability, wide-spread adoption has been hampered by public opposition, often reductively dis-missed as lacking 'social acceptance'. Potable water reuse blurs the long-established societal and infrastructural separation between wastewater and drinking water, leading to concerns about safety, system reliability, trust in authorities, and disgust (the 'yuck factor'). This dissertation argues that although addressing social ac-ceptance is critical, current approaches remain largely insufficient and overlook vital social and ethical concerns. For instance, the dominant paradigm of spreading information to combat a lack of knowledge must give way to approaches that better address all relevant public concerns. Moreover, by shifting the lens to incor-porate ethical acceptability, this work uncovers critical but neglected issues, includ-ing the potential marginalisation of non-vocal publics, the risk that potable water reuse entrenches technological lock-in through unsustainable infrastructure, and unresolved challenges in managing concentrated waste streams. Ultimately, this work highlights that social acceptance and ethical acceptability must be treated in tandem to ensure the desirable and responsible development of a technological system – a strategy for which this dissertation lays the groundwork.

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