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On-site Water Reuse Systems

in Bengaluru, India

Bengaluru represents a globally unique context for the diffusion of on-site wastewater treatment and reuse systems (ONWS). Local authorities have introduced a series of mandates that triggered a dynamically evolving mass-market for ONWS.

Since 2004, all new residential buildings larger than 20 apartments or 2000 m2 and commercial buildings larger than 2000 m2 must install on-site sewage treatment plants and reuse 100% of the treated wastewater. To date, more than 2500 systems have been installed in the city.

Collection & Transport
A typical system consists of a small-scale sewage treatment plant (SSTP) that treats household sewage at the apartment complex scale. Systems are typically installed in buildings not connected to central sewerage networks or piped water supply. Treated wastewater is distributed in the compound and within buildings through dedicated pipes.

Treatment
Installed treatment systems include biological treatment combining a wide range of aerobic and anaerobic technologies, and various tertiary treatment steps, such as filtration and disinfection.

Products
Recycled wastewater for non-potable onsite (e.g. toilet flushing, irrigation and car washing) and offsite uses (e.g. laundries, public parks or construction sector).

Benefits
Enabled urban development in parts not covered by centralised infrastructure, reduced environmental pollution, enhanced flexibility and resilience of water- and sanitation infrastructure, reduced dependence on costly long-distance water transfers and tanker water, and treated wastewater as tradeable commodity.

Lighthouse Synthesis Report

Introduction

Bengaluru is a major economic hub in south India that is experiencing rapid population growth. As in many megacities, growth outpaces infrastructure expansion and neither piped water nor sewerage networks serve the entire city. The water supply system relies on the long-distance transfer of water from the Cauvery River, and largely unregulated private bore wells that tap into groundwater resources as do tanker trucks delivering water. This has resulted in severe water stress and price hikes during drought periods. Moreover, a significant portion of the population disposes wastewater directly into stormwater drains that feed into local rivers and lakes. Coupled with poorly performing large-scale wastewater treatment plants, this has led to widespread environmental pollution and health risks.

Until the late 1990s, urban water management largely followed the conventional template of a state-led expansion of centralised pipe-networks. Yet, given the city's explosive growth, the relative share of households served by centralised water and sanitation infrastructure has been constantly shrinking. Over the last two decades, in an attempt to address issues of environmental pollution and water security, Bengaluru has adopted ambitious policies promoting on-site wastewater treatment and reuse systems (ONWS), in addition to expanding the centralised pipe networks [1].

In 2004, local authorities started mandating the installation of small-scale sewage treatment plants (SSTPs) in all new apartment buildings larger than 20 apartments or 2000 m2 [2]. This mandate reflected a monumental shift in the underlying logic of urban water management in Bengaluru. Instead of a public utility, private firms and resident welfare associations (RWAs) became responsible for building, operating, and maintaining SSTPs and ensuring adequate treatment quality. This was followed by mandates to reuse treated water for non-potable onsite purposes, such as gardening and toilet flushing, and later for off-site reuse, e.g. in the construction industry. In India, RWAs are the entities responsible for managing residential apartment complexes on behalf of their members, who are the homeowners.

To date, estimates suggest that more than 2500 SSTPs have been installed in the city [3]. The mandate has induced a quickly growing market for ONWS, with many new and established wastewater treatment firms entering the field. This fast and uncontrolled market growth did not, however, come without challenges. Many installations have been made by firms without proper technological expertise, sometimes with the blessing of cost-cutting builders and plumbing consultants. In addition, once construction is finalised, RWAs are typically responsible for operating the plants. Yet, even well-designed systems require expert knowledge and skills for proper operation and maintenance (O&M), which is often lacking. There is also a lack of monitoring and enforcement activities by the local authorities. As a result, it is estimated that up to 80% of the systems perform poorly [3].

