

“Tre-Rör-Ut”

in Helsingborg, Sweden

The H+ area in Helsingborg, Sweden, is a sustainable city development project, served by “Tre-Rör-Ut” (Three-Pipes-Out), a world-unique source-separation and resource-recovery system for water, wastewater and food waste.

Operational since February 2020, “Tre-Rör-Ut” currently serves ca. 900 people (ultimately 2'500), 340 apartments, and 32'000 m² of office space.

Collection & Transport

Three separate pipes collect and transport blackwater (toilet), greywater (bath/shower, laundry, kitchen) and food waste (food waste grinder) to the treatment plant “RecoLab”. Vacuum pipes are used for blackwater and food waste, gravity flow for greywater.

Treatment

Blackwater and food waste are digested in separate reactors, which separate the liquid effluent and biogas.

Biogas is upgraded to vehicle fuel. Sludge from both reactors is dewatered and returned to farmland. The liquid effluents are combined to recover struvite (a phosphate fertiliser) and ammonium sulphate (a nitrogen fertiliser) via struvite precipitation and ammonium stripping. These are mixed with potassium chloride and dewatered sludge to produce NPK fertiliser pellets. Options for greywater reuse are currently being explored.

Products

Recovery of biogas for vehicle fuel, nutrients for fertiliser production, concentrated sludge for agricultural application, and greywater for potential water reuse.

Benefits

Using low-flush toilets, sorting blackwater and food waste at source and using vacuum pipes increases biogas production and allows for nutrients' recycling. Greywater separation enables water reuse and efficient removal of micropollutants.

Introduction

Since 2006, the city of Helsingborg (Sweden) has developed 100 hectares of land into a modern urban area. First in the staged process of the H+ project is the Oceanhamnen district, comprising 340 apartments and 32'000m² of office space. Work on the H+ Master Plan started in 2007, accompanied by the vision-shaping 'Imagine Helsingborg' competition in 2008/09. At the same time, in 2009, the city adopted a new Energy Strategy [10] that outlined Helsingborg's ambition to use 100% renewable energy by 2035, emphasising its strategic prioritisation within municipal planning activities. In this spirit, the 'Imagine Helsingborg' competition report presented the area's lighthouse character: "[...] to serve as a role model for the concept of 'the sustainable city' [...] [6]." The competition-winning proposal 'The Tolerant City' conceptualised how to achieve CO₂-neutrality via a circular resource-recovery (and source-separation) approach [6]. Against this background, the strategic guiding document 'Environmental Profile H+' from 2010 defined the high environmental goals for the H+ area [7, 10-12]. Among others, it envisaged a CO₂-neutral area served by innovative recycling technologies [7].

In 2011, the H+ management started the 'EVAA'-project (Energi-Vatten-Avlopp-Avfall, Swedish for Energy-Water-Wastewater-Waste) to maximise sustainable synergies between the energy, water, wastewater and waste sectors [15]. A mixed group with representatives from the city and the three utilities for water & wastewater (NSVA), waste (NSR) and energy (Öresundskraft) led the work. In its first stage during 2011, EVAA generated a common objective, located potential synergies and created strategic guidance on how to contribute to the city's overall sustainability objectives [32]. In the second stage from 2012 to 2013, EVAA investigated a palette of technical options for an integrated energy, water, wastewater and solid waste system [20]. These established the conditions to start detailed planning of an integrated system and, in about two years, EVAA grew from a loose concept into a thriving entity. Initially, given Helsingborg's ambition to be energy neutral by 2035, the H+ project was energy focused and it was planned that it could provide an energy surplus by using

innovative recycling infrastructure. The target was a so-called plus-energy area, which is where the '+' in 'H+' originates. However, given the technical options available, the respective energy sub-study concluded that the resources in the area would not be sufficient to reach the envisaged target – even in the most extreme efficiency scenarios [16]. With this finding, the energy component within the overall H+ infrastructure strategy moved into the background and the energy utility Öresundskraft became increasingly less involved in the project. The city commissioned NSVA and NSR, the water, wastewater and waste utilities, to lead the planning and implementation of the innovative decentralised urban water treatment and reuse system (DUWTRS) [15]. In 2014, the most suitable system options were identified through a Multi Criteria Decision Analysis [5]. These were further analysed on and in 2015, via the 'Blackwater & Food Waste Challenge', with the participation of technology expert teams from around the world, the final system set-up was defined.

