CHALMERS
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Sustainable Solutions for Reduced Water Use in Solna Stad

A multi-dimensional assessment of water-saving technologies in multi-family buildings

Master's thesis in the Master's Programme Industrial Ecology

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ABSTRACT

Reducing potable water demand in multi-family buildings is an increasingly relevant measure for municipalities facing growing demand and capacity limitations in water supply infrastructure. This study assessed building-level water-saving technologies in Solna, Sweden, with focus on municipally owned multi-family housing and the municipality's ability to support implementation. Water-efficient technology, rainwater harvesting systems (RHS), and graywater recycling systems (GWRS) were evaluated across retrofit, planned renovation and new construction scenarios. A reference building representing the local municipal housing stock was used to quantify water savings, energy savings, climate impact and life cycle cost. The assessment used a mixed-methods approach including literature review, semi-structured interviews, quantitative calculations, life cycle assessment (LCA), life cycle cost assessment (LCCA) and multi-criteria decision analysis (MCDA). The criteria weights used in the MCDA should be interpreted as illustrative for decision-support rather than a robust stakeholder consensus. Water-efficient technologies were estimated to provide the highest potential water and energy savings and the lowest costs and climate impacts across all scenarios. The GWRS showed potential for substantial water and energy savings when combined with heat recovery, but was found to mainly be suitable for new construction or major renovations due to higher cost and technical complexity associated with retrofitting. The RHS showed limited water-saving potential in the selected reference building configuration, but may be relevant in other building configurations or where it can also support stormwater management. The municipal assessment showed that Solna has limited authority to require specific building-level technologies but can indirectly support implementation through stormwater-related requirements, land allocation processes, guidance, knowledge sharing and collaborative pilot projects. The study concludes that potable water demand in Solna can be reduced using water-saving technology, but that implementation likely needs to follow a gradual pathway combining short-term fixture replacement with long-term knowledge-building around more complex reuse systems.

Key words: Water-efficient technology, rainwater harvesting, graywater recycling, Multi-family housing, LCA, MCDA, Solna

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Preface

The table below summarises the author contributions to this report. The initials M. E. and B. T. refer to the two project authors.

(X) = Major contribution, (O) = Minor contribution, (-) = No contribution		
Chapter	**M.E.**	**B.T.**
Abstract	-	X
Introduction	X	X
Background	X	X
Methodology	X	O
Results	X	X
Discussion	X	X
Conclusion	O	X
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List of Acronyms

BBR	Boverket's Building Regulations
CAPEX	Capital Expenditure
EoL	End-Of-Life
EPD	Environmental Product Declaration
FU	Functional Unit
GFA	Gross Floor Area
GLA	Gross Living Area
GWP	Global Warming Potential
GWRS	Graywater Recycling System
WWTP	Wastewater Treatment Plant
W&WW	Water and Wastewater
LAV	Public Water Services Act
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
MB	The Swedish Environmental Code
MBR	Membrane Bioreactor
MCDA	Multi-Criteria Analysis
OPEX	Operational Expenditure
O&M	Operation and Maintenance
PBL	Planning and Building Act
PBP	Payback Period
RHS	Rainwater Harvesting System

1 Introduction

Water is essential for human existence. Although 70 percent of the Earth's surface is covered by it, only about three percent is freshwater, of which only a small fraction is readily accessible for human use. Growing water demand from population growth, agriculture and industry, combined with the increasing impacts of climate change, is placing greater pressure on global water resources. This highlights the urgent need for sustainable water management through both international cooperation and local actions that reduce consumption and improve efficiency.

Sweden is generally considered to have good freshwater access in a global context, and the country has so far experienced limited direct impacts of water scarcity compared to many other regions [1], [2]. Other aspects, however, such as infrastructure limitations and increasing water demand, still emphasize the need for sustainable water management. Additionally, recent periods of drought and increasing seasonal variation in water availability have highlighted the vulnerability of local water supply systems and the importance of proactive water management strategies [3], [4].

To better understand these challenges and how to address them on a local scale, this study focuses on the municipality of Solna, in Stockholm, Sweden. Despite access to a relatively stable raw water source in Lake Mälaren, the municipality faces capacity limitations and increasing water demand. As recently as 2025, the region's vulnerability to climate change was also evident when water scarcity was reported in Stockholm and surrounding municipalities due to high water temperatures in Mälaren [5]. To meet increasing demand and improve climate resilience, the area serves as a relevant case for studying strategies for sustainable water use reduction.

1.1 Aim and objectives

The aim of this report is to evaluate strategies for reducing potable water demand in residential multi-family buildings within the municipality of Solna. To achieve this, the study analyses technical building-level water-saving measures that can be implemented in residential multi-family buildings, with particular relevance for municipal housing companies. Possible municipal-level actions to support these measures are also identified. The feasibility of different solutions is evaluated for implementation in new developments, retrofitting in existing buildings, and implementation aligned with previously planned renovations to determine which strategy is most suitable under different conditions. The studied solutions are compared and prioritized based on several criteria, including cost, saving potential, and feasibility. Data for the analysis are collected through a literature review, interviews, and a partial life cycle assessment (LCA).

1.1.1 Research questions

To guide the literature study and project work, the report aims to answer the following questions along the way:

- Which water-saving technologies are most suitable for reducing potable water demand in multi-family buildings in Solna under the following implementation scenarios: in a new building, in an existing building, or during planned renovation?

  - What are the water-saving and energy-saving potentials, climate impacts, and costs of the different technical solutions?
  - How do implementation feasibility and sustainability performance differ between the different implementation scenarios?

- To what extent does the municipality have the authority to incentivize/support public housing companies to implement these solutions?
- What barriers and drivers affect the implementation of these solutions in multi-family buildings in Solna, both from a municipal and municipal housing company perspective?

1.2 Delimitations

The scope of this study is limited to technical solutions at building-level that can be governed or facilitated by the municipality. The study is specifically delimited to municipally owned multi-family housing within Solna municipality. Multi-family housing is selected for two main reasons. First, this housing type represents the majority of the building stock in Solna, and substantial new construction is expected in the coming years [6]. Second, the residential sector accounts for the largest share of total municipal water use [7], making it a relevant focus area for water-saving interventions.

The assessment will primarily focus on technical solutions at building-level. Behavioral water-saving measures are not explicitly assessed as standalone alternatives, as they are inherently different from technical solutions and therefore difficult to evaluate consistently within the same methodolgy framework. However, behavioral and social aspects are discussed in relation to the assessed technologies, particularly with respect to user acceptance and the potential role of information and incentive-based measures in supporting implementation. Centralized or district-level water systems will not be considered due to the significant infrastructural complexity involved in retrofitting such systems [8]. Such solutions are more relevant for new developments on previously undeveloped land, where required infrastructure and piping can be integrated from the outset. Furthermore, Solna is a densely populated municipality with limited available space [6], which further constrains the feasibility of large-scale centralized systems.

Because the purpose of this study is to support decision making rather than deliver a final implementation it will not include detailed engineering design or implementation planning of specific systems. While capacity needs and related space requirements are considered, the work does not provide detailed layouts, pipe routing, or exact placement of technologies within buildings. Such detailed design would require site-specific investigations and falls beyond the scope of this assessment.

2 Background

This chapter provides the theoretical background and context for the study. It first presents drinking water use patterns, the municipal water system in Solna, and characteristics of Solna's housing stock, as these factors influence future water demand and implementation opportunities. Building on this context, different strategies for reducing potable water use are introduced, followed by an overview of the water-saving technologies evaluated in this study.

2.1 Drinking water use in Sweden

According to the Swedish Water and Wastewater Association, Svenskt Vatten, the average daily drinking water use per person in Sweden is 140 liters [9]. This number aligns well with the locally reported number of 137 L per person and day in Solna [10]. As many of the standard values applied in the following sections are based on the national average of 140 L, it will hereafter be used to represent Solna as well.

The overall distribution of potable water use is illustrated in Figure 2.1, with the largest end use, approximately 43%, being "Personal hygiene". This category includes showers, handwashing, teeth brushing, and any other activities associated with hygiene. While some of these activities may to some extent be executed in the kitchen sink, this report attributes all hygiene-related water use exclusively to the shower and bathroom basin, as no detailed distribution is provided by Svenskt Vatten. Using standard values for average showering time and water use per minute shows that approximately 50 L can be attributed to showering, and the remaining 10 L is thus attributed to bathroom basin use.

For the remaining 57% of the daily drinking water use, the second-largest use category, "Toilet flushing", accounts for a little more than 21%. "Dishes" and "Laundry" each account for about 11%, and the categories "Consumption" and "Other" represent approximately 7% each.

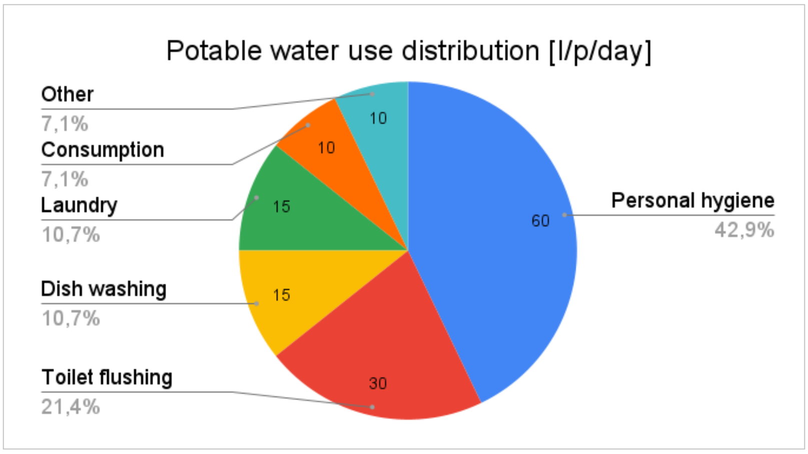


Figure 2.1: Potable water use distribution in Sweden, in liters per person per day, based on data from Svenskt Vatten [9].

Hot water

In 2012, the Swedish Energy Agency (Energimyndigheten) reported that approximately

40% of daily potable water use per person consists of hot water [11]. Similar figures (50-60 L) have also been reported more recently by energy companies in Sweden [12], [13]. The only use category that does not utilize any hot water is "Toilet flushing", as toilets in Sweden generally are only connected to the cold water line. The energy use associated with heating the incoming drinking water is reported by the Swedish Energy Agency to be approximately 55-60 kWh/m3, where the higher value applies to buildings with hot water circulation [11]. For a hot water use of 50-60 L, this corresponds to 2,75-3,6 kWh per person per day. According to Karlsson (as cited in Werecki, 2024 [14]), the energy consumption of heating water can account for up to 50% of the total energy consumption in modern multi-family buildings.

2.2 Drinking water in Solna

The municipality of Solna purchases its drinking water from the producer Norrvatten before distributing it within the municipality [15]. Norrvatten is a municipal association owned by Solna and 13 other municipalities north of Stockholm. The raw water used for the drinking water production originates from Sweden's third-largest lake, Mälaren, and is treated in Görvälnverket [16], [17]. Although Mälaren is currently not considered at risk of depletion, the capacity of the water treatment and distribution infrastructure is limited [18]. Critical periods occur during hot and dry summer days, particularly in May and June, when water consumption can increase by up to 35% for several weeks [19].

According to Norrvatten [17], despite population growth, the potable water use followed a declining trend until 2014, thanks to the development and implementation of water-efficient technologies. Since 2014, however, the water use in the area has started increasing again. Norrvatten predicts that this trend will continue and is therefore planning on expanding its treatment capacity in the future. This is a significant undertaking that will take many years to complete. In 2024, Norrvatten produced approximately 52 million m^3 of potable water [20], with an energy use of 511 Wh/m^3.

Following production, the drinking water is delivered to the water distribution network owned and managed by the municipal subsidiary Solna Vatten AB [15], [21]. Approximately 6 million m^3 of drinking water was distributed by Solna Vatten AB in 2024, with an energy use of 0.415 Wh/m^3 (Solna Vatten AB, personal communication, February 11, 2026). In addition to supplying the city with drinking water and managing the water and wastewater (W&WW) network, Solna Vatten is also responsible for conveying municipal wastewater to the treatment plant, Käppalaverket. This is facilitated by an almost 100 km long wastewater network equipped with 21 pump stations (Solna Vatten AB, personal communication, February 11, 2026). The wastewater transportation is associated with an energy intensity of 52.15 Wh/m^3. Although not specified by Solna Vatten, the higher energy use per m^3 compared to drinking water distribution likely stems from higher levels of solids, meaning higher friction and a higher need for pumping.

Käppalaverket, which is also a municipal association, treats wastewater from Solna and 10 other member municipalities [22]. In 2024, the wastewater treatment plant (WWTP) reported treating 59.3 million m^3 of water in total [23]. Through anaerobic digestion of sewage sludge, the WWTP produces biogas, making it both a consumer and producer of energy. Between 2020 and 2024, the plant achieved an averge annual energy surplus of 59.76 Wh/m3 treated water [23], [24], [25], [26], [27]. In addition to wastewater, the volume of treated water also consists of inflow and infiltration water. This extra water enters the wastewater system through direct connections (inflow) or through leaks and defects in pipes and joints (infiltration). According to Käppalaverket [28], water from inflow and infiltration represents almost 40% of the water treated by the plant. Figure 2.2 summarizes the municipal water system, from production to wastewater, including the relevant actors for this study.

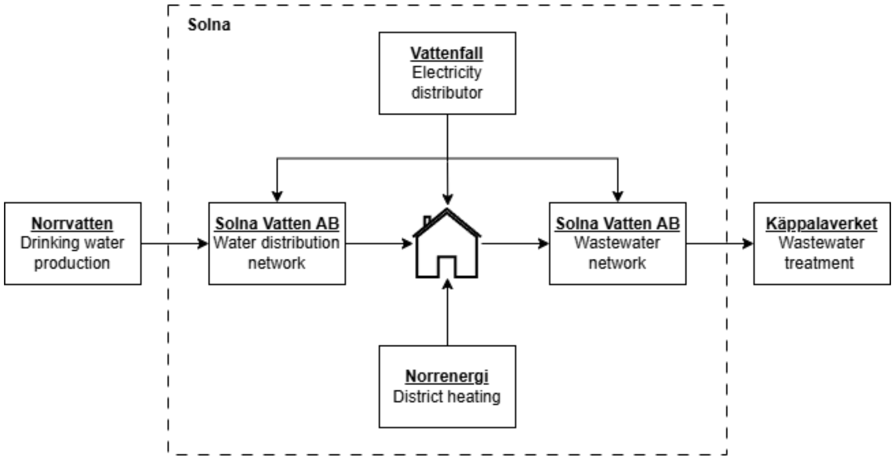
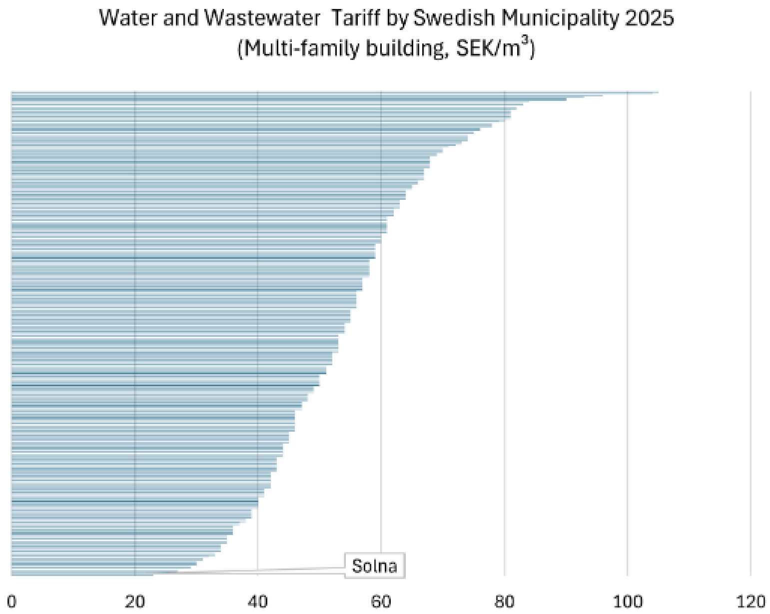


Figure 2.2: Schematic illustration of the municipal water and energy system, showing the flow of water from production and distribution to households, and further to wastewater collection and treatment. The system boundary also includes key energy actors: Vattenfall, which supplies electricity in the Solna region, and Norrenergi, which provides district heating for domestic hot water production [29].

For the aforementioned W&WW services, Solna Vatten charges an annual W&WW tariff consisting of fixed and variable fees. While the fixed fee covers stormwater management, the variable fee is based on the volume of delivered water and covers drinking water supply, W&WW distribution, and wastewater treatment [30]. Historically, Solna has had relatively low W&WW tariffs compared to other Swedish municipalities, partly due to its compact size and the relatively short pipeline network per capita [6]. In 2023, the tariff was increased for the first time since 2009, rising from 12,7 SEK/m^3 to 14,6 SEK/m^3, reflecting growing costs for water and wastewater treatment [31] Since then, the W&WW tariff has continued to increase. Today, the variable W&WW tariff is 19.3 SEK/m^3 of delivered water, split equally between drinking water and wastewater services [30]. Nevertheless, Solna still has the lowest W&WW tariff in the Stockholm region and one of the lowest in Sweden [32]. This places Solna at the bottom end of a massive national divide. Svenskt Vatten reports a large variation in W&WW tariffs across Swedish municipalities, with a 457% difference between the lowest and highest tariffs [32], as illustrated in Figure 2.3.



Municipalities with highest tariff	SEK/m³
Trosa	105
Vaxholm	104
Nordanstig	96
Norrtälje	93
Tjörn	90

Municipalities with lowest tariff	SEK/m³
Västerås	29
Staffanstorp	27
Motala	27
Solna	27
Fagersta	23

Figure 2.3: Water and wastewater tariff by Swedish municipality. Data was retrieved from Svenskt Vatten's tax statistics for 2025 for a type B building, which corresponds to a multi-family building [32].

2.3 Multi-residential building stock and future development in Solna

Multi-family housing dominates the building stock in Solna, with single-family homes and row houses accounting for only 1% of the municipality's approximately 40,000 dwellings [33]. As one of Sweden's fastest-growing municipalities, Solna is expected to undergo substantial development in the coming years, particularly within the residential sector [6]. Around 800 new apartments are planned to be constructed annually, some of which will be public housing [33]. Currently, there are approximately 4000 municipally owned apartments in Solna. According to Signalisten, the public housing company in Solna, this number is expected to increase by around 2000 new apartments between 2024 and 2035. In addition, a large share of the existing housing stock was constructed during the 1960s and 1970s and will therefore require major renovations, including pipe replacements, during the same period [34].

Figure 2.4 below illustrates the share of Signalisten's building stock in the categories planned new construction, planned renovations, and existing buildings not scheduled for renovation between 2024 and 2035.

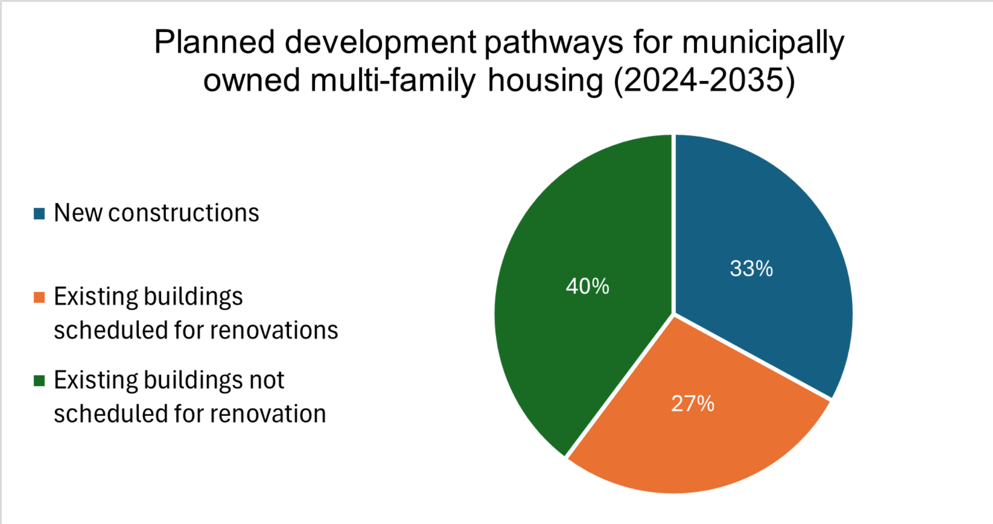


Figure 2.4: Signalisten's projected distribution of the building stock for the three categories considered in this study (new construction, renovations, and existing buildings not scheduled for renovation) between 2024 and 2035. Source: Data compiled from Signalisten's annual and sustainability report 2024 [34].

The future development of Signalisten's building stock involves more than just growth in numbers, it also represents an opportunity to improve the sustainability of the housing stock. This is reflected in Signalisten's sustainability goals for its renovation and new construction projects. The company is part of Allmännyttans klimatinitiativ (Public Housing Climate Initiative), which includes targets to reduce the climate impact and energy use of both renovations and new developments, with an overall goal of a 50% reduction in climate impact between 2025 and 2035 [35]. Furthermore, Signalisten aims to achieve the environmental building certification Miljöbyggnad Silver in new construction projects, which sets requirements related to energy performance, materials, and indoor environmental quality [34].

Overall, the development plans for Solna indicate a dynamic context in which decisions regarding implementation pathways for integrating water-saving technologies are equally relevant for new construction, renovation projects, and existing buildings without need for renovation.

2.4 Local water use reduction strategies

Potable water use at the local level can be reduced in several ways [36]. Many of the existing methods can be grouped into four main strategies: efficiency, reuse, harvesting, and behavioral/awareness measures.

Efficiency
The first strategy involves directly reducing water use through water-efficient technologies, such as faucet and shower aerators, dual-flushing toilets, or water-efficient dishwashers and washing machines. These technologies achieve water savings while often still maintaining usual function and user experience.

Reuse
The second strategy, reuse, refers to saving water by substituting potable water with

reused water from non-potable sources, such as treated graywater. This approach can therefore reduce, or even eliminate, the need for potable water permanently in some instances, once implemented [37]. However, these technical solutions typically require early-stage integration during building design and may be comparatively costly and challenging to retrofit into existing buildings. They may also alter the user experience in some aspects, such as visual aesthetics and perceived health risks, and can therefore face some implementation barriers.

Harvesting
The third strategy, similar to the second one, refers to replacing potable water with water from an alternative source, such as harvested rainwater, desalinated water, or water from another surface water source.

Behavior/awareness
The fourth and last strategy shifts focus from technological solutions to consumer behavior and awareness. The goal with this approach is to reduce water use by making the individual more aware of their water-using behavior. Although not inherently a technological strategy, it may be aided by simple technologies such as displays showing water use in real time. It can, however, also rely on information campaigns and simple analog signage in environments where potable water is used.