Over time, firms started experimenting with new technologies and business models, and they developed new skills and capabilities related to ONWS design, implementation and operation. In parallel, policymakers introduced new regulations and mandates, and local NGOs and research institutes started to engage in broader system building activities. This included targeting the lack of quality labelling and technology standardisation in the ONWS market. The importance of proper SSTP installation and O&M is increasingly emphasised by local authorities.

Despite these challenges, Bengaluru spearheaded the implementation of a city-wide mandate aiming for 100% reuse of wastewater treated on-site. Approximately 20% of the city's wastewater is now treated in SSTPs, which is globally unique. Bengaluru has developed into a potential lighthouse initiative that could serve as a template for developing an ONWS program in other rapidly urbanising areas in middle-income countries – if certain problems with the current technologies, business models and governance arrangements are resolved. In this brief, we will examine the key drivers that have contributed to the successful implementation of ONWS in Bengaluru and challenges. This discussion will be structured around the five key analytical dimensions of the Lighthouse project. By examining these dimensions, we hope to gain a better understanding of the key factors that have led to the success, and to identify recomendations for other cities that seek to adopt similar decentralised urban water solutions.

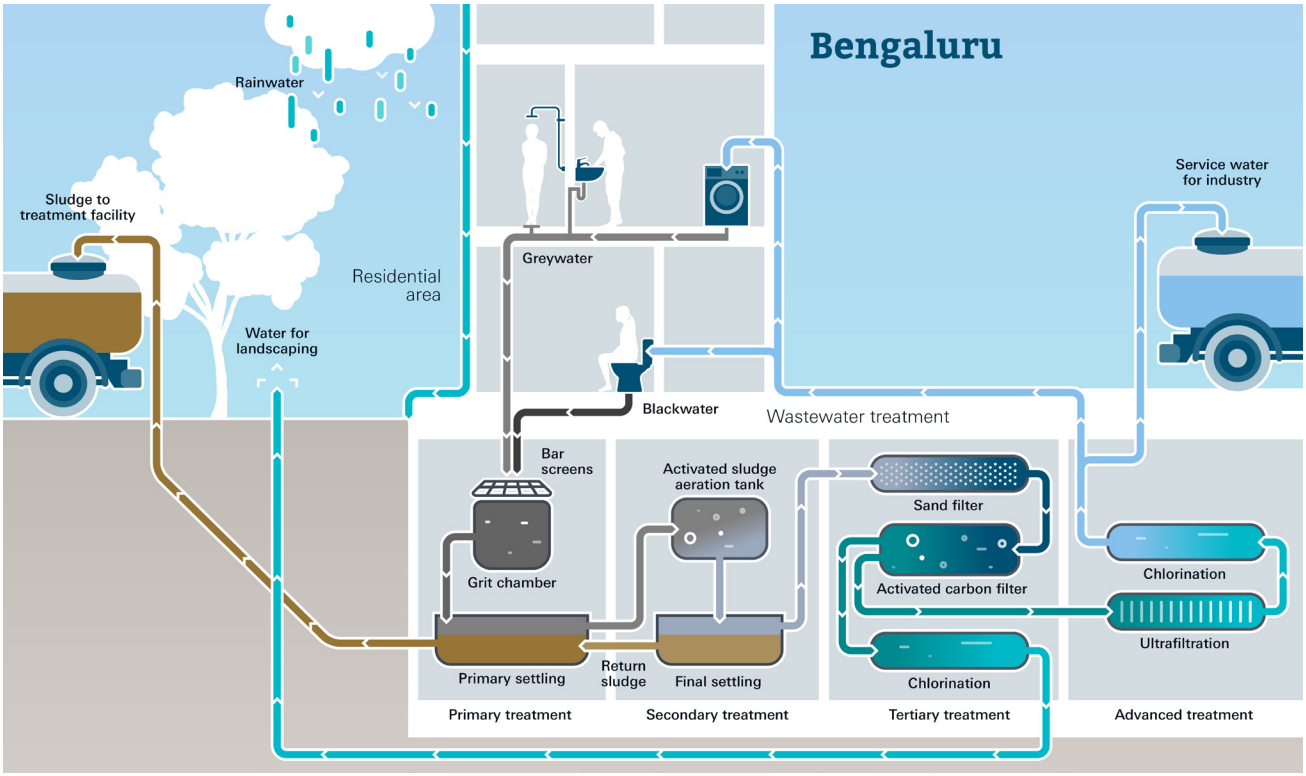

Figure 1: Exemplary schematic overview of a typical ONWS in Bengaluru.