Today, three pipes separately collect and transport three waste streams to a local treatment plant 'RecoLab': one for blackwater (wastewater from toilets), one for greywater (domestic wastewater without faecal contamination) and one for food waste (via a waste grinder). The goal is to digest blackwater for biogas production, treat greywater for water reuse, and produce fertiliser. Construction started on the 'Tre-Rör-Ut' (Three-Pipes-Out) system in 2017 and the first residents moved in during 2020. On 16 June 2021, RecoLab officially opened [4]. To date, the vacuum and the greywater treatment systems are in full operation. Calibration and fine-tuning of the biogas and nutrient recovery components are not yet finished. However, no major performance incidents or user acceptability issues have been reported.

The project has increasingly developed into an internationally recognised lighthouse initiative. It has won several national and international awards¹ and is attracting water experts and urban planners from around the world. Discussions are taking place whether to implement a similar concept in Östra Ramlösa. Given that this is a new development area located outside Helsingborg, it is potentially cheaper to implement a DUWTRS there than to construct a connection to the

1 'Sewage and Circularity' prize (2018), 'Sustainable Future' prize (2019), 'Smart City Implementation Award' (2020), 'Wastewater Project of the year' (2022) [24, 28].

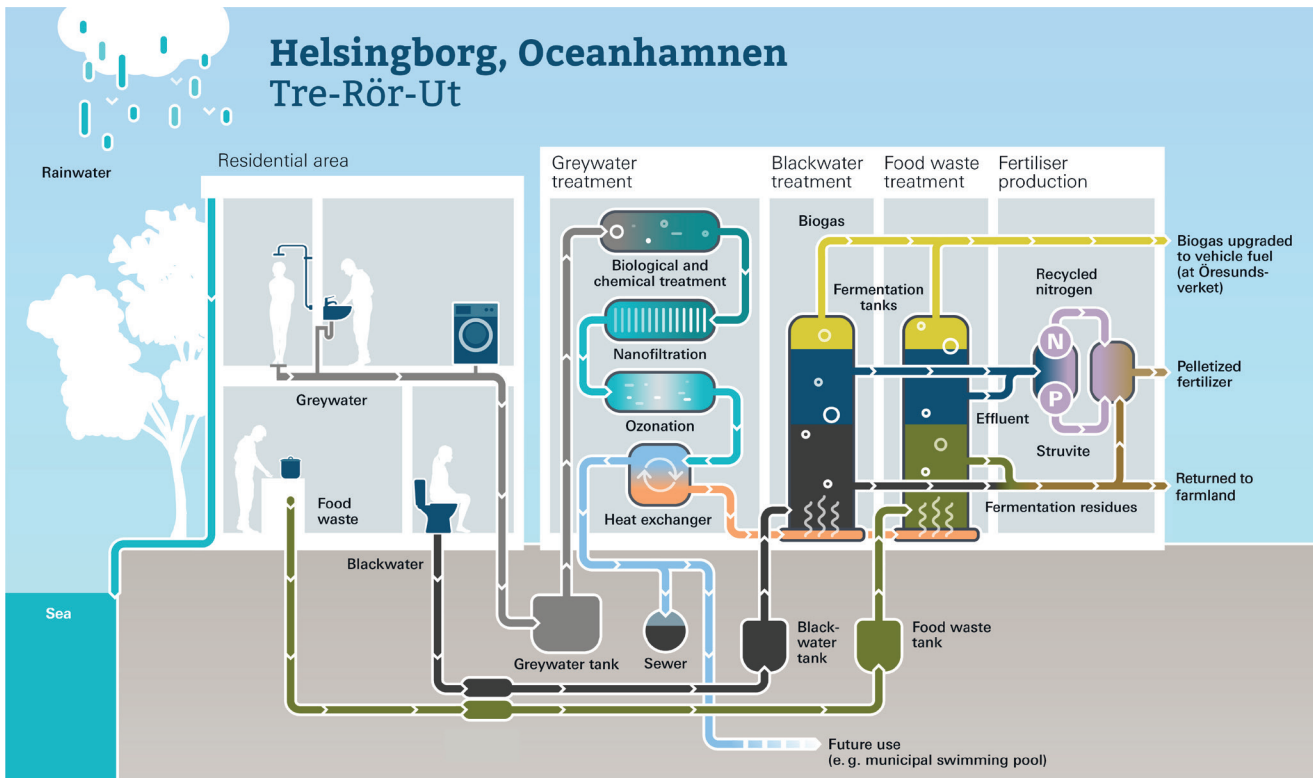


Figure 1: Schematic overview of the Tre-Rör-Ut System and RecoLab (Own illustration based on [23]).

centralised system. Similar projects in Sweden are already underway in Visby (without organic waste separation) and – potentially – in Stockholm (Stockholm Royal Seaport). In this brief, we examine the key drivers that have contributed to the successful implementation of Tre-Rör-Ut and the challenges. This report is structured around the five main 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 its success, and to identify recommendations for other cities that seek to adopt similar decentralised urban water solutions.