Despite the availability of these strategies, municipalities often lack well-defined foundations for assessing and prioritizing water-saving measures. Although some relevant research exists, comparable knowledge adapted to municipal contexts and practical use scenarios remains limited, which can contribute to uncertainty in decision-making.

2.5 Multi-dimensional evaluation of sustainable water-saving technologies

Sustainability is an interdisciplinary concept comprising environmental, economic, and social dimensions [38]. Previous studies highlight the importance of addressing trade-offs between these dimensions when evaluating sustainable water-saving measures.

Svenskt Vatten, in collaboration with stakeholders from municipalities, academia, and industry, has developed a decision-support tool called WISER (Water Investments for Sustainability Enhancement and Reliability), which allows for the evaluation and comparison of alternative measures to support a sustainable and resource-efficient water sector [38]. In this framework, a fourth dimension, technical sustainability, was introduced to capture technical considerations relevant to water supply systems, addressing aspects such as implementation feasibility, operational and maintenance requirements, and system reliability. In addition, permitting and legal compliance are identified as critical factors for practical implementation, and in some studies are treated as “knock-out criteria”, meaning that solutions that do not meet these requirements are excluded regardless of their performance in other dimensions [39].

Key indicators within the environmental dimension typically involve evaluating water-saving potential, energy use, and climate impact. For the latter two, Svenskt Vatten suggests a life cycle perspective for a more comprehensive evaluation [38]. Evaluating the potential trade-off between water savings and climate impact is important, as water-saving technologies tend to have high embodied carbon and may, in some cases, result in net carbon emissions [40]. This is particularly relevant for decentralized building-level solutions, where climate impacts become even more significant, as they are often higher than those of centralized systems due to scale effects [41]. Previous studies describe energy use, or potential energy savings, as closely related to water savings due to the strong energy-water nexus [42], [43]. Processes throughout the water cycle, including water production, heating of water and wastewater treatment, are energy-intensive processes. Consequently, reducing water use can also lead to significant energy savings and synergy effects.

The economic and social dimensions are important for the overall viability of water-saving measures. Economic aspects, such as investment costs, can act as direct barriers to implementation, as more expensive solutions may be less attractive or impossible to adopt without financial support [43]. This is closely related to the social dimension, which generally includes user perception and acceptance [43], [38]. The social dimension has been identified as a critical factor in water reuse and water-efficiency projects, where user perception and willingness to adopt such systems can strongly influence their success [44], [45].

The relative importance of different dimensions and performance indicators varies depending on context. For example, a study by Wallin shows that water savings may be prioritized lower than energy savings in water-abundant regions, whereas in water-scarce regions, water savings are given greater importance [44]. The same study also highlights that economic performance indicators can vary significantly depending on geographical context due to differences in water and energy tariffs.

2.6 Water saving technologies

This section provides a more detailed overview of the water-saving technologies considered in this study: water-efficient technologies, rainwater harvesting systems, and graywater recycling systems. The section describes their key characteristics and presents examples of technologies currently available on the Swedish market. The overview further serves as the basis for the initial screening and selection of the system alternatives evaluated in this study.

2.6.1 Water-efficient technologies

The overall pattern of water consumption results from the interaction between user behavior and the flow rate, or water efficiency, of installed equipment. Consequently, reducing water use directly at the source through technological advancements has been a primary strategy in water conservation efforts. This so-called micro-component approach focuses on individual household fixtures and appliances as key points of intervention for reducing water use [46].

In the context of residential water conservation, water-efficient technologies generally refer to plumbing fixtures and appliances designed to provide the same level of service as conventional alternatives while using less water and energy. The United Nations and World Bank High Level Panel on Water recognised the potential of these technologies and prompted for the development of an international water efficiency labelling standard [47]. In the proposal for this ISO standard, it was stated that "the replacement of inefficient taps, toilets, showerheads, washing machines, and dishwashers with more efficient models can have significant effects on water consumption in the home, reducing per capita consumption significantly" [47].

In Sweden, the replacement of inefficient plumbing fixtures and appliances has historically been proven effective. Water-efficient plumbing fixtures and appliances have gradually been adopted in Swedish households for decades, a development that Svenskt Vatten considers to have contributed to the steady decline in per capita residential water consumption since 1970 [7]. A case study of Gothenburg, further supports this, where improvements in fixture efficiency were identified as a significant factor behind the decline in household water use, from 178 litres per capita per day in 2006 to 132 litres per capita per day in 2023 [48].

The development and adoption of water-efficient technologies have been supported by increasing political recognition at both the Swedish and EU levels, although it until recently was stipulated mainly through energy regulations rather than on water flow. In 2010, a method for energy classification of sanitary tapware was introduced (SS 820000:2010 and SS 820001:2010) [49], which led to the A–G energy labelling scheme in 2012 [50]. More recently, EU Ecodesign requirements have contributed to raising minimum efficiency standards, including mandatory limits on water consumption for washing machines and dishwashers [51], as well as voluntary Ecolabel for water efficiency in tap fixtures [52].

In parallel, building certification systems such as BREEAM, LEED, Nordic Swan, and Miljöbyggnad have incorporated requirements related to water efficiency in tap fixtures and appliances, thereby creating incentives for housing companies to implement such technologies [53]. An overview of these certification systems and their associated water flow requirements for sanitary fixtures is presented in Table 2.1.

Table 2.1: Certification requirements for selected fixtures across different systems (maximum flow rates and energy classifications)

	Building certification for new construction & renovation		**Building certification for new construction**		**Product certification**
Fixture	**Miljöbyggnad[a] [54][55]**	**LEED [56]**	**Nordic Swan Ecolabel[b] [57]**	**BREEAM-SE (range of maximum requirements)[c] [58]**	**EU Ecolabel (min-max[d] flow) [52]**
Basin faucet	6 L/min	1.9 L/min	6 L/min (Class A)	4-8 L/min	2-6 L/min
Kitchen faucet	6 L/min	6.8 L/min	6 L/min (Class B)	5-7.5 L/min	2-6 L/min
Shower	8 L/min	7.6 L/min	8 L/min (Class B)	7-10 L/min	4.5-8 L/min
Toilet	Max 6 L full flush, avg. 3.5 L/flush	Max 4.8 L full flush	N/A	3-4.5 L effective flush volume[e]	N/A

[a] The following requirements apply to Miljöbyggnad Gold for new construction, and Miljöbyggnad Gold and Silver for major renovations.
[b] Energy classification according to SS 820000 or SS 820001.
[c] In this context, "range" refers to the maximum flow required to achieve the highest versus lowest certification performance level.
[d] Maximum values for faucets refer to maximum flow rates without flow-limiting devices (maximum 8 L/min with limiter)
[e] Effective flush volume for dual flush toilets is defined as the weighted average of full flush to reduced flush volumes, which for domestic buildings is calculated as one full flush for every two reduced flushes [59].

However, since these requirements remain largely voluntary, there is still no formal regulation or unified definition of water efficiency standards for fixtures and appliances in Sweden. Instead, mandatory requirements related to tap water flow are regulated within the PBL (Boverket's Building Regulations (BBR); BFS 2011:6) [60]. Section 6:623 states that water outlets must be designed to ensure adequate water flow to the tapping point with respect to function and acceptable waiting time for hot water. BBR's general recommendation is that, at a flow rate of 0.2 L/s, the maximum waiting time for hot tap water should not exceed 10 seconds. In addition, the dimensioning of the tap water system should be based on the design flow. This applies regardless of whether water-efficient fixtures and appliances are installed, as the system must be designed to accommodate the installation of conventional alternatives. The specified design flows are as follows:

> For dwellings, the requirement of the mandatory provision for water flow at the water outlet for both hot and cold water is met if the draw-off flow is 0.1 l/s for wash basin and bidet, 0.3 l/s for bath tubs and 0.2 l/s for other water outlets. For water outlets in dwellings with cold water only, the requirement of the mandatory provision is met if the draw-off flow is 0.1 l/s for toilet and wash basin and 0.2 l/s for other water outlets [60].

As these design flow requirements are intended to ensure functionality and user comfort, they effectively establish a baseline for system design, in contrast to the lower flow rates defined in building and product certification systems. In practice, this often leads developers and contractors to select products that meet these flow rates unless stricter water efficiency requirements are specified in the project specification [61].

Although a clear definition of "water-efficient" in terms of water use is absent in Sweden, the certification requirements presented in Table 2.1 can serve as a practical benchmark.

2.6.1.1 Water-efficient technologies on the Swedish market

There is a wide range of water-efficient technologies with various functions available on the Swedish market. In this section, a selection of these are presented, with the primary focus of this study being on plumbing fixtures.

When it comes to faucets, available water-efficient technologies include aerators, flow limiters, and adjustable flow control systems that allow users to regulate flow depending on the intended use [62], [36]. Aerators are among the most common solutions and function by mixing air into the water stream, thereby reducing flow without reducing the perceived pressure. These devices can reduce flow rates to approximately 5–8 L/min [36]. In comparison, conventional bathroom faucets typically have a flow rate of around 10 L/min, while kitchen faucets can reach up to 15 L/min [63]. Among adjustable flow control systems, features such as the Eco-stop function introduce a mechanical resistance in the lever, meaning that maximum flow is only achieved if the user actively pushes the lever past the resistance point [64]. Other systems use push-buttons to temporarily increase flow when needed [62].

Similar water-saving principles are also applied in showers and showerheads, where conventional fixtures have historically had flow rates of up to 18–20 L/min [65]. For example, technologies such as Hansgrohe's EcoSmart or EcoJoy, which combine flow limiters with aerators, can reduce shower flow rates to as low as 4 L/min [66]. Additional retrofit solutions are also available on the market, such as the Shower Ecobooster, a flow-regulating device installed between the shower hose and showerhead that restricts flow in its default position (approximately 5–8 L/min) while allowing temporary increases through a push-button function [67].

Aerators and flow limiters can either be integrated into faucets or installed afterwards as separate add-on nozzles. Examples include the IKEA ÅBÄCKEN, which offer dual flow modes (mist and spray), with the manufacturers claiming water savings of up to 95% and 66%, respectively [64]. Such products may represent attractive retrofit options, as they do not require replacement of the entire fixture and are associated with relatively low costs, typically on the order of a few hundred SEK [36]. However, experiences from a project at Uppsalahem in which such products were installed in a multi-family building indicate that water-efficient faucets are generally preferred over retrofit nozzles due to compatibility issues with existing fixtures and the associated risk of internal pressure build-up, which may lead to leakage [68].

When it comes to toilets, several water-efficient alternatives to the conventional single-flush toilet (6-9 L per flush [36], [69]) are available on the market, including dual-flush toilets, vacuum toilets, and urine-diverting toilets. Among these, the most mature and widely implemented technology in multi-family buildings is the dual-flush toilet, which typically uses approximately 2 L for a small flush and 4 L for a large flush [36]. Vacuum toilets can reduce water use further, typically requiring only 0.5–1 L per flush. However, compared with conventional gravity-based toilets, vacuum systems are associated with higher technical complexity and greater system sensitivity, as they require a vacuum unit, an airtight piping system, and a separate collection tank [70]. Consequently, vacuum toilets remain uncommon in multi-family buildings and are more frequently used in ships, trains, and airplanes [71]. One Swedish example is the district of Oceanhamnen, where vacuum toilets have been installed in residential buildings as part of a source-separating wastewater system [72]. The buildings and wastewater infrastructure were specifically designed and constructed for this type of system from the planning stage, making this a unique case. A more feasible solution for multi-family buildings may be urine-diverting toilets, which, similar to vacuum toilets, enable nutrient recovery but can also function as conventional toilets connected to the communal wastewater network. Consequently, they offer low water consumption (0.3 L for a small flush and 2.5 L for a large flush), while requiring less complex infrastructure than vacuum systems [73]. However, if nutrient recovery is implemented, urine must be separated at source, requiring a separate collection system and downstream handling [71], for example through collaboration with farmers for nutrient recycling. An example of such a system was previously implemented in the rental housing building EkoPorten, where the urine was separated and managed locally by farmers for use as fertilizer [74].

The water consumption of plumbing appliances, such as washing machines and dishwashers, depends largely on the selected program settings, with many modern appliances offering dedicated eco-programs. Nevertheless, water-efficient models can reduce water consumption by approximately 10–20% compared to less efficient ones [36]. In Signalisten's apartments, the installation of dishwashers and in-unit washing machines is decided by the residents themselves [75]. While Signalisten does manage the communal laundry facilities, water-efficient variations of dishwashers and washing machines are not addressed further in this study.

2.6.2 Rainwater harvesting systems

A rainwater harvesting system, also known as RWHS or RHS, captures and stores rainwater from roofs and other impervious surfaces for later use [76], [77]. Applications for the captured water often include non-potable uses, such as garden or landscape irrigation, toilet flushing, or laundry washing [78], [79]. By substituting potable water with collected rainwater for these applications, RHS can contribute to a reduction in overall drinking water demand. Although collected rainwater can also be used for potable applications, it requires more advanced systems with additional treatment steps to ensure sufficient water quality.

To better understand the performance and applicability of RHS, this section includes an overview of system components and configurations, and a selection of systems on the Swedish market is presented and compared.

2.6.2.1 RHS components and configurations

The main components of an RHS are the catchment area, the conveyance system, the storage tank, and the distribution system [77], [80], [78], [81]. However, both the number and classification of components vary between sources, and some systems may include additional elements depending on the intended end-use applications. In this section, the most common components and configurations are described, and trade-offs following different design choices are discussed.

Components
The most commonly identified components of an RHS are listed and described below.

- Catchment area - Typically a building roof, as roof runoff is often less contaminated than runoff from other surfaces. Roads and other impervious surfaces may also serve as catchment areas if additional treatment is applied.
- Conveyance system - Pipes and drains that transport rainwater from the catchment area to the storage tank.
- Pre-filtration elements - Components such as leaf guards and first-flush diverters that remove debris and redirect the initial, most contaminated runoff before it enters the storage tank.
- Storage tank - The most central component of the system, where the collected water is stored until use.
- Overflow - An outlet that allows excess water to leave the tank when its capacity is reached. The overflow is typically directed to an infiltration area or drainage system.
- Additional treatment – May include filtration or disinfection processes depending on the intended end use.
- Secondary tank (for treated water) – An additional tank/cistern used to store treated water before distribution.
- Mains water backup - A connection to the municipal water supply to supplement the storage tank with water when stored rainwater is insufficient. Backflow prevention is required.
- Distribution system - Pump(s) (located inside or outside the storage tank), pipes,

and other components used to deliver water to the end-use applications.

For an example of a typical RHS, see Figure 2.5.

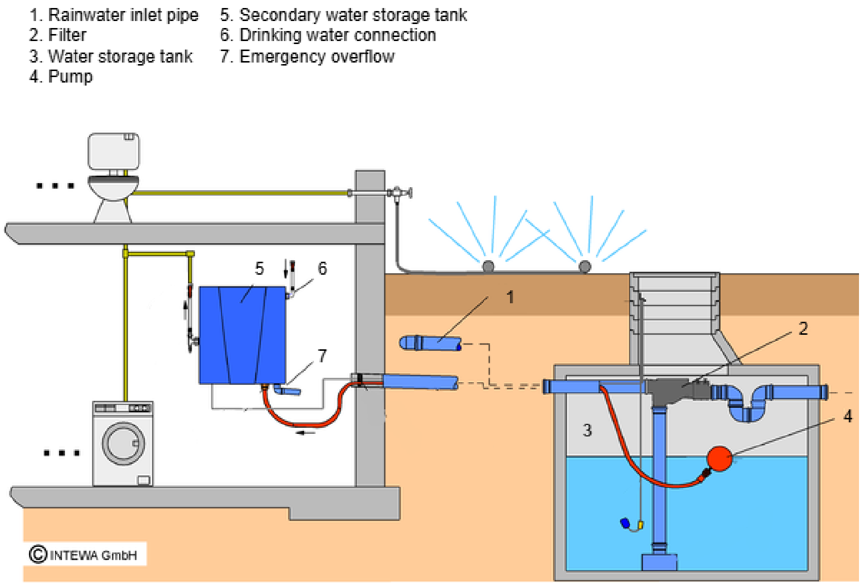


Figure 2.5: Illustration of an underground RHS. Adapted with permission from INTEWA [82].

Configuration

In addition to component selection, system configuration and method of water distribution are key aspects of RHS design. Depending on site conditions, the storage tank can be installed underground (buried), above ground (inside or outside the building), or in an elevated position. The choice of tank placement influences the distribution method. Common distribution methods include direct pumping from the storage tank to end-use applications, pumping from storage tank to an intermediate, elevated tank in the building, followed by gravity-driven distribution, and fully gravity-driven systems where water is collected and conveyed directly to an elevated tank before distribution, thereby eliminating the need for pumps.

These system configurations are described by Legett et al. (as cited in [77]), and also reflected in the Swedish Standard for rainwater harvesting systems [81]. The configurations differ not only in their physical arrangement but also in terms of energy use, system complexity, and spatial requirements. Fully gravity-driven systems, for example, can reduce energy-related environmental impacts by eliminating the need for pumping [40]. However, König (as cited in [77]) mainly recommends the fully gravity-driven configuration for industrial buildings due to the accompanying structural loads and leakage risks.

Trade-offs

The distinction between gravity-driven and pump-based systems represents one example of the trade-offs inherent in RHS design, arising from the range of available configuration options [77], [81]. Pump-based systems offer greater flexibility in system layout and are generally easier to integrate in a wide range of building types. However, they require energy for operation. Fully gravity-driven systems eliminate the need for operational energy input but instead require elevated tank placement, which can introduce structural constraints in the form of limited available space or load-bearing challenges, as well as an increased leakage risk.

Another prominent trade-off relates to tank placement underground versus above ground. Underground tanks are often better suited for projects with limited space, as they do not impose on usable building or outdoor space. However, they often involve higher installation costs due to the need for excavation. This can be especially challenging in projects where workspace is limited and heavy machinery is required for excavation. Above-ground tanks, in contrast, are generally easier and less costly to install and maintain. They, however, require available space and may also be more exposed to temperature variations, which can cause problems related to both water quality and system performance. Elevated temperatures in storage tanks have been shown to stimulate bacterial growth and microbial activity [83]. Lower temperatures, which can result in freezing, can instead make the system temporarily inoperable and lead to component damage. The choice of tank placement is consequently a highly site-specific decision and involves balancing factors such as installation feasibility, space efficiency, and cost.

2.6.2.2 RHS on the Swedish market

Several complete harvesting systems are currently available on the Swedish market. The included components vary, but as they are frequently marketed at single-family houses, the included pump often has a limited total head. This consequently significantly limits the application in multi-level multi-family buildings. Several of the companies, however, appear open to individualized system solutions, meaning this is unlikely to be an obstacle in the implementation of RHS. The focus on individualized solutions, however, means that several of the companies do not disclose costs on their website and instead require detailed information about the project before a price is given.

Listed in the table below are a selection of sellers/suppliers of RHS found on the Swedish market. As many of the companies sell several suitable systems, with variations in tank placement (made for underground, above ground or indoor use), no specific system model names are included, but this availability is specified. In addition to Swedish market availability, only sellers providing systems suitable for WC flushing and/or laundry are included.

Table 2.2: Overview of companies selling rainwater harvesting systems on the Swedish market.

Seller/supplier	Price information
INTEWA*	available online
ACO Nordic	available online
Conclean	not available online
WaterCare	not available online
4evergreen	not available online
Rewatec	not available online
Waterfix	not available online

*Sold by Graytec in Sweden. The INTEWA system had the lowest identified online price and was used in the LCA.

2.6.3 Graywater recycling systems

Domestic wastewater can generally be divided into two categories: blackwater and graywater. Blackwater refers to wastewater from toilets, while graywater includes the remaining wastewater, for example from showers, hand basins, laundry, and kitchen sinks [84]. A graywater recycling system, or GWRS, collects and treats graywater from one or several sources, after which

it can be used once again, resulting in a reduced mains water need. Common end uses include non-potable applications like WC flushing, laundry and irrigation, but depending on the treatment system, the recycled water can even be used for potable purposes [14].

2.6.3.1 Graywater treatment technologies

Despite sharing the same name, graywater from different sources can have very different characteristics. This type of wastewater is therefore sometimes further categorized according to its source and pollutant load. Light graywater refers to wastewater from showers, bathtubs and hand basins, while dark graywater refers to more polluted streams like kitchen sinks, dishwashers and sometimes laundry [85]. Dark graywater often has a higher content of organics and physical pollutants compared to its light counterpart [84]. Depending on the level of pollution and its intended end-use, different graywater streams therefore naturally require different treatments.

The treatment of wastewater can generally be divided into physical, biological, chemical and desinfecting treatment steps [14]. Physical, (often initial) treatment steps mechanically separate suspended solids. This can be achieved using for example screens, sedimentation tanks or filtration processes, which can range from coarse filters to membrane-based processes like ultrafiltration [86]. In addition to removing some pollutants, physical treatment steps also reduce the risk of clogging in downstream system parts [87].

Biological treatment uses microorganisms to break down dissolved organic matter and, to some extent, nutrients [14], [87], [88]. The treatment process can either include or exclude oxygen, i.e. be aerobic or anaerobic. Some examples of biological treatment systems include membrane bioreactors (MBR), biological aerated filters (BAF), sequencing batch reactors (SBR) and moving bed biofilm reactors (MBBR) [89]. The systems vary in design, but they all degrade contaminants by either utilizing suspended microbial biomass (such as activated sludge flocs) or biofilms on specialized media.

MBRs and SBRs usually use activated sludge flocs that are mixed with the wastewater, while BAFs and MBBRs use biofilms growing on fixed or moving carrier media. MBRs also include membrane filtration and SBRs operate in time-controlled treatment stages within one single tank. MBRs are often reported as being especially effective due to utilizing both a physical membrane barrier and a biological degradation process, and the resulting effluent is therefore often of high quality [14].

Examples of chemical treatment steps, which can be applied in addition to or in place of biological treatment, include chemical coagulation (CC), electrocoagulation (EC), ion exchange, and adsorption. Only using chemical treatment, however, can result in limited quality of the treated water [88].

Some common disinfection methods are UV light, chlorination, and ozonation [14].

2.6.3.2 GWRS components and configurations

The four main functional elements of a GWRS are collection, treatment, storage and distribution [90]. Much like for an RHS, the components that make up those elements, however, vary depending on the intended end use of the treated water and the corresponding choice of system. A list of common components is nevertheless included in this section, as well as possible system configurations.

Components

A selection of common components of a GWRS are listed and described shortly below [90], [88].