System Set-Up: Technology Description

The typical ONWS in Bengaluru is based on an on-site treatment plant (SSTP) set up on the premises of a single apartment complex, consisting of 20 to 1000 apartment units. Most complexes are not connected to the central sewerage network, or to the piped municipal water supply. Instead they rely on bore wells and/or tanker water supplies. Most SSTPs installed in the city use conventional aerobic treatment technologies. Vendors also offer anaerobic treatment plants, emphasising such benefits as low energy use and maintenance costs, or hybrid variants combining aerobic and anaerobic processes.

For safe non-potable water reuse, SSTPs are (increasingly) complemented with tertiary treatment. This typically includes such processes as microfiltration (MF), ultrafiltration (UF), ultraviolet light (UV) disinfection, ozone disinfection, and/or chlorination. In many apartment complexes, however, the wastewater treated in the SSTP is used directly for gardening, car washing and toilet flushing without tertiary treatment apart from water softener and chlorination. In rare cases, the water is additionally treated in a central reverse osmosis (RO) system. Most individual apartments are also equipped with point-of-use RO appliances, e.g. at the kitchen tap. These are used for drinking water and cooking purposes.

For toilet flushing, apartment buildings are equipped with dual plumbing, i.e. with a separate pipe supplying treated wastewater to the toilets. After the flush, the water is brought back to the treatment plant in the ordinary sewerage pipe. For other reuse purposes, such as gardening, car washing and off-site reuse, water is typically accessed directly from the treatment plant.

To date, no 'turnkey' ONWS solutions exist on the market. Treatment technology choices are shaped by the quality standards introduced by state authorities [2], which call for a consistent treatment quality regardless of wastewater source and reuse purpose [4]. Most technologies on the market can meet these standards if operated properly. Only a few standards or guidelines are available to assist builders in selecting a technology that suits the particularities of the apartment complex, different water sources or the reuse purpose. Technology selection is often made at the whim of sometimes inexperienced, technology consultants and vendors. This has led to the installation of systems that are difficult and costly to operate and prone to malfunction.

Institutional Framework Conditions

Legal & Regulatory Conditions

In India, government actors at the national, state, and city levels are responsible for urban water management. At the national level, the Ministry of Housing and Urban Affairs (MoHUA) and the Ministry of Environment, Forests and Climate Change (MoEFFC) are the ones primarily shaping developments in water management [1]. At the State level, State Pollution Control Boards are responsible for implementing pollution legislation. In Bengaluru, the Karnataka State Pollution Control Board (KSPCB) has the authority to set effluent standards and is responsible for monitoring the performance of all wastewater-discharging entities [2].

A series of government mandates, targeting environmental pollution and water security issues, have been developed to facilitate on-site wastewater treatment and reuse in Bengaluru. The first mandates targeted environmental issues resulting from the release of untreated wastewater into Bengaluru's lakes and streams. In 2004, the KSPCB mandated the installation of SSTPs in new residential buildings (larger than 20 apartments or 2000m2) and commercial establishments (larger than 2000m2) [2]. In parallel, KSPCB also established a permitting process that developers and construction companies must adhere to. This included a Consent for Establishment (CFE) based on a review of the SSTP design proposed by the builder, and a Consent For Operation (CFO) based on an on-site review of the constructed plant by KSPCB officials. In response to public complaints about lake pollution, in 2014 the KSPCB announced a Zero Liquid Discharge (ZLD) requirement [5]. This meant that no wastewater (untreated or treated) can be discharged into storm drains, lakes and rivers. This mandate primarily targeted environmental pollution issues, but also complemented previous calls about not using potable water for non-potable uses, such as landscaping or construction [6]. It created strong incentives for on-site reuse, as this became the only legal way to dispose of treated wastewater. This was followed by an explicit mandate in 2016 to reuse treated wastewater in all larger residential, commercial and educational buildings, as well as in construction projects [7], and to retrofit existing buildings over a certain size with an SSTP.