System-Set Up: Technology Description

Tre-Rör-Ut is a world-unique source-separation and resource-recovery system for water, wastewater and food waste [28]. Its main benefits entail energy recovery, increased nutrient recycling for agriculture, and reduced air pollution and nutrient discharges into the sea [15].

A vacuum-based sewer system transports the blackwater and food waste streams, while greywater is transported with conventional gravity-based technology. By sorting blackwater and food waste at source and using low-flush vacuum

toilets and pipes, the blackwater concentration and, thus, the potential for biogas and nutrient recovery increases. Greywater separation enables efficient removal of micropollutants and water reuse.

At RecoLab, the organic kitchen waste and concentrated blackwater are treated in separate Upflow Anaerobic Sludge Blanket (UASB) reactors for anaerobic digestion [29]. In the upper part of the UASB reactor, the liquid effluent and biogas are separated. The biogas is upgraded to vehicle gas (e.g. fuel for buses) in the city's centralised wastewater treatment plant (WWTP) [21]. The UASB effluent contains most of the nitrogen and phosphorous compounds that are essential fertiliser components. Thus, the effluent is suitable for nutrient recovery. Sludge from both digesters (food waste and blackwater) is dewatered and returned to farmland as fertilizer sludge [21]. The liquid effluents are combined to recover struvite (a phosphate fertiliser) and ammonium sulphate (a nitrogen fertiliser) via struvite precipitation and ammonium stripping [26, 27]. These are mixed in specific ratios with potassium chloride and dewatered sludge from both digesters to produce pelletised NPK fertilisers. This process is enabled by existing Swedish national fertiliser certifications for sludge-based 'products' and fits

in to the EU end-of-waste process.²

Greywater is treated with a biological process and passes through nanofiltration membranes to produce very high water quality. Because recirculation still faces legal barriers, the effluent is sent to the Helsingborg sewage treatment plant. Options for reuse are currently being explored, e.g. for the municipal indoor swimming pool. In addition, a heat exchanger retracts heat from greywater to heat the digestion chambers to 35°C [23].

Institutional Framework Conditions

Legal & Regulatory Conditions

In Sweden, the legal framework does not encourage, nor prohibit implementing DUWTRS. The municipalities, which are responsible for providing water supply, sewerage and wastewater treatment [25], basically have the freedom to decide on technologies. However, resource-oriented systems (at scale) lack explicit incentivising regulations. When compared internationally, Sweden's regulative framework for wastewater treatment and resource recovery can be considered progressive. At the end of the 1990s, Sweden developed 16 national environmental quality objectives [8], several of which were linked to (food) waste and wastewater systems [17]. The Swedish Environmental Code (MB), introduced in 1999, already included the objective to create closed loops [35]. In 2006, the Swedish Environmental Protection Agency (SEPA) published new advice on interpreting the MB and made nutrient recycling a priority for on-site sanitation systems [35]. In 2008, the SEPA pushed municipalities to find new solutions for resource-recovery from (small-scale) wastewater systems and urged them to develop a strategy for dealing with different wastewater fractions [15, 30, 31, 35].

At the local level, Helsingborg responded to this advice by establishing the 'Environmental Profile H+' [5, 7], which set ambitious environmental targets for the H+ area. Among others, it stated that "new technical solutions will be tested and introduced in the areas of energy, waste and water to maximise environmental benefits [...]" [7]. Transforming Helsingborg into a 'sustainable

city' that would be an example for other cities to follow was a key guiding principle. In general, the idea of being a 'sustainable city', particularly in regard to environmental issues, became increasingly pertinent within Helsingborg's vision. Already in 1983, the aim of the city's first environmental programme was to "strengthen the city's long-term environmental work and to work towards making Helsingborg an environmentally sustainable city" [8]. And since 2006, the city adopts a 'Sustainable Development Plan' every year [9]. The formulated sustainability targets and environmental programme led Helsingborg to adopt an Energy Strategy and an Energy Plan in 2009 and 2010, respectively [10]. The Energy Strategy stated that the city should be energy neutral by 2035. H+ would be the one of the areas that generated 'the energy surplus' to compensate for other city districts. In general, the entire H+ framing documents and follow-up activities manifest Helsingborg's ambitions to be at the forefront of innovation and to be an inspiring example. Thus, after completing EVAA in late 2012, it was the city itself that commissioned NSVA and NSR to drive the planning of the source-separating system [15].