- Collection network - Separate wastewater pipes that transport graywater from specific applications to the treatment system, thereby keeping it isolated from blackwater.
- Pre-screening - Coarse filters or lint traps that catch hair and fibers right away to protect pumps and prevent downstream systems from clogging.
- Equalization tank - A temporary buffer tank that collects sudden bursts of water (like morning showers) and evens out variations in water temperature and soap concentrations.
- Treatment reactor - The main unit where biological processes (like biofilms or activated sludge) break down dissolved dirt, soap, and organic pollutants
- Disinfection unit - A system using UV light, chlorine, or ozone to kill pathogens so the water is safe to reuse.
- Treated water storage - A clean tank that holds the treated graywater until an end-use appliance needs it.
- Overflow - An outlet that allows excess water to leave the system when tank capacity is reached. The overflow water is directed to the municipal sewer.
- Mains water backup - A municipal water connection that supplements the storage tank if the graywater supply runs low. Backflow prevention is required.
- Distribution system - Pump(s), pipes, and other components used to deliver the treated water to the end-use applications.

For an example of a typical GWRS, see Figure 2.6.

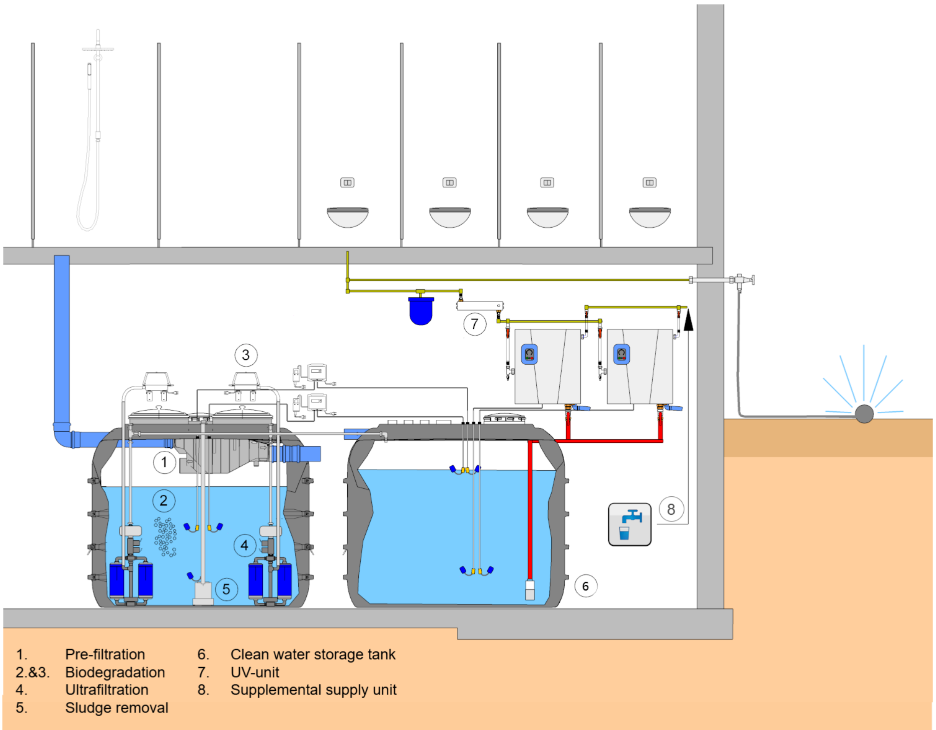


Figure 2.6: Illustration of a GWRS treating graywater from shower for toilet and irrigation use. Adapted with permission from INTEWA [91].

Configurations

Because graywater comes directly from indoor activities, the tanks and treatment units are often placed inside or right next to the building. Depending on the system and site-specific conditions, the GWRS can be buried underground, placed above ground in a basement or utility room, or installed in an elevated position.

As with rainwater harvesting systems, distribution method is directly affected by system placement. Common setups, which are described in the Swedish and European standard SS-EN 16941-2:2021 [90], include pumping treated water directly to appliances or pumping treated water up to a roof tank to let gravity feed the appliances. These layouts differ when it comes to energy use, complexity, and spatial requirements.

2.6.3.3 Energy savings

In addition to potential drinking water savings, a GWRS can also lead to savings in energy use [14]. Unlike harvested rainwater, graywater often contains residual heat as it derives from sources using hot water, like showers and bathroom basins. In cases where the treated water is reused for applications requiring hot water (washing machines, showers), the treated graywater will likely require less heating than its mains counterpart. If the intended end use, however, does not require hot water (toilet flushing or garden irrigation), a heat exchanger can instead be installed. The residual heat can then be recovered and used to preheat incoming cold water, thereby again reducing the energy required for water heating in the building.

2.6.3.4 GWRS on the Swedish market

Available GWRS suitable for multi-family buildings have been outlined in a previous study by Werecki et al. [14]. In that study, systems available in Europe were mapped. Table 2.3 below is adapted from this work, but limited to systems with Swedish suppliers. The potential water savings presented in the table are based on calculated values from Werecki et al., assuming a total water consumption of 140 L per person per day.

Table 2.3: Overview of GWRS available on the Swedish market

System	Treatment	Recycled from	Reuse for	Potential water savings	Advantages	Disadvantages
4evergreen	MBR	Shower, basin, laundry, dishwasher	Toilet, laundry, other	32%	Well-established in Swedish conditions; scalable; can be connected to a heat exchanger	High investment cost
Graytec (BlueCircle system)	Biological/ hybrid	Shower, basin, laundry	Shower, toilet, laundry, other	54%	Pilot-tested in Sweden (HSB Living Lab, Gothenburg); high potential water and energy savings	Still relatively immature technology
Hydraloop	Moving bed biofilm reactor	Shower, basin, laundry	Toilet, laundry, other	38%	Self-monitoring; compact and modular system	High investment cost
INTEWA	MBR	Shower, basin, laundry	Toilet, laundry, other	32%	Reference project in multi-family building (Junehem); can be connected to a heat exchanger	Requires relatively large installation space
Topas & Bluewater	Reverse osmosis + biological treatment	All household wastewater streams	Reuse up to potable-quality water	60%	Highest water recovery potential; enables reuse up to potable-quality water	Very high investment cost

In addition to these building-scale systems, there are also graywater recycling appliances that treat and recirculate water at the source, such as recirculating showers (e.g. Flow Loop and Orbital Shower) retrofit devices for washing machines that collect, treat, and reuse laundry water (e.g. Mimbox Mimbly) [14], [36]. Recirculating showers typically use sensors to monitor water quality, allowing excessively contaminated water to bypass the recirculation loop while cleaner water is filtered and reused [36]. Orbital Showers have, for example, been installed at HSB Living Lab, where reported hot water savings of approximately 80-90% were achieved [92]. Compared to building-scale systems, these solutions are generally more expensive per unit of treated graywater but have the advantage of not requiring extensive piping distribution and collection system. However, with a unit cost of approximately 50 tSEK for a recirculating shower [36], full-scale installation across all apartments in a multi-family building may result in very high total investment costs depending on the number of apartments.

3 Methodology

The methodology is designed as a mixed-methods approach, combining qualitative and quantitative methods. It consists of a literature review, semi-structured interviews, LCA and other performance calculations, and multi-criteria decision analysis (MCDA). Using these methods, a case study was conducted on a fictitious reference building located in Solna to evaluate the performance and implementation barriers of various water-saving technologies. In addition, the literature review and interviews aim to provide an understanding of enablers, barriers, and municipal governance and authority in implementing these solutions. An overview of the methodological process is provided in Figure 3.1.

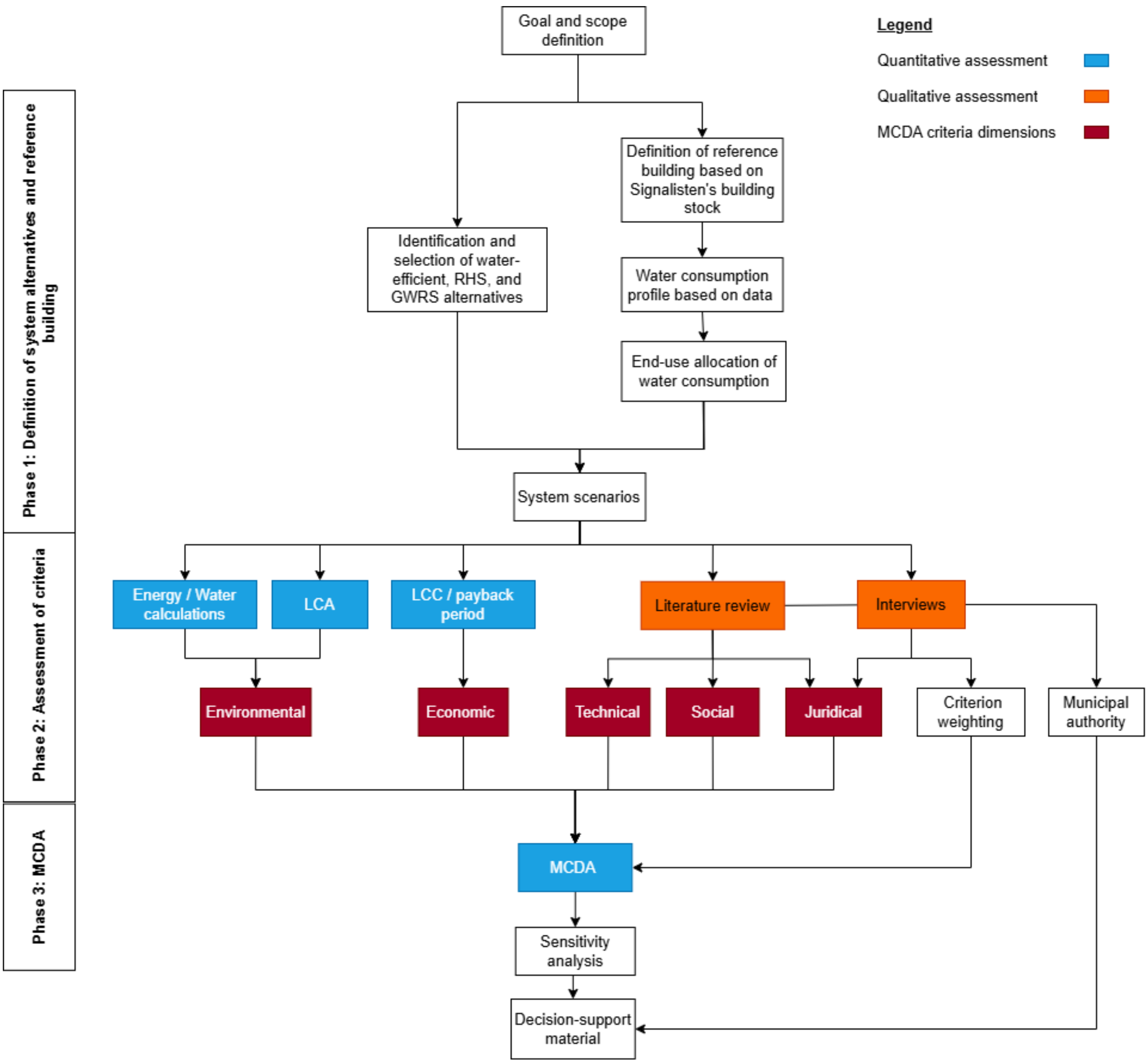


Figure 3.1: Flowchart illustrating the methodological process

A mixed-methods framework is particularly useful for analysing environmental, social, and governance aspects and has been shown to be suitable for complex decision contexts and emerging solution spaces characterised by multiple trade-offs and regulatory uncertainty [93]. LCA and MCDA were considered appropriate and complementary for the purpose of this study. LCA is a quantitative method used to assess environmental impacts across a system's life cycle, from raw material extraction to end-of-life (EoL) treatment, [94] and will be applied to capture environmental performance between different implementation scenarios. MCDA is a decision-support method used to evaluate options based on multiple criteria through scoring and weighting, often incorporating stakeholder engagement [94], and was selected to ensure decision-relevance. Both methods are well established in sustainability assessment and have been recommended by the European Union for use in circular urban water management [94]. However, it is important to note that the MCDA was not used to determine the single "best" alternative, but rather as a tool to structure and synthesize the findings. It should also be noted that, rather than conducting a complete LCA covering multiple environmental impact categories and all life cycle phases, this study applied a partial LCA limited to climate change impacts (global warming potential (GWP)) and the life cycle phases considered most relevant to the assessment. The scope and system boundaries of the LCA are further described in Section 3.4.3.

3.1 Definition of system alternatives and reference building

To identify relevant alternatives within water-efficient technologies, RHS, and GWRS, a brief market and literature review was conducted focusing on existing solutions at the building level (see section 2.6). These technology alternatives were subjected to a screening based on technology maturity, cost, market availability in Sweden, and suitability in multi-family buildings, ensuring that only solutions with potential feasibility for implementation in the studied context were included in the assessment.

Although some information can be drawn from real-world reference cases, the direct transferability is limited due to site-specific conditions and parameters. For the quantitative assessments, such as calculations on water savings, energy savings, environmental impacts and costs, a fictitious reference building was therefore developed. This reference building was based on Signalisten's housing stock, using average characteristics for a typical building in terms of number of apartments, number of floors, gross floor area (GFA), gross living area (GLA) and water consumption. Due to the lack of a more recent property list from Signalisten, data on construction and renovation year, GFA, GLA, and the number of apartments for each residential property were retrieved from Signalisten's 2020 property list [95]. Ideally, the reference building should be based on properties that have not undergone major renovations in recent years, in order to better represent baseline conditions prior to efficiency improvements. However, due to the somewhat outdated property list, properties constructed after 2020 (approximately 1200 apartments [34]) are not included in the dataset. Similarly, renovations carried out after 2020 are not reflected in the property list. As there is uncertainty regarding which specific properties have undergone recent renovations, no exclusions were made on that basis. Instead, properties were excluded if identified as statistical outliers based on a boxplot analysis of property area and number of apartments. One property, Tunet 1, was identified as a clear outlier and was therefore excluded from the dataset to avoid overestimations. Properties without residential units, as well as parking facilities, were also excluded from the dataset. The number of floors (including basement levels) were estimated using Google Maps Street View, and water consumption data for 2025 were provided by Signalisten (Signalisten, personal communication, February 13, 2026). For an overview of the collected data used for the definition of the reference building, see Appendix A.

The water consumption data provided by Signalisten consisted of aggregated annual water consumption data per service connection point. As multiple properties can be connected to a single service point, each data point was matched to the corresponding property or properties in the property list based of address. In cases where there was uncertainty regarding which properties were included, the data points were excluded from the analysis. The data was used to characterise consumption profiles representing different levels of water consumption per GFA (see Figure 3.2), where the average value was chosen to be scaled to the reference building's GLA. This approach represents a simplification, as water consumption is primarily driven by occupancy rather than floor area [11]. However, in the absence of data on the number of occupants for the given data year, scaling GFA to BOA provides a closer approximation of residential water use by excluding non-residential areas.

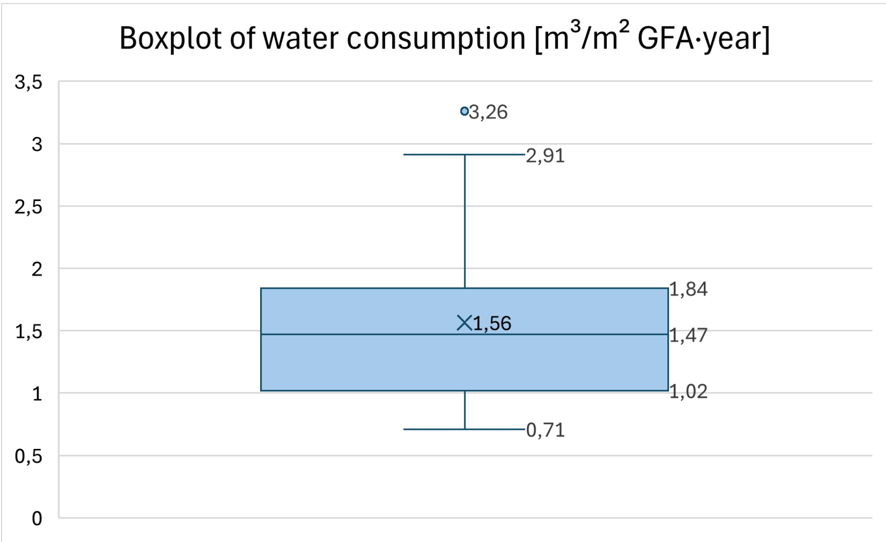


Figure 3.2: Boxplot of annual water consumption per gross floor area (m^3/m^2 GFA·year), based on data from Signalisten's housing stock. The boxplot illustrates the average, median, interquartile range (25th–75th percentile), and extreme values, and is used to assess the distribution and identify outliers in the dataset.

The mean was calculated to 1.57 $m^3/(m^2 \cdot yr)$, which is comparable to Signalisten's reported value for their total building stock in 2024, including commercial facilities, of 1.6 $m^3/(m^2 \cdot yr)$ [96]. Although on outlier was identified in the water consumption data set, see Figure 3.2, it was retained in the calculation of the mean as its impact was deemed negligable (1.57 compared to 1.56). Furthermore, even with the higher mean value, the estimated daily water consumption per person (156 L/p/d) for the reference building is at the lower end compared to other studies, e.g. 198 L/p/d reported in a study of Signalisten's building stock in Hagalund [11], and 184 L/p/d reported as the Swedish average for multi-family buildings [97]. This indicates that retaining the outlier did not lead to any significant overestimation. The key characteristics for the reference building in this study are presented in Table 3.1.

Table 3.1: Key characteristics of the reference building

Parameter	Value
GFA [m^2]	5518
GLA [m^2]	4867
No. of apartments	67
No. of floors (excl. basement level)	7
Estimated no. of residents	130[a]
Average annual water consumption [m^3]	7641

[a] Based on 2012-2025 SCB data, the average number of persons per household in rental apartments in the municipality of Solna is two [98].

Due to the limited granularity of the obtained data from Signalisten, a top-down approach was applied in which the total water consumption of the reference building was disaggregated into different end-use categories using literature-based assumptions rather than being estimated from specific installations and user behavior. The approach was selected due to limited data availability and to utilize observed water consumption patterns from Solna and estimate potential savings based on current water use.

As a default assumption, the potable water use distribution reported by Svenskt Vatten [9], see Figure 2.1, was used to estimate the distribution of end-use categories. "Bathroom sink" and "Shower", which are assumed to represent "personal hygiene", were disaggregated using a distribution of 75% shower and 25% bathroom sink. This is consistent with both benchmark values and measured data for a multi-family building reported by Knutsson [99]. For "Kitchen sink" water use, 10.7% was adopted as a proxy based on water use for "Dish washing". Total kitchen water use is reported to be higher in the literature, with values around 25% [99] and 27% [100], as these studies include additional end-uses such as dishwasher use and direct consumption. In this study, however, consumed water (i.e. cooking and drinking) is excluded as it is not affected by any of the systems considered. Since kitchen sink water use varies depending on whether dishwashing is performed manually or with a dishwasher, the lower value of 10.7% was selected to represent tap-based kitchen sink use excluding dishwasher-related consumption as well as consumed water.

Shared water use in multi-family buildings includes communal laundry facilities and other uses, such as cleaning and irrigation. Since it is voluntary for Signalisten's residents to install their own washing machine [75], in-unit washing machines are beyond Signalisten's control, and therefore outside the scope of this study. The theoretical maximum for "Laundry" is thus achieved if all households use the communal laundry facilities. However, in practice, approximately 50% of residents in multi-family housing have their own washing machine [101], meaning that the actual water use for this end-use category is closer to half of that reported by Svenskt Vatten. Studies on shared water use in multi-family housing show similar ranges. For example, Energimyndigheten measured communal laundry use at 5.4% of total water consumption [102], while Wahlström et al. reported a value of 4.4% [103].

Table 3.2 presents an overview of the water use distribution, including the share of hot water within each end-use category. The latter was used to calculate energy savings and cost savings associated with reduced energy demand for water heating.

Table 3.2: Distribution of water use and share of hot water by end-use

	Bathroom basin	Kitchen sink[a]	Shower	Toilet	Communal laundry		Other[b]
					Theoretical maximum	Realistic assumption	
Share of total water consumption [%]	10.7	10.7	32.1	21.4	10.7	5.35[c]	7.1
Share of hot water within each end-use category [%]	58[c]	59[d]	63[d]	0[e]	ND		ND

[a] Excluding consumed water.
[b] Shared water use other than communal laundry, e.g. irrigation and cleaning.
[c] Assuming 50% of the households have their own washing machine.
[d] Data are retrieved from Johansson et al. (2007) [104].
[e] Data is retrieved from Knutsson and Knutsson (2020) [105].

3.2 Scenario development

The selected system alternatives evaluated in this study were: (1) water-efficient plumbing fixtures, including bathroom faucets, kitchen faucets, shower heads, and toilets, (2) RHS, where rainwater is collected from the roof for use in communal laundry, (3a) GWRS, where graywater from showers is collected for reuse in toilet flushing and communal laundry, and (3b) the same system as in (3a) but with heat recovery via a heat exchanger. The selected end uses for RHS and GWRS are based on the reference building, which is further explained in Sections 3.4.1.2 and 3.4.1.3.

The system alternatives were assessed against a baseline representing the current conventional water supply and wastewater system using MCDA. To capture differences in performance and shifts in trade-offs, the assessment was performed for three implementation scenarios: (1) retrofit in existing buildings, (2) integration during major renovation or pipe replacement, and (3) integration in new construction. An overview of these systems, scenarios, and their combinations is presented in Figure 3.3.

Retrofit
The retrofit scenario represents a case where water-saving technologies are installed in an existing building without planned renovation. In this scenario, all construction activities, costs, and climate impacts are allocated entirely to the intervention.

Renovation
The renovation scenario represents a case where the water-saving technology is installed during major renovation or pipe replacement in an existing building. In this scenario, plumbing fixtures are replaced and the bathrooms are stripped to their structural core. This involves the demolition of walls and floors down to the concrete slab to expose and replace the existing pipe systems, followed by the reconstruction of the bathrooms. According to Berglund [106], this is the standard procedure for pipe replacement. Since these interventions are already part of the renovation process, the additional construction work required for integration of the water-saving technology is reduced compared

to retrofit installation.

New construction
The new construction scenario represents a case where water-saving technologies are integrated from the design and construction phase in a new building. Since the building and pipe systems are designed for the selected technology from the outset, system integration is facilitated compared to installation in an existing building. Similarly to the renovation scenario, only the additional construction activities, costs, and climate impacts (compared to the construction of a conventional building) are allocated to the intervention.

