

ARTICLE SUMMARY

CHARACTERIZING NON-TECHNICAL BARRIERS FOR ON-SITE ALTERNATIVE WATER SYSTEMS

An overview of findings from peer-reviewed literature

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What do we know about on-site alternative water systems?

Urbanization, climate change and depletion of natural resources increasingly challenge the conventional paradigm of centralized water supply, treatment, and reuse [1–3]. There is growing evidence that addressing key challenges for urban water management requires more flexible, modular, decentralized or small-grid water systems that are implemented in parallel with or as a substitute to expansive sewer-based systems [3,4]; referred to here as on-site alternative water systems.

The term on-site is defined by Sharvelle et al. (2017) as systems where “local sources of water (e.g., roof runoff, stormwater, graywater, and wastewater) are collected, treated, and reused at the building, neighborhood, and/or district scale, generally at a location near the point of generation of the source of water” [5]. While initial adoption has begun [6–8], cities have encountered various non-technical challenges in adopting and diffusing on-site reuse technologies [9–12], such as risk aversion due to the risk to public health, lack of legitimacy and user acceptance, and challenges in creating new

governance frameworks that clarify different actor's roles in designing, installing, and operating on-site reuse systems.

These challenges are an inherent part of the transition process. In the same way that centralized water and wastewater utilities have established actors, roles, regulation, and buy-in from end users and the public in the past, a fitting institutional support structure needs to be developed for on-site alternative water systems.

Existing work has addressed this issue using a variety of different perspectives. Case studies around the world have looked at institutional support structures for different types of recovery, such as stormwater capture [13–17], greywater reuse [5,9,18–21], reuse of the full wastewater stream [22–26], and source separation [27–31]. The academic article associated with this summary report pulled together the wealth of knowledge scattered in different types of literature within a conceptual framework designed to present a more organized approach for what is needed for successful transitions. Based on work done on enabling environments for urban water management [32,33] and technological innovation systems [34], different dimensions were combined in one holistic framework (see figure 1). A new governance system is needed for adoption of any on-site alternative water system, and six components were identified as necessary conditions for successful implementation: equity, financial investment, knowledge and capabilities, legal and regulatory frameworks, legitimacy, and market structures [35–41].

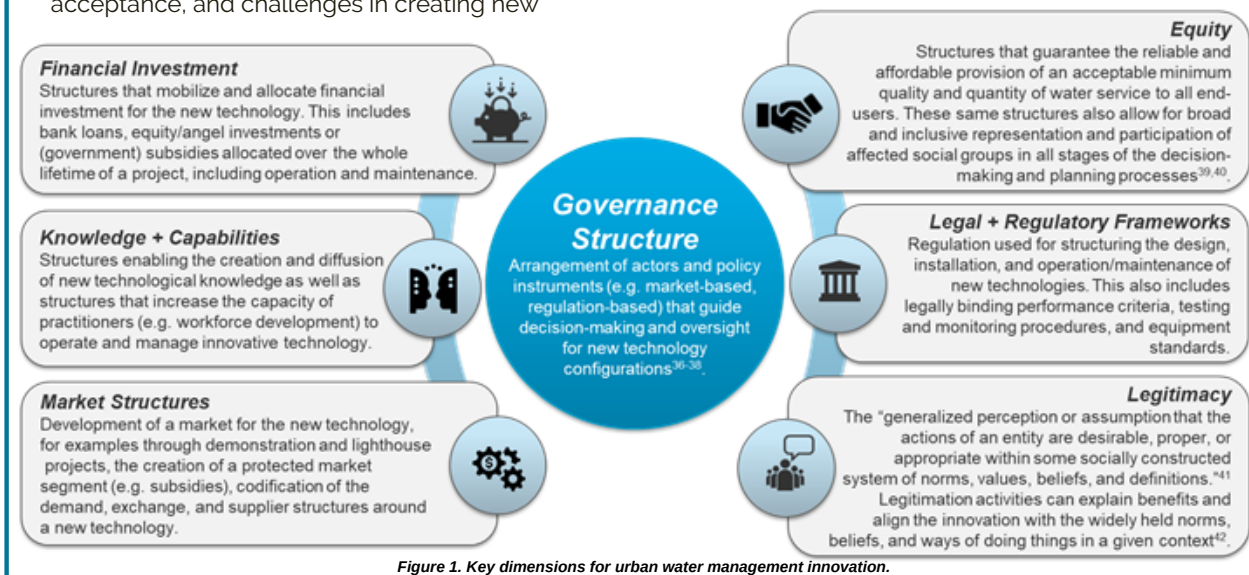


Figure 1. Key dimensions for urban water management innovation.

Global reach of on-site alternative water systems

A systematic review of over 350 articles shows that about two thirds of peer-reviewed literature on on-site alternative water systems in urban areas focus on developed economies (mostly in Australia, the USA, Spain, Germany, the United Kingdom, and Sweden). One third focus on developing and emerging economies (mostly China, India, and South Africa). Of these studies, only a small handful mention socio-technical challenges, which we focused on in more detail.