To date, the regulatory framework specifies: 1) when an SSTP should be installed in new and existing buildings, 2) quality standards of the treated wastewater, 3) that no treated wastewater can be discharged in storm drains and local water bodies, and 4) that treated wastewater should be used for non-potable purposes i.e. toilet flushing, gardening, car washing and construction. It also specifies a permitting pathway for ONWS managed by the KSPCB. In addition, state authorities have mandated the installation of sensors to measure the quality of the treatment process. This complements the manual sampling and monitoring procedures currently in place; the owners of plants (e.g. RWAs) are supposed to take grab samples of the effluent and send them to third-party labs. However, this is often not done [3], and it remains to be seen if such sensors will actually be installed.

Beyond these rather general mandates, the regulatory framework does not specify in much detail how to fulfil the water quality requirements. For example, there is no guidance on selecting approved technologies or defining actor responsibilities beyond those of RWAs and real estate developers. The design and implementation of reuse systems has largely been left to the private sector and residents; the regulators provide very limited guidance, oversight and/or enforcement. The regulatory environment, especially for water reuse, is characterised by widespread non-compliance and enforcement deficits.

Contractual & Financial Arrangements

Most SSTPs in Bengaluru are privately constructed, owned and operated with minimal public sector involvement. The SSTP and reuse mandates, thus, essentially shift the financial burden for sanitation from public service providers to residents. No financial support (e.g. tax reliefs or subsidies) is provided by the government to builders or residents. The building owners are responsible for the capital expenditures for the installation (CAPEX) and the costs of O&M (OPEX) of ONWS.

In the early phase after the 2004 mandate, homebuyers generally lacked awareness of the importance of well-designed SSTPs. Builders tried to minimise CAPEX, which led to low quality components being used and mediocre system designs. This increased the OPEX for the RWAs,

which usually have the responsibility for operating the plants. This tempted the RWAs to cut OPEX, e.g. by hiring low-cost (and low-quality) operator firms or turning aeration pumps off during the night, thus, risking the operational quality of the plants [8]. As a general rule, RWAs with a high water demand have more incentives to invest in proper O&M of their ONWS and proper tertiary treatment to fully reap the potential of reusing water instead of relying on tanker supplies.
There are only a few funding sources that s upport innovation activities among smaller local ONWS suppliers, hampering innovation in the sector. In recent years, firms experimenting with alternative treatment technologies have started to apply for funding from the start-up field, technology incubators and smart city funds. For example, a "property technology" incubator initiated by a major real estate developer funded innovation activities among SSTP start-ups. Some industrial actors have also started to direct funds earmarked for corporate social responsibility or carbon offsetting to investments in SSTPs. And because the business models of firms focusing on high-quality water reuse often include promises of rather quick returns on investments, this may give them access to the vast ecosystem of venture capital and private investors in Bengaluru and beyond in the future.

Industry and Market Structures

One key feature of the Bengaluru case is the speed at which the initial mandates led to the emergence of a mass-market for SSTPs. The exploding market induced an industry capable of designing and constructing a variety of systems. In many respects, market-driven implementation was, however, 'running ahead' of local capability formation, standardisation and market governance, thus, leading to quality issues along the value chain.