Contractual & Financial Arrangements

NSVA is the municipally owned water utility of eight municipalities and the city has ownership and responsibility for it [15], while the waste management company NSR is owned by six northwest Skåne municipalities [15]. Delineating responsibilities between them for (waste)water and waste has been a challenge, particularly regarding legal aspects, such as connection points, areas of operation and costs/tariffs [15].

Concerning costs, within the public spaces owned by the city, not by private real estate developers (subsequently referred to as 'developers'), taxes covered the capital expenditures (CAPEX) for installations. The building owners are responsible for all costs incurred in the private areas. Because the municipality owns NSVA, it paid for (and owns) most of Tre-Rör-Ut's infrastructure, i.e. the vacuum sewer network and treatment plants. The costs for establishing the RecoLab were mostly covered by municipal funds available for upgrading the centralised WWTP. In addition, the team acquired national and international research funds, which were used to pay CAPEX,

² End-of-waste criteria specify when waste ceases to be "waste" and takes on the status of a product (or a secondary raw material).

but were not essential for the project's realisation. Concerning the total costs for 'Tre-Rör-Ut', no detailed numbers are available. However, two cost analyses were carried out in 2012 and 2017 [14, 15]. The 2017 study estimated that there would be a moderate cost increase of around 940 SEK (€ 90) per capita/year compared to a conventional centralised system (including total annual CAPEX and OPEX).

In terms of management, an operational project group with representatives from NSVA and NSR and an associated strategic steering group were established (including relevant city departments and utilities' CEOs) [15]. This organisational set-up was more or less copy-pasted from the EVAA project. It was agreed that RecoLab would be jointly operated by the City of Helsingborg, NSVA and NSR together with a number of partners. When the final system set-up was agreed upon in 2016, ownership and operational responsibilities were regulated in a new agreement [15] that established NSVA as the managing entity and is valid for five years. It also defined that the ownership of Tre-Rör-Ut remains with the City and NSR [15]. The operational responsibility for the three pipelines and the treatment plant lies with NSVA, which in turn invoices NSR and Öresundskraft for parts of the operational and maintenance costs [15]. The tariffs are set just as they are for city customers; there are no financial incentives [15].

Because the city owned the Oceanhamnen area, it was able to mandate all new developments to connect to Tre-Rör-Ut via contracts when selling the first plots in 2014.

Industry & Market Structures

According to the literature review and expert interviews, weak industry and market structures were key challenges to the project's realisation. There is no big pool of planners, technology suppliers and operators of source-separating and resource-recovery technologies to draw from. Tre-Rör-Ut was, thus, established with the expertise of small and medium enterprises distributed across (Northern) Europe.

On the supply side, the scale of the planned system and the fact that it is a residential project made finding adequate technical partners difficult. For example, most suppliers of vacuum-based technologies originate from the transport sector (airplane, train and ferry toilets). Residential areas have different requirements, for which adapted technologies need(ed) to be developed. This particularly concerned reducing the sound emissions from flushing vacuum toilets and developing novel maintenance options as the pipes are built into walls. The above-mentioned 'Blackwater & Food Waste Challenge' helped to identify business partners and technical suppliers.² Given the lack of a general contractor, different technical suppliers provided specialised technological components. The technical partner for the vacuum technology is Jets. RecoLab's treatment facility was designed by DeSah, which also installed the systems for heat recovery, blackwater and food waste, and greywater and sludge treatment [24]. At RecoLab, NSVA partnered and worked with technologies from EkoBalans Fenix AB (fertiliser), Landustrie BV and DeSah (grey- and blackwater, and food waste), as well as Jotem, Primozone and NX Filtration (greywater) [23, 24].