Not all on-site systems experience the same institutional hurdles: a breakdown

Figure 2 shows the results of an in-depth coding of 39 articles that dealt most deeply with non-technical challenges for on-site alternative water systems in an urban context. Relevant challenges differed systematically between types of configurations.

Challenges for **stormwater capture** mostly revolve around financial issues, like the initial cost for installation and finding a way to incentivize end users. In some cases, there has been enthusiasm for rainwater harvesting, but building owners were constrained by existing regulations. For example, it was illegal for a period to capture rainwater on-site in Colorado (USA) [42] and building owners in the City of Johannesburg (South Africa) needed to obtain permission before installation [16], creating additional administrative hurdles.

Greywater systems for non-potable use still lack widely accepted definitions and standardized regulations. For example, systems recycling greywater for indoor purposes might be subject to different requirements than outdoor purposes. Similarly, the scale of the system (e.g., building vs. district) can also affect the challenges encountered [5]. These nuanced aspects to system design required tailored regulation. Regulations for on-site greywater recycling can be constrained by existing regulations and market structures developed for centralized systems, highlighting the need for more flexible and tailored regulations and financial incentive/pricing structures. Efforts have been taken to address these challenges. For example, in the United States, the National Blue Ribbon Commission for On-Site Non-Potable Water Systems developed guidance for implementing a risk-based regulatory framework for on-site alternative water systems [5].

Recycling of the full **wastewater** stream brings additional concerns for impacts to public health, sometimes resulting in stricter regulations to avoid risk. Similar to greywater systems, the need for a tailored approach to regulating and monitoring on-site systems was observed in multiple countries. In one example, government officials transposed regulations from another country due to the technology development, but issues with enforcement emerged [23]. The amount of treatment for these systems requires additional financial investment, which can create a hurdle for developers and building owners. A business case for recycling wastewater on-site remains a challenge in every country mentioned in the literature.

Source	Stormwater	Greywater	Wastewater	Wastewater and Blackwater (Dry feces + Urine)
Recovery Purpose	Non-potable reuse	Non-potable reuse	Non-potable reuse	Agricultural use
Barriers	<p><i>Countries: Australia, Germany, South Africa, South Korea, United States</i></p> <p>Financial Investment</p> <ul style="list-style-type: none"> - Installation costs - Lack of financial incentives 	<p><i>Countries: New Zealand, Spain, United States</i></p> <p>Knowledge & Capabilities</p> <ul style="list-style-type: none"> - End users need more info about how systems work - Lack of education about design guidelines and standards <p>Legal & Regulatory</p> <ul style="list-style-type: none"> - Need for tailored regulations - Need for standard definitions 	<p><i>Countries: Australia, China, United Kingdom, United States</i></p> <p>Financial Investment</p> <ul style="list-style-type: none"> - High capital costs - High operating costs <p>Knowledge & Capabilities</p> <ul style="list-style-type: none"> - Data is needed to create regulations - More training needed for operations and maintenance <p>Legal & Regulatory</p> <ul style="list-style-type: none"> - Need for tailored regulations; enforcement <p>Legitimacy</p> <ul style="list-style-type: none"> - Perceived risk to public health 	<p><i>Countries: Finland, Sweden, The Netherlands</i></p> <p>Knowledge & Capabilities</p> <ul style="list-style-type: none"> - Lack of research for guidance documents - Information breaks in actor networks <p>Legal & Regulatory</p> <ul style="list-style-type: none"> - Strict regulation due to risk aversion - Interfacing regulations from multiple industries <p>Legitimacy</p> <ul style="list-style-type: none"> - "Yuck factor" - Perceived risk to public health <p>Market Structures</p> <ul style="list-style-type: none"> - Lack of strong business case - Interfacing multiple industries: agriculture and wastewater infrastructure

Figure 2. Distribution of institutional barriers across alternative water systems (i.e. combinations of sources and recovery purposes) with some examples from literature.

Finally, **nutrient recovery systems**, like source separation or composting toilets experience challenges with regulatory frameworks for a variety of reasons. First, designs for these systems (e.g., urine-separating toilets) might be different from what end users are familiar with, requiring more legitimation to improve perception of the technology. This and the perceived increase risk to public health leads to stricter regulations. Second, the fertilizer that is produced has to meet standards in both the wastewater and agricultural industries. In some cases, regulations are non-existent or are ill-fitted for the alternative system. Extra effort is needed to overcome these existing industry structures and create a protected space for nutrient recovery and its end use (i.e. fertilizer products).

Socio-technical complexity of on-site alternative water systems

From these findings, we observed that as the technical complexity of on-site alternative water systems and potential risk to human health increase, so does the number of dimensions from figure 1 that need to be addressed when diffusing the respective solutions (socio-technical complexity). As decision-makers look to introduce different types of systems beyond the pilot-scale, it can be helpful to reflect upon their socio-technical complexity and the types and breadth of non-technical barriers that are most likely to be encountered in the process.

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Authors

Miriam Hacker, Postdoctoral Researcher (formerly)
Christian Binz, Group Leader, Environmental Social Sciences

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