Acting upon the sudden demand for SSTPs coming from real estate developers, a wide range of predominantly local firms began providing services, such as consulting, design, technology delivery, and O&M. While some had solid expertise in large-scale treatment plants and SSTPs, many had been plumbing consultants or came from unrelated fields. Reportedly, market entry was easy and based on personal relationships and price-based competition, rather than on technologies or product quality. Over time, the challenges of this laissez-faire, market-driven approach became increasingly visible. A lack of standards, labels, certificates, etc., made it hard for buyers to make informed decisions about the quality of ONWS products and services. The 2016 mandate asking for zero liquid discharge proved a critical pivot point in increasing the awareness of O&M issues among home buyers and residents, as treated wastewater now had to be reused within their apartment complexes (for gardening) and inside their apartments (for toilet flushing). Firms, thus, started offering products and services that: 1) addressed malfunctioning SSTPs, 2) made the relationship between CAPEX and OPEX explicit, and 3) emphasized the benefits of substituting expensive tanker water with a more reliable (and cheaper) local water source.

Some market segments have, therefore, experienced a recent shift from price- to quality-based competition, incentivising innovation among technology- and service providers. Firms started to offer new business models, i.e. rehabilitating malfunctioning ONWS and operating them over a set period of time for a fee. Some of the most innovative business models are found among firms seeking to harness the potential value of treated wastewater. These companies offer 'turnkey' tertiary treatment modules as an add-on to existing SSTPs. They then sell the treated water back to on-site or off-site customers at a price lower than the average cost of tanker water, but high enough to achieve decent returns on investment. Firms with a 'platform' business model also started to match the supply of wastewater from the plants they operate with demand for treated wastewater in local industries, particularly the construction sector.

Knowledge, Skills & Capacities

The rapid growth of the ONWS market and the high number of newly implemented SSTPs also outpaced knowledge and capacity development. Consequently, the first decade after the 2004 mandate was characterised by learning-by-doing and catching up processes. These included efforts to develop the technical capabilities of local ONWS suppliers along the full value chain, particularly among real-estate developers and RWAs.

Today, 'best practice' ONWS examples are usually supplied by firms with strong technological capabilities gained through experience in the SSTP field. These are often based on the extensive

learning done by individuals at the RWA level who use the internet and exchange with people at other RWAs to learn about various ONWS technologies. However, the complexity and 'tacitness' of O&M has prevented the formalisation of knowledge and knowledge transfer from technology vendors to RWAs. Developing standardised manuals or instructions is challenging given the vast variation in SSTP designs and technologies.

Efforts are currently underway to more strategically build-up knowledge, skills and capacities around ONWS. At the public administrative level, the KSPCB began training SSTP operators in 2019 with the help of the Environment Management Policy & Research Institute. Engaged RWAs are using the Bangalore Apartment Federation (BAF) and local research institutes as platforms for knowledge exchange. For example, RWAs organise tours of best-practice apartment complexes through the BAF.

At the level of ONWS suppliers, the basic knowledge of treatment processes has increased in all but the lowest market segment. There are now a number of firms profiling themselves as aware of the problems in the ONWS field and as competent to solve them. There are also companies fostering innovation to minimise the O&M skills required for operators. This includes the introduction of standardised designs and modular plants. Recently, some operators have started to provide technology-specific training for their staff, established trainee systems and built up technological expertise by rotating personnel between different plants. The slowly increasing competence of certain operators has substantially reduced the pressure on RWAs to internalise the knowledge required to successfully operate their ONWS.

Recognition & Legitimacy

The legitimacy of ONWS has developed in several ways over the past decade. Real estate developers and RWAs initially did not support the mandates, as these burdened them with additional responsibilities, e.g. installing and managing wastewater treatment facilities. However, the determination of local governments to introduce the mandates meant that decentralised SSTPs quickly spread and became a taken-for-granted feature in mid- and upper-tier apartment complexes. High-profile pollution problems in the local lakes, the SSTP mandates' alignment with national policies, and the local framing of SSTPs as a solution to environmental problems supported legitimation processes. Only in 2016, when a revision required existing apartment buildings to be retrofitted with SSTPs and dual plumbing, did organised opposition pop up. Due to public protests, this mandate was relaxed in terms of the size of buildings included in the retrofitting requirement.