To date, business models exist only for Tre-Rör-Ut's biogas and fertiliser production³. Biogas is upgraded to biomethane at the centralised WWTP [21]. It is primarily used as vehicle fuel in Sweden as it is not taxed, whereas petrol is heavily taxed [18]. Since 2005, biomethane is being produced in increasing amounts and private companies have moved into this market. Several investment support programmes have developed to facilitate this [18]. For fertiliser, it works as follows: EkoBalans delivers the 'turnkey' fertiliser production plant. NSVA operates the plant and produces ammonium sulphate and struvite that is then sold to EkoBalans, which sells it to farmers / private customers. The product can be tailored to fit the needs of both domestic garden and agricultural applications. In addition, the recently introduced EU Fertiliser Regulation from 2019 (2019/1009) has opened new marketing opportunities [2]. It allows for CE marking of manure products and selling struvite

³ Initially, the Swedish national sludge certification system incentivised the production of fertiliser from sludge [5]. Sludge-based fertiliser certificates are available for biogas digestate (SPCR 120, launched in 1999), hygienised sludge from large-scale WWTP (SPCR 167, "REVAQ", established 2008) and from onsite/small-scale WWTP (SPCR 178, established 2012). Whether sludge is safe enough for agricultural application remains a controversial topic [1, 13].

(a phosphate fertiliser) across the EU since July 2022.

To date, the demand for the products generated at H+ remains limited. Both the fertilisers (at least before the current war in Ukraine) and treated greywater cannot compete with the low (and subsidised) prices of mineral fertiliser and drinking water. In addition, greywater reuse faces legislative barriers, although options for reuse are being explored – e.g. for the municipal indoor swimming pool.

Knowledge, Skills & Capacity

The knowledge on how to plan, build, connect, operate and maintain Tre-Rör-Ut and RecoLab was developed in a learning-by-doing way during the project. While the listed activities suggest strategic capacity development, at times they were developed in an ad-hoc manner.

Basic knowledge, skills and capacities were established from 2011 to 2016 through technical feasibility studies, an innovation competition (Blackwater & Foodwaste Challenge), and excursions (incl. developers) to similar projects in Europe. These were key in establishing technical know-how and trust among the utilities, the city (planners) and developers and moving the project from a conceptual to a detailed planning stage.

To enable knowledge transfer, the city and NSVA organised regular (voluntary) meetings for developers and builders, respectively, and brought in external experts to share experiences. Yet, the information did not trickle down to those responsible for construction. Therefore, together with the developers, design guidelines that included norms and standard procedures were established [3]. Also, the Tre-Rör-Ut team regularly reviewed the detailed installation plans. Moreover, together with Jets, they offered trainings for maintenance companies; these also served as a key feedback mechanism for the identification of technical issues.

When the residents moved-in, they received an information brochure on how to operate the kitchen grinder and vacuum toilets (see below) [22]. Since then, to consolidate and expand understanding of operational issues, the Tre-Rör-Ut project team regularly organises bi-monthly meetings. To improve technical understanding of the vacuum system (e.g. pipe incrustations), NSVA

began a monitoring project together with Jets in summer 2022. In addition, NSVA participated in national exchanges on circular systems, co-published a Swedish guidebook for planning source-separating UWM systems in urban areas [19] and provided inputs to installation guidelines on vacuum installations in buildings [3, 34]. Given its importance, the project team intends to keep these training and information campaigns running in upcoming H+ development stages.

Recognition & Legitimacy

Resource-recovery and source-separating sanitation systems have received increased recognition by national policy makers in Sweden. However, many of the implemented small-scale systems generated mixed results on user-acceptability [35]. In view of this and to develop a user-friendly system for H+, in 2014, a transdisciplinary workshop was organised by NSVA and NSR [5]. In the workshop, participants identified the main requirements, success factors and pitfalls of source-separating systems. The results helped the stakeholders to identify issues and to address them.

In parallel, during the conceptualisation and planning stages, the project team organised several excursions to similar projects in Germany (Jenfelder Au) and the Netherlands (Sneek). These had a vital trust- and team-building effect and created a shared understanding and vision among project team members, utilities, and developers. Interviewees reported that the hands-on experience of flushing a vacuum toilet and the opportunity to exchange with actual users was invaluable to establish trust in the envisioned technical solutions.

To foster awareness and acceptability among end users, the project team organised meetings for future residents and distributed information sheets. After moving-in, unexpected user behaviour by the residents caused technical malfunctions (clogging). Apart from an information brochure [22], there was only one person responsible to instruct new residents on how (not) to use the vacuum toilets and kitchen grinders. This proved insufficient and required additional investments in active user support. Nonetheless, no major acceptability issues among end users were reported.

Key Interventions & Lessons Learnt

Although specific technical components still need adaptation, the absence of major incidents and successful operation qualifies Tre-Rör-Ut and RecoLab as a lighthouse case for neighbourhood-scale DUWTRS. The interplay of several favourable conditions and constructive interventions were key for turning the project into today's success story. Five key coordination mechanisms stand out.