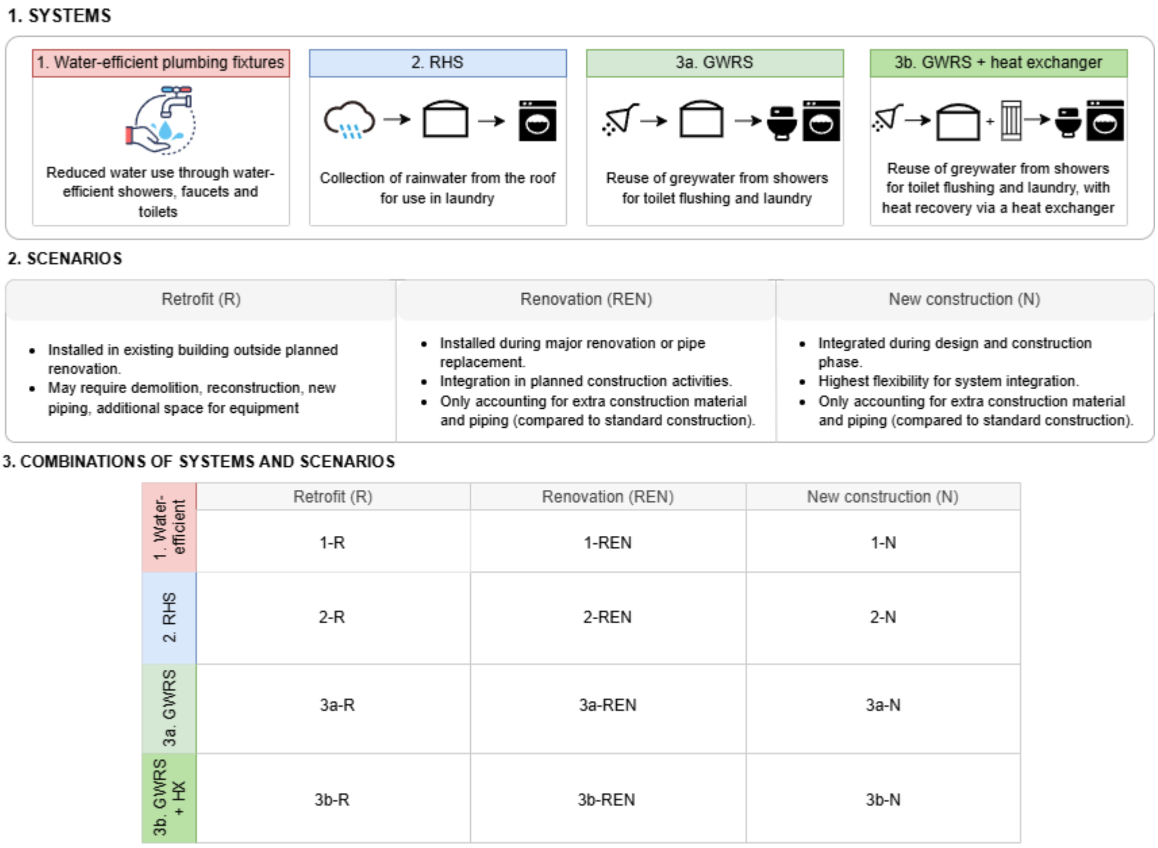


Figure 3.3: Summary of evaluated systems, scenarios, and system-scenario combination IDs

3.3 MCDA

For the setup of the MCDA, the MCDA framework developed by Svenskt Vatten for decision support within the drinking water sector, WISER, was used [38]. Accordingly, environmental, technical, social, economic, and legal/regulatory dimensions were considered in this study. However, as this framework primarily concerns municipal-level measures, the criteria presented in the WISER framework were adapted to fit the assessed technologies. Drawing on previous studies [107], [44], [38], [42], [108], [39], we evaluated the dimensions using the criteria in Table 3.3.

Table 3.3: MCDA criteria

Dimension	Criterion	Description	Indicator/unit	Sources with similar MCDA criterion
Environmental	Water savings	Amount of water that can be saved	m^3/yr ; %	[107], [44]
	Energy savings	Amount of energy that can be saved	kWh/yr ; %	[107], [44], [42]
	Greenhouse gas emissions	Net climate impact, including emissions from installation and operation	kg CO_2e/yr ;	[107], [42]
Economic	Life cycle cost	Total cost over the system's lifetime, including investment and O&M	tSEK/yr	[107], [44], [38], [42], [108], [39]
	Economic savings	Financial benefits due to reduced water and energy use	Payback period (yrs)	[44], [108], [39]
Social	Acceptance	User and resident acceptance of the water-saving solution	User perception indicators (e.g., perceived health risk, comfort, awareness, trust, and satisfaction)	[107], [44], [38], [42], [108], [39]
Technical	Implementation complexity	Technical difficulty of installing the system	Scope of installation work, space requirements	[38], [39]
	Maintenance complexity	Technical requirements for maintenance	Frequency and complexity of maintenance	[107], [38]
Juridical	Juridical complexity	Juridical and regulatory conditions affecting implementation	Permit requirements, likelihood of approval, and complexity of process	[107], [38], [39]

The WISER framework applies a weighted sum model, shown in Equation 3.1, together with an ordinal scoring system ranging from –10 to +10. In general, a score of zero represents the reference point (i.e., no change compared to the conventional system). Positive scores (+1 to +10) indicate a favourable impact relative to the reference system, whereas negative scores (–1 to –10) indicate an unfavourable impact. Since an assessment of this sort would require the ability to distinguish between closely related score levels, a high level of precision was considered difficult to achieve reliably. Hence, to avoid false precision, the scale was simplified to a five-level ordinal scale, as shown in Table 3.5. The scoring was based on the degree to which each measure fulfilled the objectives presented in Table 3.4. For the quantitative criteria, threshold intervals were defined to ensure consistency in the scoring. The intervals were based on the range of calculated results and the degree of objective fulfillment. The thresholds are presented in Table 3.6.

Table 3.4: MCDA criteria and corresponding objectives used in the scoring

Criterion	Objective
Water savings	The measure results in a reduced water demand
Energy savings	The measure results in reduced energy consumption
Greenhouse gas emissions	The measure results in reduced greenhouse gas emissions
Life cycle cost	The measure is associated with a low life cycle cost
Economic savings	The measure is associated with a short payback period
Acceptance	The measure is associated with a high level of user acceptance
Implementation complexity	The measure is associated with a low degree of technical complexity during installation, including construction work and system integration
Maintenance complexity	The measure is associated with low maintenance requirements
Juridical complexity	The measure is associated with few regulatory barriers, and the necessary permits can be obtained with high certainty

Table 3.5: Score interpretation for the MCDA

Score	Degree of objective fulfilment
+2	High
+1	Moderately high
0	Neutral
-1	Moderately low
-2	Low

Table 3.6: Threshold values used for scoring quantitative MCDA criteria

	Water savings	Energy savings[a]	Greenhouse gas emissions[b]	Life cycle cost	Economic savings[c]
+2	>50%	>50%	>20% reduction	>50 tSEK/yr savings	<25% of service life
+1	35-50%	35-50%	5-20% reduction	10-50 tSEK/yr savings	25-50% of service life
0	20-35%	20-35%	± 5%	± 10 tSEK/yr	50-75% of service life
-1	5-20%	5-20%	5-20% increase	10-50 tSEK/yr cost increase	75-100% of service life
-2	<5%	<5%	>20% increase	>50 tSEK/yr cost increase	>100% of service life

[a] Energy savings expressed as % reduction in energy demand for domestic hot water (assuming 40% of potable water use consists of hot water).
[b] GWP expressed relative to the conventional water system, including impacts associated with water heating.
[c] Payback period expressed relative to system service life.

$$I_{a,s} = \sum_{k=1}^{K} v_k \cdot p_{a,s,k} \tag{3.1}$$

where

$I_{a,s}$ = Weighted index for system alternative a in scenario s [-]

v_k = Relative weight of criterion k [-]

$p_{a,s,k}$ = Score of system alternative a in scenario s for criterion k [-]

Criteria scoring was informed by results from the LCA, literature review, and qualitative insights obtained through semi-structured interviews with relevant key informants, including experts and practitioners with experience in permitting, regulation, and implementation of water-saving solutions. These informants included representatives from Solna municipality and Signalisten.

To determine the criteria weights, a subjective weighting method was applied to reflect decision makers' priorities. The weights were obtained from a survey sent to a selection of the interviewees. Although information about the weighting method was provided in advance, a simple point allocation method was used to facilitate participation and reduce the risk of misunderstandings. This method involves allocating a fixed number of points across the criteria based on their relative importance [109]. Following the example provided by Odu [109], this fixed number was set to a total of 100 points.

To capture differences in implementation scenarios, the respondents had to complete the survey for two cases: existing building (including retrofit and renovation) and new construction.

3.4 Quantitative assessment

In this section the methodology applied for calculating water savings, energy savings, climate impact, and costs is presented. While greenhouse gas emissions are evaluated from a life cycle perspective, the energy and water assessments are limited to the operational phase. This is because these indicators are intended to reflect operational resource efficiency and system performance rather than full life cycle impacts. Furthermore, from a property owner perspective, the relevant savings are those occurring during the operational phase rather than the resource use associated with material production and installation. All underlying inventory data and parameters for these calculations are detailed in Appendix C and D.

To account for the different service lives of the water-efficient technologies compared to the RHS and GWRS, all quantitative criteria units were annualised. The specific service lives used for these calculations are outlined in Table 3.7.

Table 3.7: Service life of the different system alternatives

System alternative	Service life [yrs]	Source
Water efficient technologies		
Bathroom basin	16	[110]
Kitchen sink	16	[111]
Shower head	15	[112]
Toilet	30	[113]
RHS	50	[41]
GWRS	50	[41]

It should be emphasized that the purpose of the quantitative assessments was to generate estimates of these criteria rather than exact results. Consequently, the focus was placed on including the major factors influencing performance rather than on detailed precision. As an example of the uncertainty associated with such estimations, Reicherter (as cited in [114]) states that cost estimates may have an accuracy of approximately $\pm 30\%$ compared to the final costs.

3.4.1 Water savings

This section describes the quantitative methods used to estimate water savings for the evaluated technologies.

3.4.1.1 Water-efficient technology

For water-efficient technology, the potential water savings depend on the reference used for comparison. As a simplification, water savings from installing water-efficient plumbing fixtures were calculated assuming that savings are directly proportional to reductions in flow rate, without accounting for potential changes in user behavior and rebound effects. Although rebound effects associated with water-efficient technologies have been identified in several studies ([115], [46], [116]), these effects were not included in the model. This assumption was made to maintain a consistent technical system perspective across the evaluated technologies, as behavioral aspects were similarly excluded from the RHS and GWRS models. Consequently, the study evaluates the maximum theoretical water-saving potential of the system alternatives. To partly address this limitation, the influence of user behavior and potential rebound effects is instead discussed based on findings from the literature review in the Results and Discussion sections. Accordingly, the maximum theoretical water savings for a fixture type can be calculated as the difference between the reference flow rate and the flow rate of the installed fixture (see Table 3.8), multiplied by the corresponding end-use share of total water consumption (see Table 3.2), as shown in the formula below:

$$\textit{Water savings \%} = \left(1 - \frac{\textit{Flow rate}_{installed}}{\textit{Flow rate}_{reference}}\right) \cdot \textit{Share of total consumption} \tag{3.2}$$

The flow rates used as reference in the different implementation scenarios were defined as follows:

- Retrofit: replacement of high-flow fixtures with water-efficient fixtures
- Renovation: replacement of high-flow fixtures with water-efficient fixtures
- New construction: installation of water-efficient fixtures using today's standard as the reference flow rate

Today's standard was used as the reference in the new construction scenario, as installation of older high-flow plumbing fixtures in new buildings is considered unlikely. In addition, the potential water savings achieved when water-efficient technologies are compared to best available technology (BAT) fixtures were also evaluated, reflecting the marginal improvement beyond the water-efficient level and the additional performance potential available if Signalisten aims to exceed the standard for Miljöbyggnad Silver.

Table 3.8: Assumed fixture flow rates by efficiency category

Fixture	High flow	Today's standard	Water-efficient	Best available technology
Bathroom faucet [L/min]	11	6	4	1.90
Kitchen faucet [L/min]	15	12	6	3.10
Shower [L/min]	19	12	8	4.80
Toilet [L/flush][a]	9	4	2.67	1.03

[a] For the "High flow" category, the value is based on a single-flush toilet. For the other categories, the values are based on dual-flush toilets: "Today's standard" (3/6 liters) and "Water-efficient" (2/4 liters). The values in the table therefore represent the calculated effective flush volume, as described in [59].

The flow rates and costs for water-efficient faucets and shower heads were based on KIWA-certified products [117], [118], where the average flow rate and cost of the five products with the lowest flow rates were selected to represent water-efficient technologies. BAT was identified based on the products with the lowest flow rates within the LEED/BREEAM category from the manufacturers Hansgrohe, FM Mattsson, Mora, Gustavsberg, and Grohe. For toilets, a urine-diverting toilet was selected to represent BAT. The selected flow rates were chosen to comply with the minimum flow requirements specified in the EU Ecolabel.

3.4.1.2 Rainwater harvesting

Water savings from rainwater harvesting systems are determined by the interaction between rainfall, roof area, water demand, and storage capacity and can be estimated using modeling.

Despite the existence of numerous RHS modeling methods in the literature, this study focuses on the two methods (basic and detailed) described in the Swedish and European standard for RHS (SS-EN 16941-1:2024) [81]. While the basic approach is recommended for simpler projects where demand and yield are regular, such as residential buildings, previous studies have highlighted limitations of similar simplified methods. In particular, they fail to capture temporal variability in rainfall and water demand, which can lead to inaccurate estimation of water savings and oversized tanks [119], [120].

Due to this, the detailed modeling approach was adopted in this study. The basic approach was, however, used for initial sizing as it required minimal data and gave an indication of relevant tank sizes to evaluate using the detailed method.

The detailed approach is a time-series-based model that simulates available tank storage, inflow, demand, and overflow with a daily time step, based on a fixed catchment area. The approach corresponds to a behavioral simulation model often referred to in the literature as Yield After Spillage (YAS) [121], [120]. The name refers to overflow being assumed to occur before daily demand is met, instead of after, resulting in a more conservative performance estimate [122].

A ten year (2016-2025) local rainfall series, acquired from SMHI.se [123], was used following the recommendation in SS-EN 16941-1:2024 [81]. Due to the limited detail in water consumption data provided by Signalisten, daily demand was set as constant and linked to a pre-defined end-use. Laundry (six washing machines in shared laundry room; see Appendix F for specifics) was chosen as end use based on the maximum potential annual rainwater yield, estimated from the relationship between local annual rainfall and roof area of the reference building. This was to ensure that the yield-demand relationship was relatively well matched. Information about annual rainfall, roof area, maximum yield as well as demand for different end-use applications is shown in Table 3.9. The initial tank water volume was set to 0 m^3, and tank sizes ranging from 5 m^3 to 25 m^3 were tested in the model, based on results from the basic model. Results from the detailed model were plotted to illustrate the relationship between tank sizes (m^3) and corresponding water savings (%).

Table 3.9: Input parameters and calculated annual yield and demand values used to select the RHS end-use application for the reference building.

Roof area ref. building [m^2][a]	983
Annual rainfall in Solna [mm][b]	547
Maximal annual yield [m^3][c]	436
Annual WC water demand for ref. building [m^3]	1637
Annual laundry water demand for ref. building[m^3][c]	409

[a] Based on GLA, no. of floors, and an assumed 45° gable roof design.

[b] Average value based on the period 1991-2020 [124].

[c] Losses were accounted for using a hydraulic coefficient (0.9) and runoff coefficient (0.9), resulting in a combined loss coefficient of 0.81.

[c] Based on "Realistic assumption" in Table 3.2.

Since several of the RHS suppliers listed in Table 2.2 did not provide online price information, the system selection was narrowed to INTEWA and ACO Nordic. Based on the modeling results, site-specific constraints, available technical data, and overall cost-efficiency, a customized INTEWA system with a 15 m^3 tank was selected. The system was based on the product package “Rainwater harvesting House-Basic-Kit 2,000 liter”, but the included tank was replaced with the “Flat underground tank HD, 15.000 liters”. This tank is designed for underground placement and can withstand groundwater levels up to shoulder height. It was selected as a conservative option due to assumed spatial limitations at the reference building and uncertainty regarding local soil and groundwater conditions. INTEWA also offers a similar 15,000-liter underground tank designed for groundwater levels up to half of the tank height, but the HD version was chosen to reduce the risk of underestimating site-related constraints. The same below-ground placement was assumed for all three implementation scenarios. For a detailed illustration of the system and tank see Appendix B.

3.4.1.3 Graywater recycling

The water-saving potential of a GRWS depends on the amount of water that can be replaced by graywater, which, in turn, is determined by the system’s capacity as well as the yield and demand of graywater. The GWRS for the reference building was sized in accordance with the Swedish and European standard for GWRS for non-potable uses (SS-EN 16941-2:2021), which recommends balancing water yield and demand, with the system capacity being based on the lower of the two values [90]. Two approaches for estimating yield and demand are described in the standard, where the more detailed approach includes behavioral factors such as usage rate per person and duration per use for each end-use as well as their respective flow volumes. Since the water consumption data inherently captures these aspects, yield and demand were instead estimated based on this data, and the formulas described in the standard could be simplified to:

$$\begin{aligned} Y &= W_{tot} \cdot \sum_{i \in S_Y} f_i \\ D &= W_{tot} \cdot \sum_{j \in S_D} f_j \end{aligned} \tag{3.3}$$

where,

Y = The estimated graywater yield [L/d]

D = The estimated graywater demand [L/d]

W_{tot} = The total daily water consumption of the reference building [L/d]

f_i, f_j = The fraction of total water consumption for the specific end-use i, j [-]

S_Y = The set of appliances/fixtures supplying graywater to the GWRS (e.g., shower, bathroom basin, kitchen sink, washing machine)

S_D = The set of end-uses supplied by the treated graywater (e.g. toilet, laundry, irrigation)

In Table 3.10 an overview of the calculated yields and demands are presented, which was used to determine the choice and sizing of the GWRS.

Table 3.10: Estimated daily graywater supply, demand, and net balance by source and end-use (L/day)

Graywater from	**Treated graywater to**	**Yield (L/d)**	**Demand (L/d)**	**Difference**
Shower	Toilet	6729	4486	2243
Shower	Toilet, laundry	6729	5608	1121
Shower, bathroom basin	Toilet, laundry	8972	5608	3364
Shower, bathroom basin	Toilet, laundry, other	8972	7103	1869
Shower, laundry	Toilet, laundry	7851	5608	2243
Shower, laundry	Toilet, laundry, other	7851	7103	748

As shown in the table, the best balance between yield and demand (marked in green) is achieved either by treating graywater from showers for toilet flusing and laundry, or by treating graywater from showers and laundry for toilet flusing, laundry and other uses (irrigation and cleaning). Available options (in reasonable price range and technological maturity) for these applications included the INTEWA AL-GW5400 (water treatment capacity of 5400 L/d), INTEWA AL-GW10800 (water treatment capacity of 10800 L/d), Hydraloop Cascade (comprising 6-10 H600 units with a combined water treatment capacity of 4320-7200 L/d), and 4Evergreen. Since cost information for these systems is not publicly available, and limited information was available for the 4Evergreen system, suppliers of the systems were contacted for additional details. Of the contacted suppliers, only Graytec (INTEWA) and Enava (Hydraloop) provided sufficient information. The INTEWA systems were ultimately selected based on their significantly lower cost. Although the INTEWA AL-GW10800 would result in higher water savings, it would also lead to an overcapacity of 52%. The INTEWA AL-GW5400 system was therefore selected for treating graywater from showers for reuse in toilet flushing and communal laundry.

For the subsequent calculations, it was assumed that the treated water is primarily used for toilet flushing, with the remainder allocated to communal laundry. This reflects the capacity-constrained operation of the system, where toilet flushing constitutes a continuous low-volume demand, while communal laundry involves larger intermittent withdrawals. As the system is underdimensioned relative to total demand, it can be assumed that toilet flushing is prioritized when the availability of treated water becomes limited.

3.4.2 Energy savings

Net energy savings were calculated based on the net energy balance, accounting for both energy consumption and energy savings, as shown in Equation 3.4, where E_{net} represents the net energy use [kWh/yr], $E_{consumption}$ represents energy consumption [kWh/yr], and $E_{savings}$ represents energy savings resulting from reduced hot water demand [kWh/yr].

$$E_{net} = E_{consumption} - E_{savings} \tag{3.4}$$

Water-efficient technology
Non-electrical plumbing fixtures were assumed. Therefore, only energy savings resulting from reduced hot water use were included. The saved water is assumed to contain the same share of hot water as in normal use for each end-use category.

Rainwater harvesting
Energy consumption for the RHS was limited to the operational electricity use of the submersible pump. A probable flow rate, based on the use of six washing machines, was used to estimate pump operating time and associated energy use. No energy savings from reduced hot-water demand were included, as the harvested rainwater was assumed to replace only cold potable water.

Graywater recycling
The energy consumption of GRWS included operational electricity use, pumping, and, where applicable, electricity use of the heat exchanger. A probable flow rate, based on the use of six washing machines and 67 toilets, was used to estimate pump operating time and associated energy use. Energy savings were calculated using the potential energy savings described by Knutsson [99]. With a heat exchanger, energy savings were assumed to be 19.8 kWh/m^3 of treated water, and an efficiency of 70% (GEISER AT 8455 [125]) was applied. In cases without a heat exchanger, only energy savings associated with reduced heating demand for incoming water to washing machines were included, corresponding to 7 kWh/m^3.

3.4.3 LCA

A comparative attributional partial LCA, covering the impact category climate change, was used to inform the environmental criteria "greenhouse gas emissions" in the MCDA. The purpose was to compare the climate impacts of the different system alternatives across the implementation scenarios. Since the study is comparative, only processes that differed from the conventional system were included in the assessment.

Data was primarily collected from primary sources, such as environmental product declarations (EPDs), as well as secondary sources, including LCA databases and LCA reports. Where specific data were not readily available, proxy data and estimates were applied. Additionally, data regarding the municipal water system was obtained through email correspondence and annual environmental reports.

For plumbing and construction-related activities, materials, quantities, costs, and environmental impacts, Bidcon (version 2025.1), a construction cost-estimation software developed by Elecosoft, was used as the primary tool. The software includes both individual resources and combined work results that represent larger construction activities (e.g. piping installation in bathrooms). For building materials, Bidcon's climate module was used, which directly links EPD data to the materials included in the cost estimate. Since the climate module for plumbing materials was not available, these were instead estimated manually using EPD data.

Functional unit

In an LCA, a functional unit (FU) should describe the function of the assessed systems and and serves as the reference unit for all calculations [126]. Therefore, and similar to many other LCAs concerning water systems, a service-oriented FU was used [126]. Since the assessed systems in this study differ fundamentally, both in service lifetime and in function (including demand reduction (water-efficient fixtures), water reuse (GWRS), and alternative water supply (RHS)), the FU was broadly defined as "the provision of water to the reference building over one year".