When the government's focus shifted from wastewater treatment to onsite wastewater reuse around 2016, additional legitimacy challenges emerged. In addition to the universal 'yuck factor' connected to recycled wastewater, many residents did not trust the treatment quality of their SSTPs due to recurring problems with the odour and colour of the treated water used for toilet flushing. Using treated wastewater, therefore, still has legitimacy and acceptability issues, even for basic reuse applications, such as gardening and toilet flushing [9]. Nevertheless, there has been no substantial pushback from the public when it comes to the reuse mandate. Similar to the SSTP mandate, water reuse is increasingly becoming taken-for-granted and even an aspirational solution for some RWAs that depend on unreliable and expensive tanker water supplies.

Important sources of legitimacy are water self-sufficiency and additional income streams. Reusing as much water on the premises and within the building (even up to potable uses in some visionary RWAs) can make buildings 'water independent'. Also, economic arguments are increasingly at play due to increasing tanker water supply costs from higher fuel costs, which increases the price of freshwater, particularly during droughts. Selling excess treated wastewater to local construction sites, laundries or parks (which have all become increasingly relevant) can provide additional income streams to cross-subsidise some of the OPEX.

Key Interventions & Lessons Learnt

Despite the prevailing challenges, the globally unique scale of diffusion and legitimacy of ONWS as an alternative to centralised water and sanitation systems qualifies Bengaluru as a lighthouse case. Four key features stand out as enablers of the diffusion and legitimation of ONWS achieved so far in this city.

First, the 'top-down', policy-induced and technology-neutral approach used by regional and local regulators has proven very effective in establishing a large market and supplier structure for ONWS and positioning it as a promising solution to the city's pressing sanitation and water scarcity problems. In contrast to other Indian cities, the national push for (onsite) water reuse has been transposed very consistently and consequentially into local mandates and regulations. This long-term policy programme has de facto established a new infrastructure paradigm in the city that is now legitimised beyond early adopters.

Second, the local mandates have induced a unique local entrepreneurial ecosystem around ONWS, with firms capable of designing and constructing a variety of systems. The average technological capabilities have increased substantially among SSTP providers and O&M firms since the first mandate two decades ago. This technological and industrial variety could be a powerful breeding ground for radical innovation. Innovative firms are increasingly experimenting with globally unique business models and advanced ONWS technology suitable for local contexts. Specifically, business models based on selling treated wastewater to off-site customers with specialised demands, such as laundries, parks or construction sites, have great potential. Emerging connections to the IT start-up and venture capital scene in Bengaluru, as well as the strong involvement of returnee entrepreneurs, could further leverage innovation activities in the field.

Third, Bengaluru's market-based (and laissez-faire) implementation logic has stimulated sophisticated demand-side dynamics and the emergence of innovative 'lead users'. RWAs with highly visionary and engaged board members, real estate developers with sustainability profiles, and industrial actors with high water needs, have especially taken on the role of lead-users. RWAs are demanding better ONWS technologies and 'turnkey' solutions, affordable and efficient O&M services, and business models around water reuse that create economic benefits. This emerging demand has already started to trigger powerful innovation dynamics in the field of on-site and off-site water reuse. Examples include 'rehabilitate-operate-sell' business models that sell treated wastewater in booming off-site markets (construction, public parks or laundries). Another example are RWAs that opt for achieving (almost) potable water quality in their ONWS systems.

Finally, despite some contestation over the years it is striking how end-users and other key stakeholders increasingly take ONWS for granted. Albeit often considered a nuisance among RWAs, most accept the current provisions and many do their best to try to exploit the potential of wastewater reuse and fulfil the mandates. Also, at the government level, ONWS are increasingly discussed as a potential solution to local water problems, despite the centralising of infrastructure that results.