First, consistent political support and the buy-in and strong lead of local utilities were key for realising Tre-Rör-Ut. Helsingborg's established a long-term vision that included concrete and ambitious targets to be a spearheading, innovative city. Its goal was to be energy neutral by 2035, and the project's energy efficiency and environmental co-benefits, helped to convince decision-makers to choose this environmentally friendly option rather than the cheapest / conventional one. Furthermore, it resonated with SEPA's national call for municipalities to find innovative wastewater solutions that enable nutrient recycling in agriculture [5, 15, 31]. A supporting factor was that the site was a largely undeveloped former harbour area. Residential infrastructure was planned for this area already. The city as the land owner could mandate Tre-Rör-Ut to all developers and future owners. Individuals in key positions were present and exercised strong leadership across all project phases, which guaranteed continuity. These included in particular the mayor of Helsingborg, the H+ project manager, as well as the CEO's of NSVA and NSR. Their positive attitudes, openness to experimentation and change and personal commitment resulted in a high degree of project-identification among the involved stakeholders.

A second key success factor was the strong vision developed in Helsingborg. This pushed the three utilities and the public and private actors to define a holistic sustainability solution that strongly deviated from the status quo. The project team strategically addressed planners, developers, builders, residents and farmers when developing the project and made them engage in networking and joint problem solving activities. Technical feasibility studies, excursions to similar projects in other European countries and an innovation competition played a key role in enabling this alignment. These generated a shared understanding among the city (planners), the utilities and developers, played a key role in

establishing trust and technical know-how and made different actors increasingly converge around a shared vision.

Third, and closely related, a collaborative and cooperative culture among utilities, city leaders and the private sector emerged. The city hired a dedicated H+ project manager and requested that the utilities and the administrative city departments provide human resources and support. This was key for project coordination and enabled meaningful interdepartmental and transdisciplinary exchanges.

Fourth, continuous and structured outreach to the system's users was critically important. The user-friendliness and demonstrations of Tre-Rör-Ut's sustainability and socio-economic benefits were emphasised early and continuously [5, 33]. RecoLab also worked to legitimise the project by developing a test facility for research and development, a visitor centre and meeting areas. In effect, there was never any opposition during planning and implementation.

Fifth and finally, knowledge transfer between the project management, technology suppliers and builders was strategically fostered during the construction stage. This included meetings with developers and builders, and with external technical experts, making participatorily developed technical guidelines, offering assistance in reviewing the detailed construction plans, as well as trainings with Jets for construction and maintenance companies. Users received instructions on how (not) to use the vacuum toilets and kitchen grinders. Taken together, these interventions were of key importance to make the final system work and created a common technical and applied understanding among all involved parties.

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 (DUWTRS) will play a key role in enabling sustainability transitions in the water and sanitation sector. DUWTRS 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 DUWTRS 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 synthesised 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

Long-term vision and strategy.

National/local sustainability goals and binding targets fostered an environmental profiling and set generic framework conditions. Having few, realistic and generic, i.e. unspecific targets to be concretised at later stages can foster a common vision and create a shared understanding.

Political and utility support/lead.

Political support and the participation (or even lead) of the utilities are key to securing the resources required and for long-term management. An arc of tension from planning to implementation must be maintained. Key positions should not undergo personnel changes.

Adequate project management.

Installing dedicated ‘operational’ project management, complemented with a ‘strategic’ steering group, including key individuals (e.g. mayor, utility CEOs, and relevant city departments). Having influential people’s continued support helps to create a shared understanding, locate potential synergies and develop strategic guidance. Commission public planning departments (and utilities) to provide human resources (e.g. working hours) to support collaboration among waste, water and energy and the public and private sectors.

Accompanying realisation management.

User-acceptability is key to success. Residents received an information brochure, which is not enough. An easily reachable ‘caretaker on site’ is key to user support, especially during system start-up. Establish scheduled feedback mechanism(s) to evaluate(s) user’s perspectives to understand and adapt to their needs.

Provide accessible and understandable information.

Good documentation is essential to prevent knowledge drain once key persons retire or quit. Guiding documents must be known, accessible and comprehensible for specific target audiences. Otherwise, the knowledge

acquired remains untapped. A dissemination strategy is necessary. Establish a (inter-)national network of practitioners. The respective national associations could serve as promoters and as a platform.

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