Allocation

Allocation concerns how environmental burdens should be distributed between main products and co-products [127]. In this study, system expansion was applied to the Käppala WWTP, as the plant is both a consumer and producer of energy. This means that the WWTP receives an environmental credit from the co-production of biogas, which is upgraded to compressed biogas for use in buses, thereby replacing fossil fuels such as diesel [23]. Aside from this, no manual allocation was performed, as product-specific EPDs were primarily used, and allocation was therefore handled according to the predefined methodologies of the respective data sources.

System boundaries

Since the LCA constitutes only one part of the overall qualitative assessment, the assessment was delimited to include only the life cycle phases expected to have a significant impact. The system boundary was therefore limited to the production (raw material extraction and manufacturing, including system components and construction materials needed for its installation), installation/construction (on-site construction activities, machinery use, demolition where applicable, and handling of construction waste) and operational (energy use and potential environmental savings from reduced water demand and reduced water heating demand) phase, which previous studies have shown to have a large impact ([128], [129], [41]). Transportation, other than where it was covered in the underlying data (A1–A3), was excluded, as well as EoL. It should be noted that the climate change impacts associated with production phase of the RHS and GWRS are subject to uncertainty, as information on the material composition of these systems was limited. However, in order not to underestimate the climate impact, these phases were estimated to the best of our ability based on available bills of materials. Flowcharts clarifying the system boundaries of the assessed systems and scenarios are shown in Figures 3.4, 3.5 and 3.6.

The geographical scope of the LCA is Solna, Sweden. Data related to energy use and water services (i.e. the conventional water system), including electricity mixes and the environmental impacts associated with water production and wastewater treatment, are specific to the Solna context. Data related to building materials were obtained from sources with a geographical scope of Sweden, or Europe, to ensure that production processes and, in particular, waste-handling practices are representative of Swedish conditions.

Impact Category

The impact category considered in this study was, as previously mentioned, climate change, which was measured using the midpoint indicator GWP, expressed in kg CO_2eq/yr. Since Bidcon's climate data was limited to GWP-GHG, which only considers fossil greenhouse gas emissions while excluding biogenic carbon and land use impacts, the entire LCA was limited to GWP-GHG for consistency. Because the majority of the components are made of non-biogenic materials such as plastics and metals, restricting the scope to fossil greenhouse gas emissions was deemed acceptable.

Flowcharts

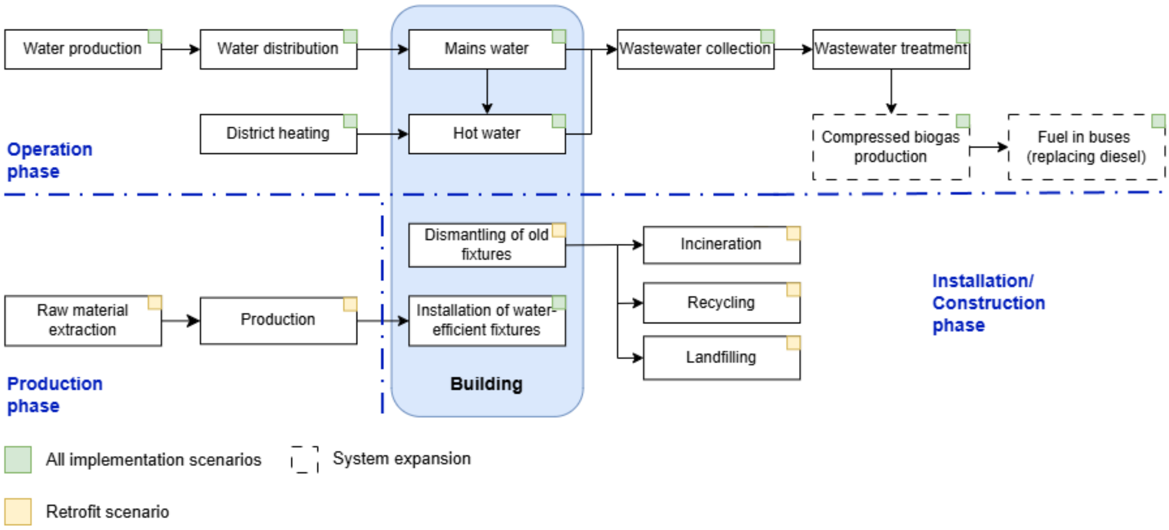


Figure 3.4: Flowchart illustrating the modeled lifecycle elements for water-efficient plumbing fixtures in the different implementation scenarios.

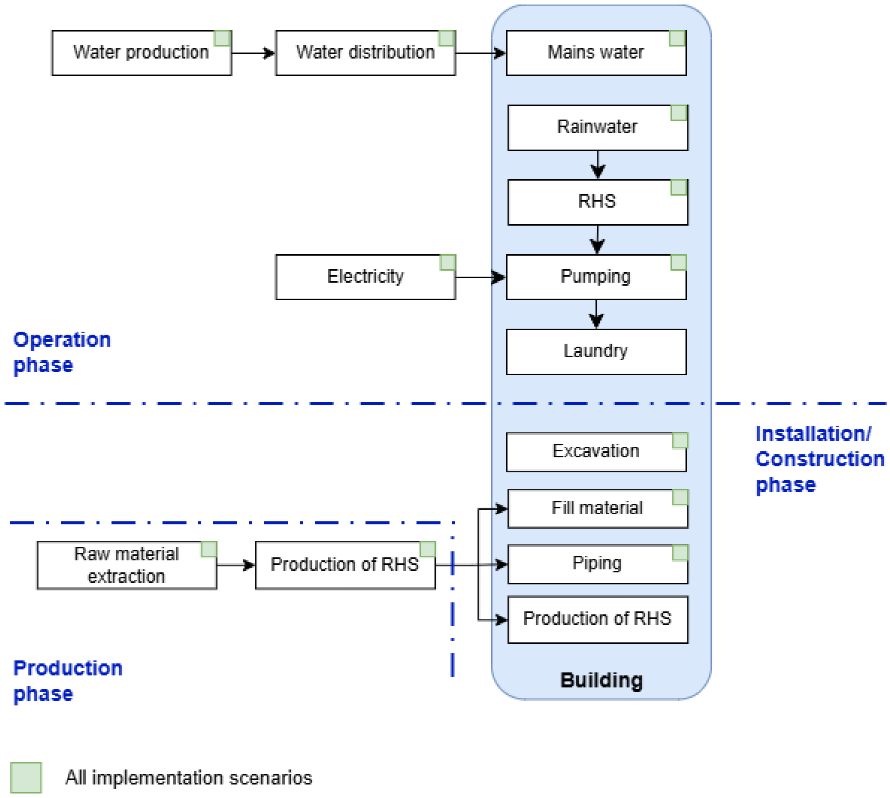


Figure 3.5: Flowchart illustrating the modeled lifecycle elements for RHS in the different implementation scenarios.

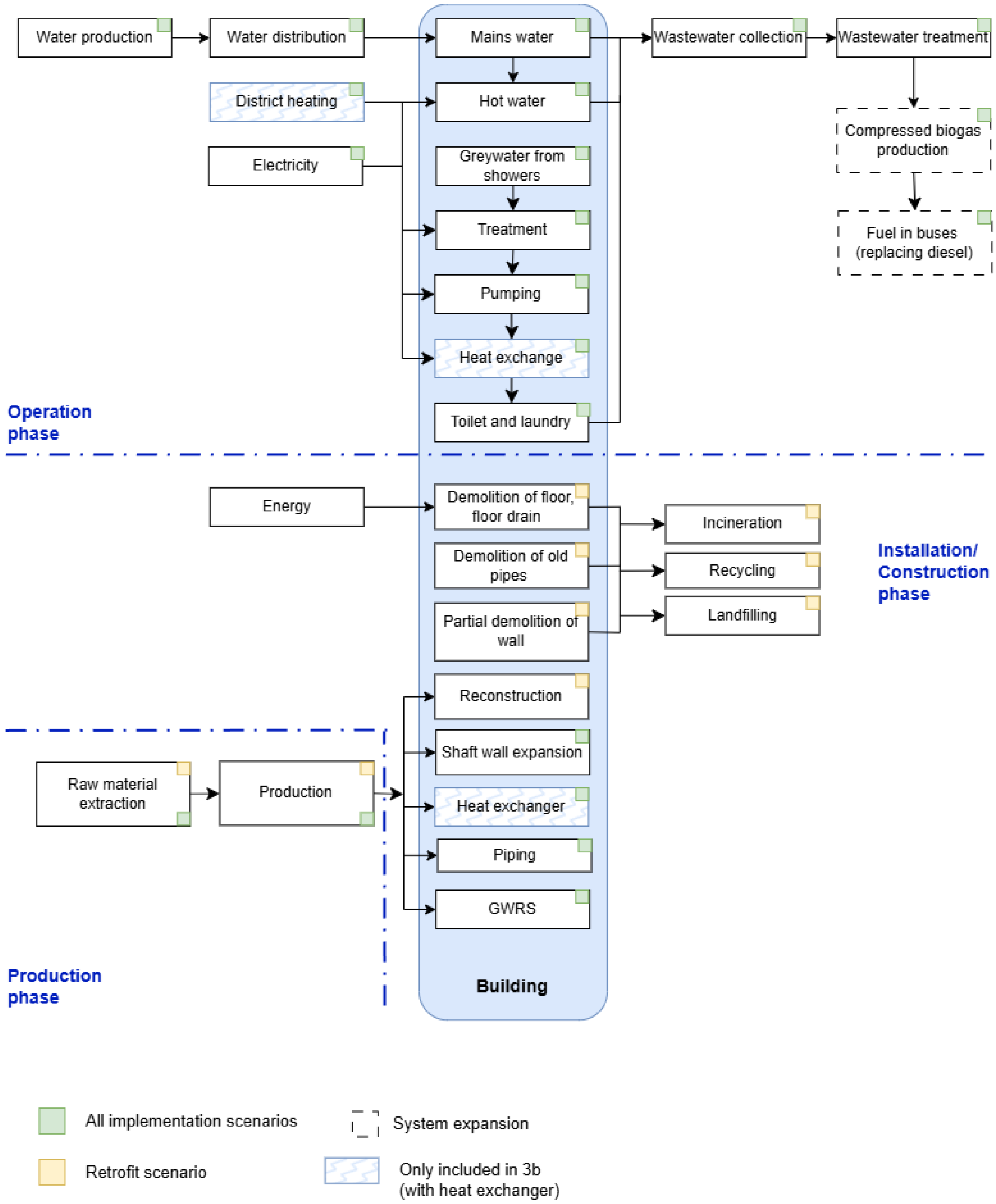


Figure 3.6: Flowchart illustrating the modeled lifecycle elements for GWRS in different implementation scenarios.

3.4.3.1 Water-efficient technology

In the renovation and new construction scenarios, no additional environmental burdens were allocated to the production and installation phase, since new fixtures would be installed regardless of the intervention. The production impacts of conventional and water-efficient fixtures were assumed to be equivalent, an assumption that is supported by previous LCA studies reporting negligible differences between the two alternatives [128]. Climate impacts from the production phase were therefore only accounted for in the retrofit scenario, where existing fixtures must be replaced. This includes impacts associated with the production of new plumbing fixtures, the production of mounting materials (e.g. screws)., and the disposal of replaced plumbing fixtures. Because the installation process does not require the use of machinery [130], no environmental impacts were associated with this phase.

The environmental benefits during the operational phase of water-efficient fixtures result from reduced water production, water distribution, wastewater treatment, and energy use for water heating.

3.4.3.2 Rainwater harvesting

As the RHS installation was assumed to look the same across all implementation scenarios, the associated climate impacts are also assumed to be identical in all scenarios.

The complete RHS installation includes excavation, tank placement, backfilling, routing of pipes and wall penetrations. However, the climate impact assessment for the RHS was limited to embodied carbon of the PE storage tank, filter, pump and pipe materials, production of backfilling material and use of excavation and backfilling machinery. The climate impact associated with the operational energy of the pump during the use phase of the system was also included. Embodied material effects of the pump as well as components and work such as fittings, wall penetrations and indoor installation work were not included due to system design uncertainty. Life cycle literature shows that for the physical infrastructure, the storage tank overwhelmingly drives material-related climate impacts and fossil energy depletion, accounting for up to 92% of the total impact profile of the manufacturing phase [115]. Thus, the excluded components were assumed to have a limited effect on the assessment of installation-related climate impacts, although the results should still be interpreted as a simplified estimate [131].

3.4.3.3 Graywater recycling

Because the potential water savings of the GWRS are assumed to be identical across implementation scenarios, it follows that the use-phase impacts, including electricity consumption of the GWRS, pump, and heat exchanger (3b), as well as the environmental benefits resulting from reduced water demand, are also identical. The differences between the implementation scenarios therefore lie in the production and construction/installation phase. The assessment focused on the dominant installation interventions, excluding minor local interventions, such as drilling and limited wall openings, as they were considered negligible compared to the larger demolition and reconstruction activities.

The installation of a GWRS requires a dual-pipe system with two additional pipes: one wastewater pipe collecting graywater and one pipe distributing treated graywater to end uses. In addition, expansion of the installation shaft wall is required to accomodate the additional pipes [14].

To estimate the required shaft expansion for the GRWS, a simplified reference shaft was first defined. This reference shaft was intended to represent a conventional shaft for the reference building, without the additional pipework needed for graywater recycling. The shaft was assumed to include one wastewater pipe, one hot water pipe, one cold water pipe and one hot-water circulation pipe. The chosen pipe diameters and insulation thicknesses were largely based on the example dimensions presented in the guidance document by Säker Vatten [132]. The requirement of at least 50 mm spacing between pipe insulation, or between pipe insulation and shaft wall, was also accounted for.

The shaft was then expanded by adding two pipes required for the graywater recycling system: one for untreated graywater and one for treated graywater. The untreated graywater pipe was assigned a smaller diameter than the regular wastewater pipe, as it only conveys wastewater from showers and hand basins. Similarly, the treated graywater pipe was dimensioned smaller than the cold and hot water pipes, since it only supplies water for WC flushing and laundry. See Appendix E for the final dimensions of the reference shaft and the expanded shaft.

The pipes included in the model were two vertical pipes in each shaft, two horizontal pipes in each bathroom (one underfloor shower pipe and one surface-mounted toilet pipe), one main collection and one main distribution pipe between the shafts and the GWRS, and one main distribution pipe for treated graywater to washing machines. Minor connection pipes to individual washing machines were considered negligible.

To calculate the required material quantities, several assumptions regarding the reference building layout were made. An overview of these assumptions is presented in Table 3.11, and a schematic illustration of the pipe layout is shown in Figure 3.7.

Table 3.11: Assumptions regarding the reference building

Parameter	Value	Motivation/Description
No. apartments per floor	10/9	The reference building was assumed to contain 10 apartments on four floors and 9 apartments on three floors, based on the estimated floor area of the building.
No. of shafts per floor	5	Typical shaft placements in multi-family buildings are either in the stairwell, where multiple apartments share a common shaft, or directly adjacent to bathrooms, where one shaft is shared by two apartments per floor [133]. In this study, the latter configuration was assumed to minimize uncertainty related to construction interventions outside the bathrooms. Furthermore, floor plans from several of Signalisten's buildings indicate that this is a common shaft placement in their housing stock [134].
No. of bathrooms (No. of bathrooms containing a shaft)	67 (35)	One bathroom was assumed per apartment.
Bathroom area	4 m^2	Based on a reference bathroom in Bidcon.

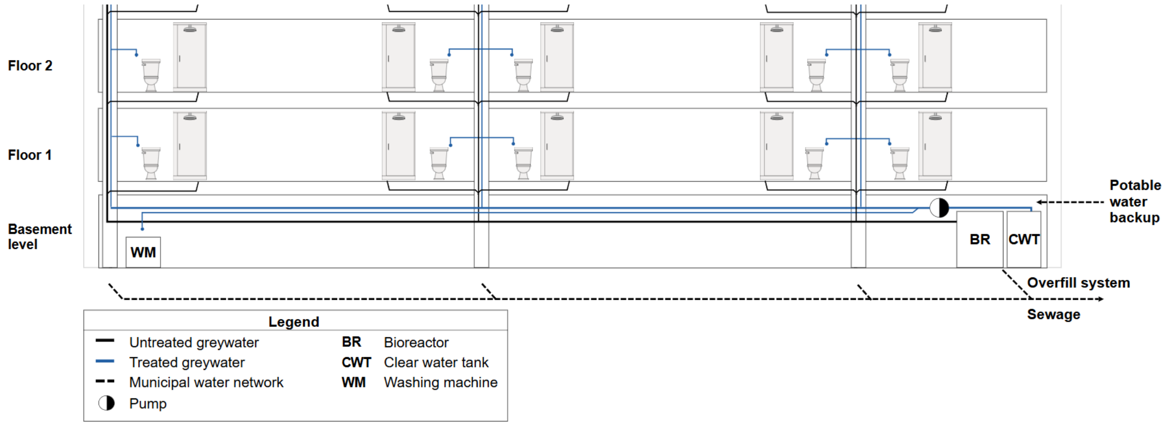


Figure 3.7: Schematic illustration of the cross-section of the reference building showing the pipe layout for the GRWS. Note that only three shafts are visible, as the remaining two are located behind the visible section.

In the retrofit scenario, demolition and reconstruction activities associated with the installation of the new pipe system were included. Information regarding the required construction activities, materials, and machinery was based on an LCA study on pipe replacement [106] and communication with the construction and renovation company Totalbyggarna.

To install the new graywater drainage pipe from the shower, the entire bathroom floor was assumed to be demolished down to the concrete slab. This assumption was made both to simplify the modeling and because waterproofing layers typically need to be fully replaced once breached in order to comply with GVK's branch regulations [135]. Furthermore, the upper concrete layer was assumed to be demolished to expose the existing pipe and install the new one. While Totalbyggarna states that demolition is typically limited only to the required pipe trenches, the interventions may still become relatively extensive in small bathrooms (Totalbyggarna, personal communication, April 26, 2026). Although conservative, the assumption of full floor demolition was therefore considered acceptable given the limited bathroom size. The floor drain was also assumed to be replaced in accordance with standard renovation practices (Totalbyggarna, personal communication, April 26, 2026).

For the treated-water supply pipe to toilets, surface-mounted piping was assumed. Consequently, no wall demolition was assumed for bathrooms without shafts. In bathrooms containing shafts, demolition and reconstruction of the wall section required for shaft expansion were included.

According to Berglund [106] and Totalbyggarna (Totalbyggarna, personal communication, April 26, 2026), the primary machinery equipment used for the demolition work includes demolition hammers (for concrete floor removal), industrial vacuum cleaners (for removal of fine construction waste and dust), vacuum suction trucks (for removal of heavier waste fractions), and dust traps (for capturing dust during demolition). Once the pipes are installed, the floor is rebuilt. Once the pipes are in place, a mixer and a material pump are used to pour a layer of concrete and EPS mixture, followed by a layer of screed to rebuild the floor [106]. The GWP associated with the use of these machines was estimated based on their operating time, which was determined using Bidcon and the operating times reported by Berglund.

In the renovation and new construction scenarios, only the additional interventions required for the GWRS installation beyond those already included in a traditional renovation (including pipe replacement) or new construction were considered. These consisted primarily of the additional piping and the material required for shaft expansion.

3.4.4 Cost calculations

This section describes the methodology used for the costs calculations, including Life Cycle Cost (LCC) and payback period (PBP) assessment. Product investment costs were obtained through email correspondence with suppliers and from company product websites. Installation, material, and labor costs associated with construction work were estimated using Bidcon. For simplification, the W&WW tariff and energy prices were assumed to remain constant over time.

3.4.4.1 Life cycle cost

LCC was calculated to account for both investment costs, O&M costs and annual cost savings of the systems. As the different solutions have varying lifetimes, the costs were annualised using the annuity method (equivalent annual cost), following an approach similar to that in Kärrman et al. [114], where the LCC of source-separating systems for wastewater, including graywater recycling, and food waste, are calculated. The following formula was used:

$$\begin{aligned} LCC &= (C_I + NPV_{RI}) \cdot ANF + (C_{O\&M} - S) \\ &= (C_I + NPV_{RI}) \cdot \frac{d}{1-(1+d)^{-n}} + (C_{O\&M} - S) \end{aligned} \tag{3.5}$$

where

LCC = Life Cycle Cost [tSEK]

C_I = Investment cost [tSEK], including all costs at year 0, i.e. the system investment cost as well as additional costs for installation and related expenses (e.g. building materials, piping, labor costs)

ANF = Annuity factor [-]

d = Discount rate [-], set to 4% following Kärrman et al.

n = Life time of the system [yr]

$C_{O\&M}$ = Annual O&M costs, including system and pumping electricity costs [tSEK]

S = Annual cost savings [tSEK], including savings associated with reduced water consumption and reduced energy demand for hot water

C_{RI} = Reinvestment costs [tSEK]

To account for reinvestments, the net present value of each reinvestment, NPV_{RI} in Eq. 3.5, was accumulated as follows:

$$NPV_{RI} = \sum_{i=1}^{k} \frac{C_{RI,i}}{(1+d)^{t_i}} \tag{3.6}$$

where

$C_{RI,i}$ = Cost of reinvestment i

k = Number of reinvestments

t_i = The year in which reinvestment i occurs

3.4.4.2 Cost savings

Similar to many previous studies (e.g. [44], [99]), the payback period (PBP) was used as an indicator of the economic attractiveness of a system alternative. The PBP is defined as the time required to recover the initial investment and, although often used as an initial screening metric, the method has been widely scrutinised due to several shortcomings [136]. In particularly, the method does not account for cash flows occuring after the payback period and is therefore poorly suited for handling unconventional cash flows, which may arise from large periodic reinvestments. Although efforts have been made to define the PBP for unconventional flows, no universally accepted approach currently exists [137].

Within the field of water-saving technologies, some studies account for reinvestments [138], [129], [37] while others do not [44], [99]. In this study, the simple payback method, assuming even cash flows according to Eq. 3.7, was chosen to provide a comparable and intuitive metric, while reinvestments were instead accounted for in the LCC analysis. Using PBP in combination with LCC is common practice, where the LCC serves as a complementary and more comprehensive assessment capturing long-term economic performance [137].

$$PBP = \frac{C_I}{C_{O\&M} - S} \tag{3.7}$$

3.5 Qualitative assessment

This section presents the qualitative assessment, including the literature review and semi-structured interviews conducted in the study.

3.5.1 Interviews

Interviews were conducted primarily to assess legal and practical feasibility and to identify drivers/enablers and barriers from a municipal and public housing company perspective. Since many water-saving technologies are still considered emerging technologies in Sweden, there is significant uncertainty regarding their implementation and legal frameworks [36]. Understanding how Solna municipality interprets and applies existing regulations, as well as their legal authority and decision-making processes, was therefore deemed essential for producing reliable results. Furthermore, interviews with property owners are necessary to understand practical feasibility and the support needed from the municipality to facilitate and encourage different solutions, as they are the ones with operational responsibility.