Despite the (still fragile) successes outlined above, many challenges remain in Bengaluru. Its transition to ONWS cannot yet be declared a template for other cities. The public authorities grossly underestimated the need to provide measures accompanying the mandates. These include the lack of (adjusted) governance structures and complementary regulations, standards and labels, as well as market governance mechanisms that ensure accountability along the service chain. The regulatory environment, especially for water reuse, is still patchy and many ONWS do not yet meet required effluent standards. Finally, concerns about the health and safety of low-paid workers operating SSTPs or handling treated wastewater, such as gardeners and construction workers, have also been raised by advocacy groups and experts.

About the Lighthouse Project

Resource-oriented decentralised urban water management systems improve the flexibility, resilience and sustainability of water and sanitation infrastructure and are, thus, key in sustainability transitions. The Lighthouse Project assesses some of the most prominent examples.

Why? – Project Goals

Resource-oriented onsite/decentralised urban water management systems (ODUWMS) will play a key role in enabling sustainability transitions in the water and sanitation sector. ODUWMS close loops, recover valuable resources, produce marketable products, reduce the energy and water demand and can quickly be adapted to changing conditions. Despite increasing evidence of their potential benefits in improving the flexibility, resilience and sustainability of water and sanitation infrastructure, only a few

cities worldwide have successfully implemented "lighthouse initiatives" (LHs) at scale. Systematic evidence of critical success factors and how to best implement LHs in cities in developed and emerging economies are lacking.

The Lighthouse Project conceptualised what are LHs and selected representative projects to analyse. The objectives were: 1), to identify the distinctive characteristics of LHs, 2) to identify cities and neighbourhoods that have established LHs and assess technological and institutional best practices, and 3) to synthesise the results and produce templates for the diffusion of ODUWMS in cities in developed and emerging contexts.

What? – Lighthouse Initiatives Key Characteristics

Comprehensive arrangement: Integrating new technologies into a matching socio-economic and institutional context
Long-term perspective (project length and available funding): Stable incentives that enable 'adaptive learning'
Broad-scale adoption: Fully developed value chain at neighbourhood/city district level comparable to centralised approach
Visibility and impact beyond immediate context: Examples that can inspire/guide initiatives to replicate core features

How? – Research Logic & Methods

We adopted a cross-comparative case study approach that synthesized results from prior Eawag projects (4S and BARRIERS) and amended them with additional secondary data and targeted expert interviews. In doing so, we generated practice-oriented lessons on how to best implement LHs and derived new theoretical knowledge on the generic conditions of their success to highlight sustainability transitions within the urban water and sanitation sector.

Now? – Recommendations

Establish a long-term technology-neutral policy framework.
A long-term policy programme is crucial to the establishment of new infrastructure paradigms and legitimising them beyond early adopters. Technology neutrality in policies and mandates can be key for triggering market dynamics and experimentation among technology vendors, suppliers and service providers.

Specify clear standards and guidelines.
It is important not to underestimate the need to provide measures that accompanying mandates to ensure accountability along the service chain. For example, it is necessary to develop governance structures, complementary regulations, standards, labels, professional categories, quality certification schemes, and guidelines for both supply- and demand-side actors. These also include clear permitting pathways and monitoring mechanisms, enforcement and relevant sanctions.

Foster industry dynamics and diversity.
Technological and industrial variety can be a breeding ground for radical innovation and experimentation in the field of advanced ONWS. Systemic interaction between entrepreneurial actors, for example, through platforms, start-up incubators and competitions, can strengthen the local entrepreneurial ecosystem. Fostering connections to other sectors, such as IT and the venture capital industry, can further leverage the benefits of a diverse supplier structure for ONWS.

Incentivise involvement of end-users.
Innovative 'lead users' are crucial in shaping innovation processes. The involvement of end-users can foster sophisticated demand-side dynamics that target the challenges inherent to a market-based implementation logic. Incentivising user involvement is a key aspect of innovation system building. End-users' demand for better ONWS technologies, turnkey solutions, affordable and efficient operation and maintenance services, and business models for water reuse can facilitate and steer activities away from rent-seeking towards innovation and transformative change.

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