The majority of the interviews were semi-structured video interviews with a duration of approximately 45 minutes. While video interviews were preferred, as they allow for follow-up questions, written interviews were offered as an option for those unable to attend a video call or when a written interview was deemed sufficient. A list of the interviewees is provided in Table 3.12, and interview templates can be found in Appendix G.

Table 3.12: List of interviewees and related information

ID	Name	Role	Organization	Format	Main themes	Date
I1	Emelie Grind	Executive director	Building Committee (Solna municipality)	Video call	Municiapl governance, building permit, juridical barriers	2026-03-13
I2 I3	Erik Gunnarsson, Robin Olsson	Property manager, Project director	Technical Service Department (Solna municipality)	Video call	Technical feasibility and implementation	2026-03-18
I4	Municipal officer with expertise in environmental regulation and permitting		Environment and Health Committee (Solna municipality)	Email	Environmental regulation and permitting, juridical barriers	2026-03-18
I5	Marie Amid	Water strategist	Urban Planning Department (Solna municipality)	Video call	Municiapl governance, strategic perspectives on water management	2026-03-26
I6	Team (of three) with responsibility for strategic sustainability and water-saving measures		Signalisten	Email	Organizational strategy, enablers and barriers for implementing water-saving solutions	2026-04-02

Interviewees *I2*, *I3*, *I5*, and *I6* were invited to complete a voluntary survey to weight the MCDA criteria (the survey, in its original language, Swedish, can be found in Appendix G). These individuals were selected based on their expertise, representing either a strategic sustainability perspective or practical experience with the implementation of water-saving technologies.

3.5.2 Literature review

The literature review primarily informs the technical, social, and juridical assessment. The literature was collected from academic publications on GWRS, RHS, and water-efficient technologies, as well as from industry standards and product specifications. To address the final research question of the study, relevant legislation and case studies from other municipalities regarding municipal authority to support the implementation water-saving measures in the residential sector, were also examined. Additionally, cases where these technologies have been implemented were reviewed to capture insights from previous applications and identify factors influencing their performance and feasibility.

3.6 Sensitivity analysis

The robustness of the results was assessed through a sensitivity analysis involving the MCDA weighting, W&WW tariff, baseline water consumption, and the assumed flow rates of conventional and water-efficient fixtures (i.e. "high flow" and "water-efficient" in Table 3.8).

Since the MCDA weights are based on input from a limited number of respondents, they were considered uncertain. A sensitivity analysis was therefore performed in which the dimensional weights (i.e. the sum of all criteria weights within each dimension) were varied by +10%, representing different stakeholder priority scenarios. The remaining weights were adjusted proportionally to maintain a total of 100%. Moreover, a uniform weighting scenario was also included, where all dimensions were given equal weight.

Due to the payback calculation depending directly on the assumed W&WW tariff and its future development, a sensitivity analysis was also performed for the economic assessment. The static payback calculation, with a constant tariff, was compared with a dynamic model that accounts for future increases in the tariff as well as inflation. In the dynamic model, the W&WW tariff was assumed to increase by 4% annually until 2040, in addition to a general inflation rate of 2% per year. This assumption was based on Svenskt Vatten's estimate that W&WW fees need to increase by approximately 4% per year until then, excluding inflation, to meet future investment needs in municipal water and wastewater infrastructure [139]. Inflation was also applied to annual operational costs.

The effect of the chosen baseline water consumption was assessed by recalculating the results with the 25th and 75th percentile values from the consumption dataset, as seen in Figure 3.2. These values represented lower and higher consumption scenarios. Tank sizes and system configurations were, however, kept kept as defined for the baseline consumption case of 1.57 m^3/m^2/year.

Finally, the influence of the assumed fixture flow rates was evaluated through a sensitivity analysis. Due to the lack of information regarding both the distribution of water use across end uses and the efficiency of installed fixtures in Signalisten's building stock, the actual water-saving potential is uncertain. The end-use distribution was based on national average values reported by Svenskt Vatten, which may not reflect the specific conditions in Signalisten's buildings. Furthermore, as discussed in Section 2.6.1, there is no single definition of what constitutes a "high-flow" or a "water-efficient" fixture, and flow rates vary considerably between products. Since the base-case assumptions were based on relatively high flow rates for conventional fixtures and relatively low flow rates for water-efficient fixtures, three conservative scenarios were evaluated: (i) a 25% reduction in the assumed flow rates of conventional high-flow fixtures, representing a more efficient existing fixture stock; (ii) a 25% increase in the assumed flow rates of water-efficient fixtures; and (iii) a combined scenario where both assumptions were applied simultaneously.

3.7 Ethical considerations

The ethical considerations associated with this study are primarily related to the collection and handling of data, especially for the qualitative part of the study, and the interpretation and reporting of results.

Ethical considerations for conducting interviews include anonymity, privacy and confidentiality, voluntary participation, the option to opt out, and non-maleficence/beneficence [140]. These considerations were taken into account throughout the interview process. The conducted interviews were carried out on a voluntary basis, and participants were informed about the purpose of the study and the intended use of their responses. The option to opt out of answering any question was clearly communicated prior to the interview, and in cases where the interviews were recorded, verbal consent was obtained beforehand. The level of anonymity in how participants were referenced was determined by each participant. If requested by the participant, any quotes included in the report were reviewed by them in advance to ensure that their statements were not misrepresented.

Regarding the handling and communication of results, the assessment of the water and energy savings, as well as the LCA and LCC calculations, are based on a number of assumptions and simplifications which may influence the results. Efforts to ensure transparency have therefore been made through clear communication of assumptions and consistent documentation of data, sources, and methodological choices. This also aims to avoid overinterpretation and ensure reproducibility.

The artificial intelligence tool ChatGPT was used to assist in multiple stages of the study. ChatGPT was used to compare and select suitable cost items in Bidcon, identify relevant literature sources, and as a writing assistant tool for grammar correction. The tool was used cautiously, and all information and sources were critically reviewed and verified by the authors.

4 Results

This chapter presents the findings from the different parts of the assessment. First, results from the literature review are presented, including technical, social, juridical, and municipal governance aspects related to the evaluated systems. This is followed by a summary of the interview findings and the results of the quantitative assessment, including environmental and economic performance. Finally, the results are synthesised through the MCDA framework and complemented by a sensitivity analysis.

4.1 Literature review

The following sections summarize the main findings of the literature review.

4.1.1 Technical and social dimension

Presented in the following sections are findings related to the technical and social dimensions for each evaluated system, based on insights from previous studies and reported implementation experiences.

4.1.1.1 Water-efficient technologies

Technical dimension

Projects in which water-efficient plumbing fixtures have been implemented show varying performance and experiences. Folkesson et al. conducted a case study in Borås in which 100 municipally owned apartments equipped with kitchen faucets, bathroom faucets, and showers of energy class C–D were retrofitted with water- and energy-efficient alternatives of energy class A–B [141]. The study reported a 28% reduction in hot water use over an eight-month period. Although the project achieved water and energy savings, it also highlighted several technical challenges that may arise in retrofit projects, including longer waiting times, reduced perceived water pressure, and compatibility issues with existing installations, such as faucets not fitting existing basins properly.

Similar water savings, approximately 22%, were reported in a project by Uppsalahem where faucets and showers were replaced with water-efficient alternatives [68]. The authors describe that the positive outcome was partly due to lessons learned from previous unsuccessful retrofit experiences involving aerators. In those cases, restricting the flow through aerators was found to result in pressure variations in the piping system, blockages, and leakage problems. To comply with BBR's recommendations regarding waiting time, the study emphasize the importance of considering the performance of the entire plumbing system rather than only individual fixtures. For example, the installation of water-efficient toilets was considered unsuitable in the buildings because higher flow rates were necessary to avoid blockages in the wastewater system. Furthermore, the length of the pipes from the water heater to the tap may influences how well these fixtures perform. Longer distances result in extended waiting times, leading to increased water waste before the desired temperature is reached [142]. Ultimately, failing to account for these building-specific factors can counteract the potential savings.

While the technical implementation complexity of water-efficient fixtures may still be considered relatively low, since installation is generally similar to that of conventional fixtures, retrofit projects often require additional planning and adaptation to existing systems. Maintenance requirements may also increase due to compatibility issues between older piping systems and new low-flow fixtures, which can increase the risk of leakage and blockages. Consequently, retrofit projects may involve greater long-term maintenance requirements compared with implementation in new construction.

Social dimension

Several studies identify user behavior as a determining factor for the actual performance of water-efficient technologies and report so-called rebound effects, where water use increases after installation due to behavioral changes. These effects are often associated with perceived functionality and comfort, illustrating how technical performance is closely linked to social acceptance and user behavior, which may ultimately reduce the expected water and energy savings.

In the study by Folkesson et al., the technical implementation was complemented by a behavioral study examining factors influencing user acceptance [141]. Although the study showed an overall high acceptance of the new faucets, variations between applications were observed, with water-efficient kitchen faucets and showers generally receiving lower acceptance than bathroom faucets due to reduced perceived functionality. These fixtures were seen as more intrusive on the residents' everyday lives, for instance, when washing dishes or rinsing out shampoo, compared to bathroom basins. The study also identified correlations between acceptance and residents' personal values, suggesting that acceptance may increase when users receive continuous feedback regarding the effects and benefits of the intervention. As stated by the authors of the behavioral study: "When a water-saving function is inconvenient and benefits not recognised, familiarisation effects of water-efficient faucets do not occur quickly" [45].

In a water conservation program in Miami, where water-efficient plumbing fixtures, including toilets, showerheads, and faucet aerators, were retrofitted in single-family homes, the relationship between technical performance, resident habits, and user satisfaction was examined [143]. The study observed high product satisfaction, though initial water savings gradually decreased over time, indicating behavioral adaptation and increased water use habits following familiarisation with the fixtures. The authors described this as a rebound effect, suggesting that residents gradually adapted to the lower flow rates and modified their behavior accordingly, thereby reducing the long-term effectiveness of the intervention.

The observations from the two studies are consistent with the conclusions from a six-year study conducted by Scottish Water and Home Energy Scotland, which found that combining behavioral measures with technical interventions resulted in greater water savings than implementing either behavioral or technical measures alone [144]. The study highlighted the importance of continuous information, feedback, and user engagement for maintaining the long-term effectiveness of water-efficient technologies.

4.1.1.2 Rainwater harvesting systems

Technical dimension

The potential for potable water savings using rainwater harvesting systems has been widely investigated for various building types. Yildirim et al. [145] further show that RHS publications have increased steadily since 2005. Empirical studies on implemented systems, however, remain relatively limited, as much of the literature relies on simulation-based analysis. The available studies also differ considerably in their case-specific parameters, such as local rainfall, tank size, and end-use applications. As a result, significant variability is also found in reported savings. This section reviews relevant literature on RHS performance, with particular attention to Sweden and systems using harvested rainwater for WC flushing and laundry.

Although several RHS installations and pilot projects exist in Sweden, the number of systems that have been systematically reviewed is very limited. Some examples are three larger projects, Celsiushuset, LBVA and Sergelhusen, which are evaluated by Ivarsson et al. [146]. All three systems harvest roof-runoff and use it for WC flushing withing the building. The end-use for Sergelhusen however also includes irrigation of green areas. Potable water savings of approximately 30–60% of the intended end-use are reported in study [146], [147]. Based on the water use distribution reported by Svenskt Vatten, this corresponds to an approximate 6–13% reduction in total water demand. Although none of the three projects include residential buildings, they still provide important context for RWH systems in Sweden.

Examples of RWH systems in residential contexts include Röda Oasen in Malmö and a project by Gotlandshem in a newly built residential area in Hemse. While these projects have not undergone rigorous evaluation, they are still valuable examples of residential RHS implementation in Sweden.

Röda Oasen is a multi-family RHS project in Sweden that utilizes both drainage water from the property site and stormwater collected by the municipal network [148], [149]. The water is stored in underground tanks and treated in the building using membrane technology before it is used for toilet flushing and washing machines. Savings of 475,000 liters (approximately 40% of the buildings total water use) are estimated for the building every year, but measured performance data have yet to be reported.

In Hemse, roof-runoff is collected from several buildings within a residential area before its stored and used in washing machines in a shared laundry room [150]. To ensure no discoloration of clothes, the water passes through two filters before use. In addition to the RHS implementation, Gotlandshem also limits the number of in-apartment washing machines in new developments. By only installing washing machines in larger apartments (four bedrooms or more), residents of smaller apartments are directed to use the shared laundry room. No measured results of this project have yet been published.

The performance and overall reliability of an RHS is often reported to be dictated by several factors, one of which is local rainfall. While annual rainfall is often the baseline indicator of potential yield, Ivarsson et al. [146] argue that in the Swedish context, the variability of rainfall events (frequency and intensity) is a much stronger predictor of performance. This is based on the assumption of first flushers being included in the system, which will inevitably lead to some water losses. Hajjar [151] furhter notes that in the Swedish climate, where short-duration rainfall events are common, the diversion of initial runoff can decrease the total potential yield by up to 15%.

Another factor frequently mentioned is storage tank size. Undersized tanks result in frequent overflow and unutilized rainwater, while oversized tanks instead result in higher costs with no corresponding gains in yield, and consequently, water savings [152], [120]. End-uses associated with constant demand, such as WC flushing, are also identified as beneficial as they can allow for smaller storage devices while still providing potentially high water savings [153].

However, despite these technical optmimizations, one of the most important limiting factors of an RHS is the catchment area, and more specifically, the catchment-to-person ratio. Villarreal and Dixon [152] established that as building height and population density increase, the available roof area per inhabitant decreases proportionally, and with it, the available rainwater per person.

Because RHS performance depends on keeping key components functional over time, operation and maintenance should also be considered. Recommended maintenance typically includes regular removal of debris from roofs, gutters and filters; inspection of first-flush diverters and overflows; periodic checks of storage tanks, pumps and treatment components; and potential sediment removal [76].

Social dimension
Studies on perceptions of RWH suggest that attitudes towards harvested rainwater vary depending on the intended end-use. A study by Snelling et al. [154] found that public perceptions of RWH were mostly positive, although outdoor uses were generally preferred over indoor uses. Stec [155] similarly found that willingness to replace tap water varied between household uses and water sources, with rainwater generally being perceived more positively than graywater. In an earlier household survey, by the same author, willingness to install rainwater systems was also higher than for graywater systems. However, laundry remained a more sensitive end-use for both water sources [156].

Very limited information about user perception was found regarding reported Swedish RHS implementations. A study of Celsiushuset and Sergelhusen did, however, find that discolouration of harvested rainwater used for WC flushing did not negatively affect the user experience when users were informed about the reason behind it [157].

4.1.1.3 Graywater recycling systems

Technical dimension
If the number of reviewed RHS implementations and pilots in Sweden can be considered limited, the corresponding number of GWR projects is even smaller. HSB Living Lab, a residential research building in Gothenburg, and Junehem's Sörsjön project, a multi-family residential development in the municipality of Jönköping, represent two projects that fall in to this category. In contrast to rainwater harvesting systems, however, where performance depends on external factors like rainfall variability and available catchment area, graywater is generated by recurring human water-using activities. Graywater has therefore been described as a more stable or consistent source than rainwater, especially in studies of hybrid rainwater-graywater systems where graywater can compensate for variable rainfall supply [138], [158]. Modeling can therefore be a useful approach for estimating GWR potential, particularly when based on measured or disaggregated building water-use data [14]. Due to this, and the very limited number of Swedish implementations, modeled studies are included to broaden the basis for comparison. Findings from international implementation studies are also included to provide additional context on broader patterns in GWRS performance.

HSB Living Lab has been used as a basis for evaluating how different graywater reuse configurations affect water and energy savings. Knutsson and Knutsson [105] used disaggregated water consumption data from the building to simulate three GWR scenarios: reuse of bathroom sink water for toilet flushing, reuse of bathroom sink and shower water as hot water for sinks and showers, and a combined scenario where treated graywater was reused for both hot-water applications and toilet flushing. The results show that the selected reuse application strongly affects both the type and extent of water savings. The first scenario resulted in a 16.7% reduction in cold-water demand. The second scenario resulted in a 58.2% reduction in hot-water demand, along with an incidental 5.8% reduction in cold-water demand. In the third scenario, hot-water demand was reduced by 55.6%, while cold-water demand was reduced by 30.6%. The hot-water reuse scenarios also resulted in reductions in energy use for hot-water production of 43.5—46.8% [105].

HSB Living Lab should, however, be understood as a research and test environment rather than a conventional full-scale implementation. Dahlberg and Wallgren [159] report that the treatment configuration in the building has changed over time in order to test different end-use applications and treatment processes. Based on an interview with Jesper Knutsson, they report that the system has shifted from an earlier configuration where treated graywater was reused for showering to a later configuration with toilet flushing as end use, using a flocculation-based treatment process.

The more implementation-oriented Swedish example is Junehem's Sörsjön project in Taberg. Knutsson and Knutsson [105] describe the project as consisting of of 11 multi-family buildings with a total of 143 apartments, where graywater from showers, hand basins and laundry is treated and reused for WC flushing. Annual estimated water savings of approximately 3,300 m^3 are reported [105], [36]; however, it is unclear from the literature if the system has performed in accordance with this estimate during use.

The Junehem project, which is also studied by Alexandersson and Cammerudh [160], is also highlighted as an example of implementation in new production. Based on their comparison between implementation in an existing building and in new construction, they conclude that while the overall system principle can be similar in both cases, implementation in an existing building requires more extensive interventions in already installed water and wastewater systems. This affects both cost and feasibility of the implementation [160]. Another factor highlighted by Knutsson [99] is space requirements. In retrofit projects, limited available space can restrict which GWRS solutions are feasible and influence system sizing, and thereby also the achievable water savings.

Nolde [161] presents one of the few long-term accounts of graywater reuse for toilet flushing in multi-storey residential buildings. The system, which was installed in a Berlin apartment building with approximately 70 residents, had been operated for around ten years. Graywater from bathrooms was collected and treated before being stored and pumped to toilets for flushing. The reported experience indicates that GWRS can be operated over longer periods in multi-storey residential settings, provided that water quality, system operation and maintenance are properly managed. Nolde, however, also reported an energy demand of approximately 1.5 kWh per m^3 treated water, indicating that operational energy use can still be relevant factor even is the system is mainly introduced as a water-saving measure [161].

Concerning the maintenance complexity of GWRS, requirements differ between systems, with some being more automated and self-regulating than others. Responsibilities may also vary between suppliers, where some offer service and maintenance contracts while others place the responsibility on property managers. Generally, regular inspections and maintenance activities, such as cleaning, filter replacement, and component replacement, are required [14]. For example, the Intewa system considered in this study requires inspections every three to six months, filter replacement every two years, tank cleaning every one to two years, and quarterly flow tests [162]. However, the main potential barrier may not be the maintenance activities themselves, but rather the additional responsibility and knowledge required by property managers for operating and maintaining such systems, as highlighted by Werecki et al. [14].

Social dimension
In addition to technical and operational aspects, user acceptance is also identified as an important factor in the implementation of GWRS. Werecki et al. note that low public acceptance remains an implementation barrier in Sweden, largely caused by a lack of public awareness and the perceived health risks associated with reusing graywater [14]. Although concerns such as odour and colour may influence perceptions, there is also an inherent negative perception of graywater reuse, often described as a "yuck factor", which is independent of the actual water quality [163].

In the Swedish context, toilet flushing at HSB Living Lab was described as easier to communicate than shower reuse, partly because users are not in direct contact with the reused water [159]. Amaris et al. [164] and Gullberg et al. [165] similarly found higher acceptance for lower-contact uses, such as toilet flushing, laundry and irrigation, than for applications involving closer human contact.

Different studies report varying levels of acceptance of graywater reuse. A large-scale study [155] across twelve countries, including Sweden, found generally low acceptance, with only 39% of respondents reporting no concerns about its use, with higher acceptance in water-scarce regions and lower acceptance in countries such as Sweden. In contrast, another study [165] reported more positive attitudes overall, with approximately 80% of respondents expressing a positive view of graywater reuse. Although the results vary, both studies highlight awareness as an important factor, suggesting that increased information regarding the benefits of graywater reuse may improve public acceptance.

Overall, the studies indicate that acceptance of graywater reuse depends on several factors, including percieved health risks, availability to water, the intended application of the reused water, and the level of public awareness regarding its benefits.

4.1.2 Juridical dimension

The juridical dimension of RHS implementation is mainly related to the use of harvested rainwater as a non-potable water source within buildings. Ivarsson et al. [146] describe RWH as a still emerging practice in regions where water and wastewater infrastructure is already well developed and regulatory uncertainty is identified as an implementation challenge. The main legal and technical safety issue is preventing contamination of the drinking-water system, meaning that indoor RWH systems must be clearly separated from the municipal drinking-water system in accordance with Swedish requirements on protection against backflow and other contamination pathways [166], [167], [81].

Indoor use of rainwater can also create tariff-related issues, since W&WW tariffs are commonly based on the volume of drinking water supplied to the property. If harvested rainwater is used indoors, for example for toilet flushing, the volume of wastewater discharged from the building can exceed the metered volume of supplied drinking water.

This creates a mismatch between the basis for billing and the actual wastewater load. In Gotland, this was addressed by requiring an additional water meter [168], while Junehem abandoned initial plans to use rainwater for toilet flushing because questions regarding the W&WW tariff were considered too complicated [36]. For Celsiushuset, it was reported that no special permits were required, although the system was clearly communicated in the building permit documents.

Graywater recycling systems also require clear separation and prevention of backflow [90]. However, due to graywater originating from domestic wastewater, there are some additional juridical complexities. Isaksson et al. [169] explain that graywater is not clearly separated from blackwater in the Swedish legal framework. This means that source-separated graywater is generally treated under the same wastewater-related legislation, even though it is often less polluted. One uncertainty is therefore which quality requirements should apply when treated graywater is reused for different purposes [169]. This remains unclear for building-level reuse, since the EU regulation on minimum requirements for water reuse concerns treated wastewater for agricultural irrigation, rather than residential uses such as WC flushing [170]. Isaksson et al. [169], therefore, argue that clearer regulations or recommendations are needed so that local authorities are not left to make their own interpretations.

The Swedish projects, HSB Living Lab and Junehem, were handled differently by local authorities. For HSB Living Lab, where graywater was treated and reused for showering, an application to Göteborg municipality's environmental and health authority was required and approved with conditions [36]. For Junehem's system in Taberg, where treated graywater is reused for WC flushing, no permits were reported as necessary. Early communication with the municipality was, however, emphasized. Dialogue with local authorities was stated as important and helpful even if no formal permit process was required.

No specific juridical barriers were identified for water-efficient technologies. Unlike RHS and GWRS, these solutions do not introduce an alternative water source into the building, meaning there is no risk of backflow from a non-potable water system into the mains network. They are also described as already commonly available on the market [36]. Juridical considerations are therefore limited to general product and tap-water installation requirements like material suitability, drinking-water quality and prevention of microbial growth [166], [171].

4.1.3 Municipal governance and authority in water management

As public authorities, municipalities play an important role in the implementation of water-efficient technologies. Through legislation such as the Planning and Building Act (PBL), the Public Water Services Act (LAV), the Swedish Environmental Code (MB), and the Housing Supply Act, municipalities have several instruments that can influence the implementation of these solutions. Nevertheless, uncertainty remains regarding how and to what extent they can support or require such solutions [36]. Therefore, the following sections aim to outline municipal authority in water management, key limitations, and practical governance approaches.

4.1.3.1 The municipal planning monopoly

According to the PBL (2010:900, Chapter 1, Section 2) [172] municipalities hold the exclusive authority, commonly referred to as the municipal planning monopoly, to decide how land and water should be used within the municipality's geographical boundaries. Through detailed development plans, which are legally binding planning documents, the municipality can regulate several aspects of land use and urban development. Under Chapter 4 of the PBL, the municipality may, for example, regulate:

- land use boundaries between water areas, public spaces, industrial areas and residential areas (Section 5);
- the use and extent of buildings both above and below ground (Section 11);
- protective measures to prevent soil contamination, accidents, flooding, and erosion (Section 12); and
- the placement, design and execution of buildings and plots (Section 16) (author's translation).

In addition to the PBL, water, and stormwater, management is governed by the MB and the EU Water Framework Directive, which establish standards relating to water quality, public health, and the protection of water resources from pollution and hydrological hazards [173]. While the MB and the EU Water Framework Directive require property owners to manage stormwater and limit its environmental impact, including its pollution load and discharge to receiving waters, the PBL provides the regulatory tools that allow municipalities to set requirements for new constructions through detailed development plans. These requirements specify how stormwater shall be managed at the property level, e.g. infiltration, delay, or local stormwater treatment measures [174]. Consequently, there is an opportunity for the municipality to indirectly encourage RHS through stormwater management requirements that align with RHS functions, such as retention, as RHS can contribute to local water storage and reduced runoff.

The term indirectly is used because, although municipalities can require stormwater management and regulate the external design of buildings, they cannot impose specific technical solutions within detailed development plans. This relates to the prohibition against specific technical specifications (PBL 2010:900, Chapter 8, Section 4a), which prohibits municipalities from imposing their own requirements regarding the technical characteristics of buildings [172]. This effectively limits municipalities' ability to directly influence technology implementation at the building level.

The prohibition also applies to land allocation processes, where municipalities, in contrast to detailed development plans, generally have greater freedom to set conditions, for example related to sustainability objectives, since they own the land [175]. In so-called land allocation competitions, where multiple developers compete for the development rights to municipally owned land, many municipalities address this limitation by formulating specific requirements as ambitions, evaluation criteria, or voluntary commitments rather than binding requirements [176].

4.1.3.2 Municipal authority through water and wastewater tariffs

The municipality has authority over water services through its role as the water utility provider under the LAV, including responsibility for setting the W&WW tariff [177]. However, the legislation imposes restrictions on how tariffs may be designed, as pricing must follow the principles of cost recovery and reasonable and fair allocation. The first principle implies that tariffs should not exceed what is necessary to cover the costs of providing the water services. The principle of reasonable and fair allocation ensures that these costs are distributed proportionally among the users.

These principles limits the municipality's ability to use the W&WW tariff as a policy instrument to incentivise specific water-saving technologies. While the principles allow tariffs to vary with water consumption through volumetric pricing, municipalities cannot impose unjustified tariff increases or design tariffs that disproportionately disadvantage high consumers of water (e.g. with a progressive W&WW tariff where the unit price of water increases with higher consumption).

4.1.3.3 Municipal authority over municipal housing companies

Many municipalities fulfill their responsibility to ensure housing supply under the Housing Supply Act through ownership of a public housing company [178]. As owner, the municipality can influence the housing company through the ownership directive and articles of association, which give them the authority to for example appoint board members and shape political and strategic objectives, such as sustainability goals. However, public housing companies are required to operate according to business-like principles, meaning that decisions must support the organization's long-term financial profitability [175]. Consequently, municipalities cannot require their housing companies to invest in large-scale water-saving measures that are not considered financially justifiable. Furthermore, the principle of business-like operation restricts municipalities from distorting market competition by providing financial advantages to their public housing companies [178].

Solna is a special case, as the municipality does not own its public housing company, Signalisten. Instead, Signalisten operates as a foundation, meaning that it lacks a formal legal owner. This limits the municipality's ability to influence strategic decisions regarding sustainability, as the ownership directive does not apply [179]. While Solna municipality cannot govern Signalisten through the ownership directive, the municipal council is responsible for appointing the foundation's board members [175], and therefore still has the possibility to influence the organization indirectly by selecting board members who prioritize sustainability and water-saving measures. However, even then there are limitations on what can be decided, as foundations must operate according to their foundation charter, which defines the statutes and governance structure of the organization. The charter is established when the foundation is created, and is generally difficult to modify afterwards [175]. For example, statute 10, which states that "the foundation [Signalisten] shall strive to provide residential apartments at the lowest possible cost [...]" (author's translation) [180] could act as a barrier, similarly to the business-like principle, as large investments in water-saving technologies may be difficult to justify if they result in increased costs.

4.1.3.4 Examples of municipal governance approaches

Despite the legal, financial, and organizational constraints outlined above, there are several notable examples of Swedish municipalities supporting the implementation of water-saving technologies through both indirect and direct approaches. The following section presents a selection of these.

Facilitating implementation through guidance - Gotland
Gotland, which is a region prone to water scarcity, actively works to encourage water conservation. In recent years, the region has encouraged the use of rainwater for non-potable purposes, such as toilet flushing. Previously, the use of rainwater for this purpose was hindered due to a rigid W&WW tariff structure that assumed equal wastewater and drinking water volumes. As the tariff covers both water supply and wastewater services, but is billed solely based on the former, RHS created a mismatch by reducing potable water use without affecting wastewater volumes [181]. In 2021, increased local political support for promoting innovative solutions led to the formal approval of rainwater use for toilet flushing in Gotland [182]. To address the limitations of the tariff structure, an additional water meter was introduced, enabling separate billing of water use [168].

Following this regulatory change, the region has taken steps to facilitate the installation of RHS. These efforts include providing guidance materials and offering free water meters to households interested in implementing such systems. The main requirements are that property owners submit an application to Region Gotland, and ensure that the system is physically separated from the municipal drinking water system to eliminate any risk of contamination [168].

However, according to an interview published in 2025 in Gotland Idag, despite these efforts, the interest in installing RHS has been relatively low, with only three reported cases in three years. One explanation suggested in the article is the relatively low levels of rainfall in the area. The potential role of economical subsidies is also brought up by one of the property owners who have installed a RHS, arguing that subsidies could enable more people, particularly those with limited financial means, to benefit from rainwater harvesting. At present, the region considers RHS primarily a voluntary measure for which they do not provide financial subsidies [183].

Economic incentives - VA SYD, Mälarenergi
Although economic incentives through the W&WW tariff are generally limited, some municipalities encourage local stormwater management through reduced stormwater fees or one-time compensation schemes [184]. This typically involves managing stormwater on-site, either by delaying or by ensuring total on-site retention, rather than discharging it into the municipal stormwater network.

For example, VA SYD, the water utility serving Malmö and Lund, provides a compensation of 2500 SEK for each disconnected downpipe. While the primary aim of this measure is to reduce the load on the municipal drainage system, the additional benefits of using harvested water for purposes such as irrigation, toilet flushing, or cleaning are also highlighted [185].

Another example is Västerås, Mälarenergi, where residential property owners can receive a 50% reduction in the stormwater fee if all downpipes on the property are disconnected and stormwater from the roof is managed on-site, for example through infiltration systems or rainwater harvesting tanks. In this case, foundation drainage may still be connected to the municipal system. For complete on-site stormwater management, where no stormwater is discharged to the municipal network, a fee reduction of up to 80% can be granted. The remaining 20% covers the municipality's management of stormwater from public areas, such as local streets outside the property [184].

Innovation projects - VA SYD

One way to reduce the financial costs of investments in water-saving measures is through participation in research and innovation projects, typically involving collaboration between property companies, researchers, municipalities, and water utility companies. Such collaborations can create mutual benefits by enabling the testing of new technologies while reducing water consumption without placing the financial burden on the W&WW tariff [186].

One example is the VA SYD project Röda Oasen, where the RHS was implemented within the international EU project REWAISE (Resilient Water Innovation for Smart Economy), which aims to develop smart solutions for reducing drinking water consumption. As REWAISE is funded through the European research and innovation programme Horizon 2020, VA SYD receives EU funding for the project [186].

Land allocation - Malmö

Röda Oasen was only one of several innovation and sustainability projects developed in Sege Park. In 2016, Malmö municipality initiated plans to transform the area into a model district for sustainable urban development. The municipality outlined its sustainability ambitions in the land allocation prospectus, including goals on sharing economy and local systems for source separation [176].

Thirteen property developers were invited to submit proposals describing their interest in developing land in the area and the measures they intended to implement in order to fulfill the municipality's sustainability ambitions. Through a comparative selection procedure, the municipality selected the proposals that best aligned with the municipalaites ambitions [176].

Today, Sege Park includes several sustainable water management solutions, such as green roofs and RHS, as well as water-efficient technologies including urine-diverting toilets and low-flow taps and showers [187].

Inclusion of technical water in the water and wastewater plan - LBVA

The water utility in Halmstad, Laholmsbuktens VA AB (LBVA), has taken steps to support the implementation of technical water solutions by incorporating the concept into its W&WW plan. This includes defining "technical water," which currently lacks a standardised and legal definition in Sweden. LBVA defines technical water as "water that does not meet drinking water quality" (author's translation) [188], encompassing, for example, treated graywater, seawater, and stormwater. As the absence of a clear definition has been identified as a barrier to the implementation of technical water solutions by stakeholders in the drinking water sector in the Stockholm region [189], establishing such a definition may reduce uncertainty and create a clearer framework for how technical water can be managed and applied, at least at the local level.

In addition, LBVA's W&WW plan includes local strategies for managing technical water. For example, the potential integration of a separate distribution network, supplying industry and households with technical water for all end uses except drinking water, is being explored and included in detailed development plans [188]. However, this remains at an early stage, and current applications are largely limited to irrigation of football fields and water supply for sewer cleaning vehicles [190]. While LBVA plans primarily focus on system-level solutions, the case of LBVA can serve as an useful reference from which other municipaliteies can draw lessons when beginning to address technical water in the residential sector.

4.2 Summary of interviews

The following summary is based on the oral interviews and written responses listed in Table 3.12. Respondents are referred to by ID, role, or organization in the text to clarify the source of each statement.

4.2.1 Regulatory conditions

The interviews indicate that the regulatory process depends on how the system is designed and where it is installed. Interviewee *I1* noted that the need for a building permit, notification, or other permit likely depends on the design of the system. For new construction and renovation, stormwater management (which rainwater harvesting would likely fall under) is already included in the building permit process, meaning that a separate building permit is not necessarily required for this. If technical installations are placed inside the building, the issue may instead need to be handled through technical consultation, while outdoor placement may require a land permit. She also described new construction as easier from a planning perspective, since stormwater is handled early in the building permit process, while installation in existing buildings likely involves more of a process.

From the environmental and health protection perspective, Interviewee *I4* stated that there are no municipality-specific requirements for graywater or rainwater systems, but that such systems could possibly be considered wastewater and may therefore require a permit under the MB. She could not specify how requirements differ between end uses but referred to the MB's requirement for best available technology and the precautionary principle.

4.2.2 Municipal influence

Several respondents described the municipality's ability to require implementation as limited, especially in existing buildings. Interviewee *I1* stated that the municipality can encourage local stormwater management and work with climate adaptation in new construction, but that it is difficult to impose requirements when legislation is unclear or lacking. She also noted that stormwater management is an exception where the municipality has clearer possibilities to act.

Interviewee *I5* described the municipality's planning monopoly, strategy documents, detailed development plans, and development agreements as possible ways to express ambitions related to water management, including treatment, stormwater detention, and possibly water recycling. She also suggested that smaller pilot projects, for example, in collaboration between the municipality, a university, and a property owner, could be a more realistic way forward than broad economic subsidies to individual property owners.

Signalisten also pointed to the municipality's role, stating that the municipality could support implementation through economic incentives, but also through requirements linked to steering documents. They specifically mentioned that water-saving solutions could perhaps be rewarded in Solna's guidelines for sustainable construction.

4.2.3 Implementation feasability

The interviews suggest that implementation is generally easier in new construction than in existing buildings, although the reasons differ between respondents. Interviewee *I1* described new construction as easier because stormwater is handled early in the building permit process, while installation in existing buildings involves more of a process.

Interviewees *I2* and *I3* stated that the level of ambition may be the same across different implementation scenarios, but that what is actually implemented depends on what is possible to carry out. They also noted that building permits and approval processes can affect implementation, particularly because many older buildings are culturally classified, which can make changes more difficult.

Signalisten described water-efficient fixtures as easier to introduce in new construction because tenants experience the lower flow from the start. In existing buildings, however, reduced water flow can be perceived as a deterioration by tenants who are used to higher flow rates. Signalisten also highlighted technical constraints in existing buildings, especially the slope of wastewater stacks, which may not function well with the lower flows from low-flush equipment.

4.2.4 Economic barriers and considerations

Cost was a recurring theme across the interviews. Interviewee *I1* mentioned investment cost, maintenance responsibility, and the lack of good examples as possible barriers. She also expressed that housing companies in the Stockholm region are probably not currently choosing to invest in water-saving solutions, since the region is not perceived as having water scarcity.

It was also emphasized in the interview with *I2* and *I3* that cost and benefit need to be weighed against each other before graywater systems, rainwater systems, or water-efficient fixtures are considered. They pointed to the need for underlying data and decision support, and payback was mentioned as a relevant measure of economic savings.

Interviewee *I5* similarly described expensive technology as difficult to justify, especially because water is currently considered very cheap. This means that such solutions often need to be motivated by environmental reasons rather than direct economic savings, which she described as more difficult. She also emphasized the need to know that the systems work in the long term and are profitable.

4.2.5 Knowledge and experience gaps

A lack of knowledge and practical examples was raised by several respondents. Interviewee *I1* mentioned that there are few good examples of implemented systems and described current implementation as more likely in specific cases, such as where a property has experienced flooding or needs to secure water access in another way.

Interviewee *I5* emphasized the need for good examples and pilot projects. She described rainwater use for irrigation as a possible first step, after which the municipality could move further towards other types of water reuse.

Signalisten stated that circular graywater or rainwater solutions currently feel quite far from their practical reality, although they view them positively. They wrote that they would first need to learn more before implementing such systems in practice.

4.2.6 User acceptance and experiences

Signalisten described water-saving technology as both an opportunity and a barrier. The opportunity being linked to reduced water and energy costs, while the barrier can arise when tenants experience reduced water flow as a deterioration.

Signalisten also described a specific issue in senior housing, where low-flow mixers and taps have been difficult for some tenants to use. The hot water setting can spring back, requiring the user to keep holding the handle to maintain hot water. This was described as particularly difficult for older tenants and people with reduced hand strength and has led to fault reports and irritation.

Health and water quality concerns were also raised as potential barriers. Interviewee *I4* noted that reused water may contain contaminants, nutrients, and pathogens, and that these must not cause nuisance to people using the water. Interviewee $I5$ similarly identified contamination, fear that the water is not clean, and environmental and health risks as possible barriers to implementation.

4.2.7 Stormwater as a resource

Stormwater was discussed both as an existing municipal focus area and as a possible future resource. Interviewee *I1* described local stormwater management through green areas, underground storage, and ponds and mentioned that such measures need to be planned from the start.

Interviewee *I5* stated that the municipality is currently more focused on rainwater use for irrigation than on uses such as toilet flushing or showering. She described this as a possible first step. She also considered it a good and interesting idea to use existing or planned stormwater storage as a resource for nearby multi-family buildings but noted that the storage would need to be located close to the buildings. At the same time, she advocated open stormwater solutions over underground storage, since she considered underground storage expensive and difficult to manage.

Signalisten stated that in new construction and larger renovation projects, they work with landscape architects and stormwater investigations to address stormwater detention. They mainly work with rain gardens and infiltration rather than water storage and did not think they currently have stormwater storage at any property, although this is something they intend to look more into in the future.

4.2.8 Future relevance

Several respondents connected the issue of implementing technical water-saving solutions to future capacity restraints, resilience, or changing priorities. Interviewee I1 stated that Solna has continued building on existing systems for a long time and that the systems are beginning to reach capacity limits, which may make other water solutions more relevant in the future. She also suggested that graywater and rainwater solutions could become relevant from a resilience perspective, for example if they contribute to safer water access or reduce risks related to flooding.

When asked whether reduced water consumption in housing could contribute to reducing or postponing the need for investments in increased water and wastewater capacity, Interviewee I5 answered that it could but also said that it is likely not a matter of one single measure.

4.3 Results of the quantitative assessments

Table 4.1 presents the environmental performance of the evaluated systems, including estimated water and energy savings together with the LCA results. In the table, negative values indicate environmental savings or reductions, while positive values represent net increases. Due to model assumptions, there are no differences in energy and water savings between most scenarios. The only exception is 1-N, where a different reference water flow was applied compared to scenarios 1-R and 1-REN. Furthermore, since the implementation of RHS primarily concerned processes outside the building, GWP remained unchanged across all RHS scenarios. As GWP includes both environmental burdens and savings, a more detailed breakdown was conducted to better understand its composition, as shown in Figure 4.1, which illustrates the contribution of different life-cycle phases to the total environmental impact.

Table 4.1: Calculated environmental performance (and percentage change) for the evaluated systems and scenarios.

	1			2			3a			3b		
	R	**REN**	**N**	**R**	**REN**	**N**	**R**	**REN**	**N**	**R**	**REN**	**N**
Water savings [m^3/yr]	-3587 (-47%)	-3587 (-47%)	-2047 (-27%)		-312 (-4.1%)			-1971 (-26%)			-1971 (-26%)	
Energy savings [kWh/yr]	-89366 (-49%)	-89366 (-49%)	-55002 (-30%)		256 (+0.14%)			-63 (-0.03%)			-36754 (-20%)	
LCA (GWP) [kg CO_2eq/yr]	-970 (-39%)	-1170 (-47%)	-680 (-28%)		50 (+2.0%)		-70 (-2.8%)	-370 (-15%)	-370 (-15%)	-140 (-5.9%)	-440 (-18%)	-440 (-18%)

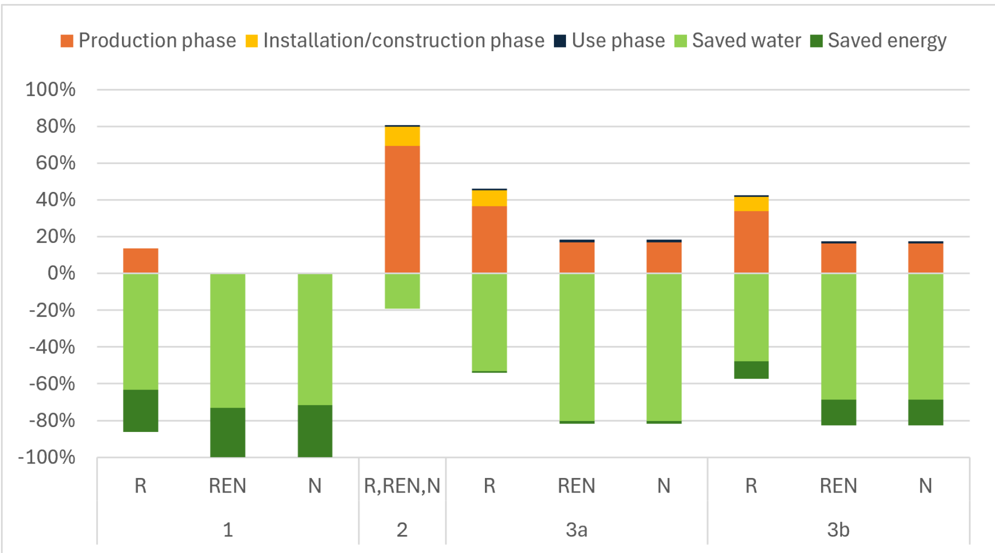


Figure 4.1: Breakdown of LCA by system and scenario, illustrating the share of environmental impact from the production, installation/construction, operational phase, and avoided impacts. Saved water represents environmental savings resulting from reduced water demand, while saved energy represents environmental savings resulting from reduced energy demand for water heating.

Water-efficient technologies show the highest environmental performance across all systems and scenarios, particularly in the retrofit and renovation scenarios, where replacement of high-flow fixtures with water-efficient alternatives results in the largest water savings. When today's standard fixtures are used as the reference, replacing them with water-efficient fixtures results in water savings of approximately 27%, compared to 47% when high-flow fixtures are replaced. For comparison, the water-saving potential of moving from water-efficient to BAT fixtures was calculated at approximately 37%. This indicates that although the marginal water-saving potential decreases as efficiency standards increase, there remains significant potential for additional water savings through the adoption of even more efficient fixtures.

In contrast to water-efficient technologies, GWRS shows its highest environmental potential in renovation and new construction scenarios due to lower production impacts from construction materials. Figure 4.1 shows that high water and energy savings can offset larger environmental burdens, as seen for example in scenarios 3a-R and 3b-R, which exhibit relatively high impacts from production and installation phases while still achieving net environmental savings overall. The figure further shows that the environmental benefits of most systems are primarily driven by reduced water demand, while energy savings become increasingly important for systems including heat recovery. From an environmental performance perspective, combining GWRS with heat recovery performs better than GWRS alone, even when the production impacts of the heat exchanger are included, as the additional environmental burden is outweighed by the environmental benefits resulting from recovered thermal energy.

RHS shows the lowest overall environmental performance among the evaluated systems. However, it should be noted that the total environmental burden of RHS, before accounting for avoided impacts, is the lowest among the evaluated systems. The lower overall performance is therefore primarily explained by its limited environmental savings rather than high environmental impacts. The low environmental savings of RHS can primarily be attributed to three factors. First, RHS achieves relatively low total water savings (approximately 4% of total water consumption, or 76.2% of water for laundry), which inherently limits its potential environmental benefits. Secondly, unlike GWRS and water-efficient technologies, RHS does not reduce hot water demand and therefore does not generate energy savings. Instead, RHS only contributes to increased energy consumption through its own operation. Finally, RHS primarily affects the water supply side of the municipal water system, i.e. water production and distribution to households, while a larger share of the environmental burden originates from wastewater collection and treatment. Consequently, the environmental benefits resulting from reduced water demand remain relatively limited.

Similarly to the environmental results, the economic performance of the evaluated systems is presented through overall performance indicators together with a more detailed breakdown of the underlying cost contributions. Table 4.2 presents the LCC and PBP results, while Figure 4.2 illustrates the contributions from CAPEX, OPEX, reinvestments, and generated savings. Negative LCC values indicate net economic savings, while positive values indicate net costs.

Table 4.2: Calculated economic performance for the evaluated systems and scenarios

	1			2			3a			3b		
	R	**REN**	**N**	**R**	**REN**	**N**	**R**	**REN**	**N**	**R**	**REN**	**N**
LCC [tSEK/yr]	-59	-72	-25		8		137	55	55	135	53	53
PBP [yrs]	6.8	5.1	8.7		82.1		188.9	70.4	70.4	110	46.2	46.2

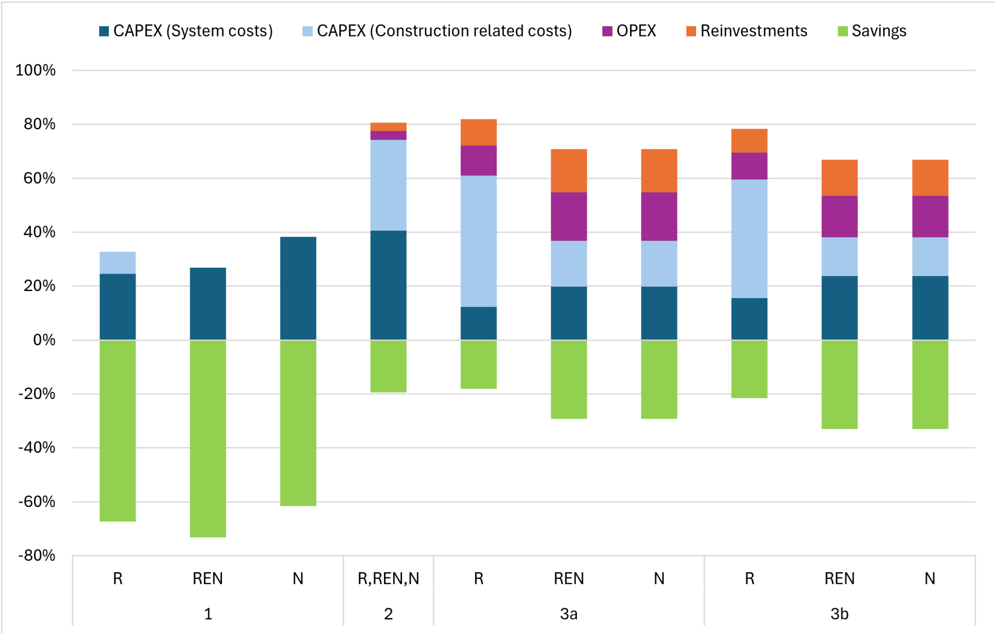


Figure 4.2: Breakdown of LCC by system and scenario, illustrating the contributions of CAPEX (capital expenditure) from system and construction-related costs, OPEX (operational expenditure), reinvestments, and generated savings.

As illustrated in Figure 4.2, the cost structures differ between the evaluated systems. While the economic performance of RHS and GWRS is largely driven by construction-related costs, the costs associated with water-efficient plumbing fixtures are primarily driven by system investment costs, which were the highest between the systems, due to the large number of fixtures required throughout the building.

Nevertheless, as shown in Table 4.2, water-efficient technologies achieve the strongest economic performance among the evaluated systems and are the only alternatives resulting in net life cycle savings across all scenarios. The relatively low investment costs combined with high generated savings result in short payback periods ranging from 5.1 to 8.7 years. Among these, 1-REN shows the strongest economic performance, with the lowest LCC and shortest payback period due to the absence of additional installation and demolition costs while maintaining high water and energy savings.

Both RHS and GWRS are generally not economically profitable within the assumed service lifetime, with 3b-REN and 3b-N being the only exceptions. However, while RHS results in relatively low life cycle costs (8 tSEK/yr), GWRS results in substantially higher LCC values ranging from 53–137 tSEK/yr. Although RHS has comparatively low LCC, the limited water and energy savings generated by the system result in low economic returns and consequently a long payback period.

The economic performance of GWRS is characterized by large differences across implementation scenarios together with comparatively high annual maintenance and reinvestment costs. Considerable differences in both LCC and PBP are observed across GWRS implementation scenarios, where 3a-R results in a PBP of 188.9 years compared with 70.4 years for both the renovation and new construction scenarios. This reflects that the largest cost contributions are not associated with the additional piping itself, which is shared across all scenarios, but rather with the demolition, reconstruction work, and additional materials required for installation in existing buildings. 3b result in slightly higher LCC values compared with 3a due to the additional costs associated with the heat exchanger, while the lower PBP indicates that the additional energy savings contribute to faster recovery of the initial investment.

4.4 MCDA synthesis

The quantitative results together with findings from the literature review and interviews were synthesised through the MCDA framework to provide an overall assessment of the evaluated systems across different implementation scenarios. The resulting unweighted MCDA scores are presented as a heat map in Table 4.3. In some cases, intermediate scores were assigned when the performance of a system was considered to lie between two scores.

Table 4.3: MCDA scoring matrix heatmap

Criterion	1-R	1-REN	1-N	2-R	2-REN	2-N	3a-R	3a-REN	3a-N	3b-R	3b-REN	3b-N
Water savings	1	1	0	−2	−2	−2	0	0	0	0	0	0
Energy savings	1	1	0	−2	−2	−2	−2	−2	−2	0	0	0
Greenhouse gas emissions	2	2	2	0	0	0	0	1	1	1	1	1
Life cycle cost	2	2	1	−2	−2	−2	−2	−2	−2	−2	−2	−2
Economic savings	1	1	1	−2	−2	−2	−2	−2	−2	−2	−2	−2
Acceptance	0.5	0.5	2	0	0	1	−2	−1	0	−2	−1	0
Implement. complexity	1	2	2	−1	−1	1	−2	−1.5	0	−2	−1.5	0
Maint. complexity	1	2	2	−0.5	−0.5	−0.5	−1	−1	−1	−1	−1	−1
Juridical complexity	2	2	2	0.5	0.5	1	0.5	0.5	0.5	0.5	0.5	0.5

The MCDA weighting survey achieved responses from 2 of the 4 respondents. Since respondents $I2$ and $I3$ submitted a joint response, only one weighting profile was ultimately obtained, which is presented in Table 4.4. The weighting profile indicates a prioritization of the environmental dimension, particularly energy savings and greenhouse gas emissions, while relatively little weight was assigned to water savings. This suggests that water savings alone are not considered a primary objective among the respondents when selecting water-saving measures. Among all criteria, LCC received the highest individual weight (25%), indicating a strong emphasis on long-term economic performance.

Table 4.4: Final criteria weights for the MCDA model

Dimension	Criteria	Weight
Environment (40%)	Water savings	5%
	Energy savings	20%
	Greenhouse gas emissions	15%
Economic (30%)	LCC	25%
	Economic savings	5%
Social (5%)	Acceptance	5%
Technical (20%)	Implementation complexity	10%
	Maintenance complexity	10%
Juridical (5%)	Juridical complexity	5%
Sum: 100%		**Sum: 100%**

The final weighted index scores are presented in Figure 4.3, which illustrates the overall sustainability performance of the evaluated systems across the different implementation scenarios. Figure 4.4 further presents the contribution of each dimension to this score.

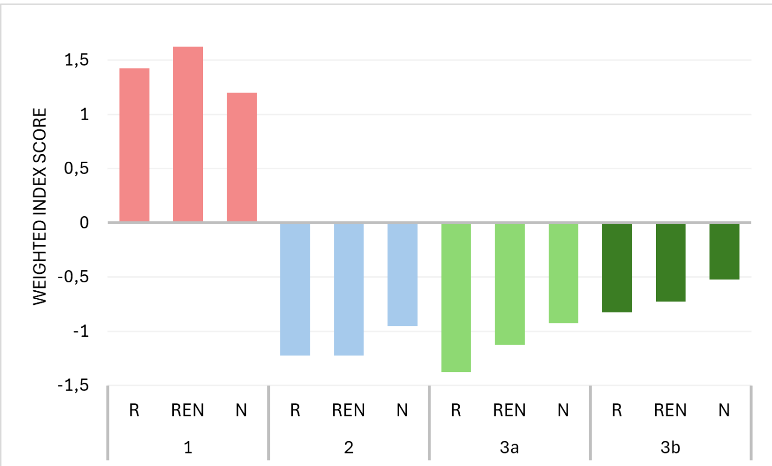


Figure 4.3: Comparison of Weighted Index Scores by system and scenario. Bars are grouped by system (1, 2, 3a, 3b) to show individual scenario variations (R, REN, N). Note: Unlike the MCDA scoring matrix heatmap, colors in this chart are used solely to differentiate between system alternatives and do not indicate positive or negative performance.

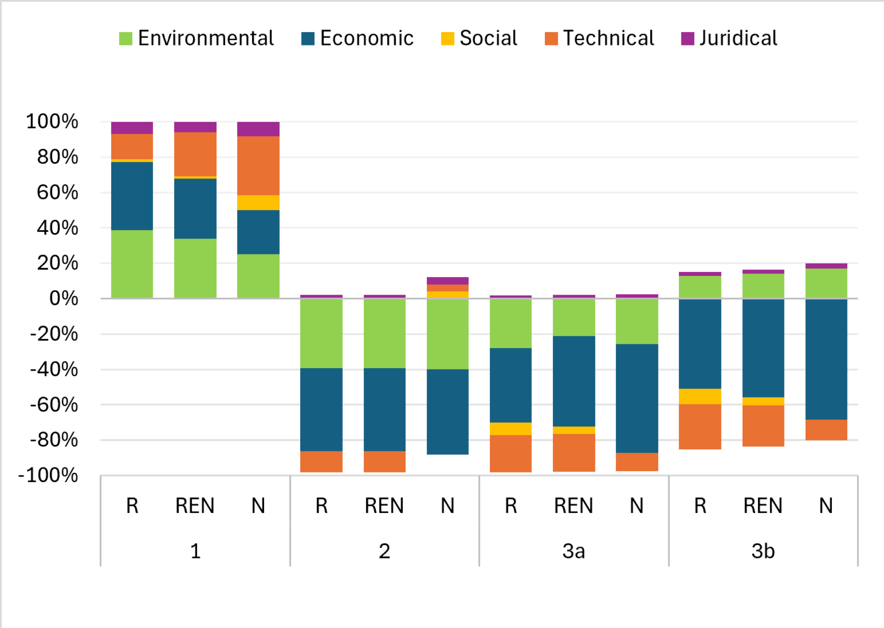


Figure 4.4: Dimensional contributions to the weighted index score by system and scenario. The bars illustrates the relative share and impact of each dimension on the weighted index score.

Overall, water-efficient technologies achieve the highest scores in all criteria, as shown in Table 4.3. Their strong overall performance is driven by consistently favourable results across multiple dimensions, particularly environmental and economic performance combined with low implementation and maintenance complexity, as illustrated in Figure 4.4. Among the scenarios, 1-REN achieve the highest overall scores.

RHS generally achieves the lowest overall scores, primarily due to limited environmental and economic benefits. However, in the retrofit scenario, 2-R outperforms 3a-R, largely due to its lower implementation and maintenance complexity as well as higher social acceptance. Among the RHS scenarios, the new construction scenario receives the highest score.

Although GWRS achieves moderate environmental performance, its overall score is penalized by weaker economic performance together with higher implementation and maintenance complexity, resulting in a negative weighted index score. The relatively small net energy savings achieved by GWRS without heat recovery further contribute to this result, particularly as energy savings received a high weight in the survey. However, the performance improves in renovation and new construction scenarios, where implementation-related burdens are reduced. Furthermore, the integration of heat recovery substantially improves the sustainability performance score due to the additional energy savings and increased economic savings.

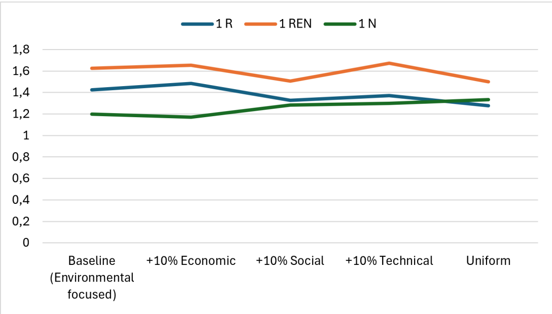
4.5 Sensitivity analysis

The results of the sensitivity analyses are presented in this section.

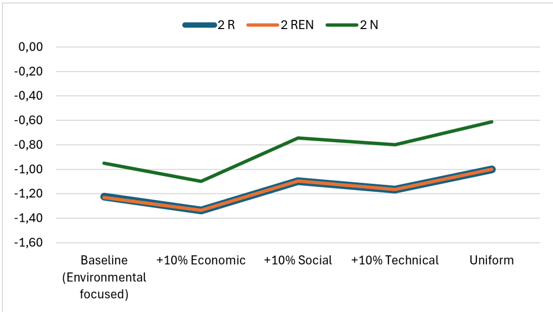
MCDA weighting

As the MCDA weights were based on a single response (hereafter referred to as the baseline weighting), a sensitivity analysis was conducted to test the robustness of the results. Given that the baseline weights already showed a prioritization towards environmental criteria, only the economic, social, and technical dimensions were increased by 10%. The juridical dimension was not adjusted in the sensitivity analysis, as it had a relatively low weight in the baseline scenario and its influence on the overall results was considered limited. However, the social dimension was adjusted despite having a similar baseline weight to the juridical dimension, as interviewees from Signalisten emphasized a high prioritization of social aspects.

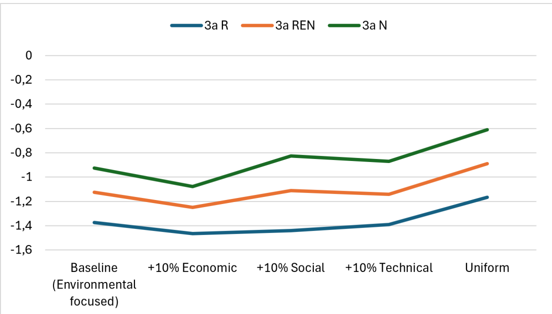
The results from the adjusted dimensional weights is presented in Figure 4.5. Overall, the results showed that the ranking of alternatives remained largely stable across the tested weighting scenarios. Although the final scores varied slightly, the relative performance of the alternatives was generally unchanged, indicating that the MCDA results are robust to moderate changes in weighting assumptions. One exception is water-efficient technologies, where changes in weighting between the social and technical dimensions affect the ranking. When these dimensions are given higher weight, scenario 1-N outperforms 1-R, whereas 1-R performs better under both environmental and economic prioritization due to its larger water savings.



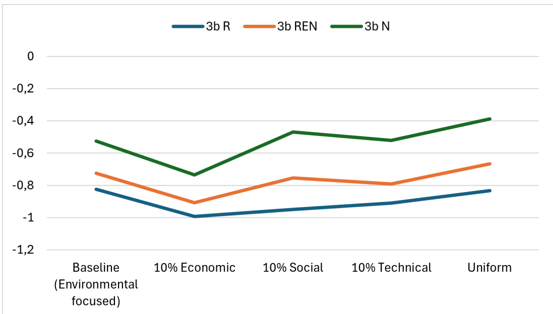
(a) Water-efficient technology



(b) RHS



(c) GWRS



(d) GWRS with heat exchanger

Figure 4.5: Sensitivity analysis of MCDA weights across the evaluated systems. The graphs illustrate how a +10% weight increase in the economic, social, and technical dimension, alongside a uniform distribution, impacts the final scores compared to the environmentally focused baseline.

W&WW tariff

The sensitivity analysis with varying W&WW tariff is presented in Table 4.5. The table shows the economic outlook under a 4% annual increase in the W&WW tariff up to the year 2040, in addition to an assumed inflation rate of 2%. The break-even tariff represents the tariff level at the point in time when full payback is achieved. The analysis showed a substantial reduction in PBP compared with the static tariff scenario, with all systems reaching payback within their service lifetime. The percentage change in PBP ranges between 47% and 77%, indicating that the W&WW tariff is a major determining factor for the economic feasibility of the technologies. In terms of break-even tariff, both GWRS and RHS reach payback at relatively high tariff rates. However, these values are not unrealistic in a national context, as seen in Figure 2.3.

Table 4.5: Sensitivity of PBP to a 4% annual tariff adjustment with 2% inflation

	1			2			3a			3b		
	R	REN	N	R	REN	N	R	REN	N	R	REN	N
PBP after tariff increase [yrs]	3.5	2.1	4.6		33.1		43.9	23	23	38.5	21.2	21.2
% change	-48%	-59%	-47%		-47%		-77%	-67%	-67%	-65%	-54%	-54%
Break-even tariff [SEK/m^3]	29.2	21.7	24.4		64.2		73.8	50.7	50.7	70.9	50.7	50.7

Water consumption

The sensitivity analysis of baseline water consumption is presented in Table 4.6 for the lower water consumption scenario and Table 4.7 for the higher water consumption scenario. The tables present recalculated absolute values rather than relative changes compared with the baseline case, as percentage changes became difficult to interpret for results with very small values, particularly energy savings.

Table 4.6: Resulting water savings, energy savings and GWP when using a lower water consumption (1.02m^3/m^2) than the baseline (1.57m^3/m^2).

	1			2			3a			3b		
	R	REN	N	R	REN	N	R	REN	N	R	REN	N
Water savings [m^3/yr]	-47%	-47%	-27%		-4.9%			-27%			-27%	
Energy savings [kWh/yr]	-49%	-49%	-30%		+0.14%			-4.0%			-21%	
GWP [kg CO_2eq/yr]	-35%	-47%	-28%		+3.3%		+5.2%	-14%	-14%	+2.3%	-17%	-17%

Table 4.7: Resulting water savings, energy savings and GWP when using a higher water consumption (1.84m^3/m^2) than the baseline (1.57m^3/m^2).

	1			2			3a			3b		
	R	REN	N	R	REN	N	R	REN	N	R	REN	N
Water savings [m^3/yr]	-47%	-47%	-27%		-3.7%			-22%			-22%	
Energy savings [kWh/yr]	-49%	-49%	-30%		+0.14%			+0.90%			-17%	
GWP [kg CO_2eq/yr]	-41%	-47%	-28%		+1.7%		-2.2%	-13%	-13%	-5.0%	-15%	-15%

Based on the results shown in Figure 4.7 and Figure 4.6, RHS is not impacted to any major extent by the change in water consumption, which can be explained by the savings of this technology depending more on the yield rather than the demand. The slight increase/decrease in savings can be explained by the unchanged tank size (slightly under/oversized) which results in a higher/lower coverage.

Graywater systems are intuitively more affected by water consumption since their performance is linked to both the amount of graywater generated and the demand for reused water. However, since the system configuration was kept unchanged, the graywater system could not make use of the higher demand in the same way as a resized system might have. This means that, in the high-consumption scenario, the same system covers a smaller share of the total water demand, which lowers the relative savings. In the low-consumption scenario, the opposite occurs: the fixed system covers a larger share of the total demand, although the lower total water use also limits the available graywater volume.

Similarly to graywater systems, the savings of water-efficient technologies are affected by the assumed water consumption level. However, their relative savings remain unchanged, as they scale directly with the assumed water demand. Their sensitivity was therefore assessed separately later in this section, by varying the assumed flow rates and flush volumes.

Fixture flow rates

The sensitivity analysis of fixture flow rates for the water-efficient technologies is presented in Table 4.8. The table shows the relative change compared with the baseline case for the three sensitivity scenarios described in Section 3.6. The sensitivity analysis showed that the results were sensitive to assumptions regarding the flow rates of both conventional and water-efficient plumbing fixtures, with the strongest effect observed in the combined scenario. In this scenario, the estimated water savings decreased from 47% to 28%, corresponding to a reduction of approximately 40% compared with the baseline case. Nevertheless, the water savings remained higher than those achieved by the RHS and GWRS in the reference building.

Overall, the ranking of the technologies remained largely unchanged. One exception is the new construction scenario, where increasing the assumed flow rates of the water-efficient fixtures reduced the estimated water savings to 14%, which is lower than the water savings achieved by the GWRS. However, the water-efficient technologies still performed better in terms of energy savings, climate impact and economic performance.

Table 4.8: Relative change (%) to the baseline case for water-efficient technologies under alternative fixture flow rate assumptions

Implementation scenario	Water savings	Energy savings	GWP	LCC	PBP
High-flow -25%					
R	-20%	-23%	+25%	+41%	+27%
REN	-20%	-23%	+21%	+33%	+28%
Water-efficient +25%					
R	-15%	-17%	+19%	+31%	+18%
REN	-15%	-17%	+15%	+25%	+20%
N	-45%	-43%	+45%	+83%	+80%
Combined					
R	-40%	-46%	+50%	+82%	+42%
REN	-40%	-46%	+41%	+66%	+75%

5 Discussion

In this chapter, the results of the study are discussed in relation to the assessed technologies, implementation scenarios and municipal context. The discussion addresses water and energy savings, climate performance, implementation feasibility, municipal governance conditions, study limitations and areas for future research.

5.1 Environmental performance

Looking at the resulting total water savings of the three technologies in 4.1, it is clear that the RHS is the weakest performer in this study. It is, however, important to interpret these results in relation to the reference building and the chosen end-use, as RHS performance is strongly determined by the relationship between available roof area, rainfall and demand.

Looking at the savings of the selected end-use (76.2%), the RHS initially appears to achieve a similar level of coverage as several of the projects evaluated in the literature (30–60% of end-use). However, this comparison changes when the size of the included end-uses is considered. In this study, the selected end-use, laundry, corresponds to approximately 7.5 L/person/day, meaning that the modeled coverage corresponds to about 5.7 L/person/day. As an illustrative comparison, the Swedish household average for WC flushing, of approximately 30 L/person/day, means that a 60% saving, which was reported for Celsiushuset [146] for example, corresponds to about 18 L/person/day. In reality, Celsiushuset is not a residential building, meaning this comparison should be interpreted cautiously. However, the main point is that WC flushing generally represents a larger demand category than laundry in the reference case. This is relevant for most of the reviewed Swedish RHS projects, where rainwater was primarily used for WC flushing, and in some cases, combined with other uses such as irrigation, rather than being limited to laundry alone.

The reason laundry became the relevant end-use in this study is also important. It was not selected because it offers the largest possible water saving, but because it provided a good match with the rainwater yield available from the reference building, which is preferable to easier optimize tank size. The maximum annual rainwater yield was estimated at 436 m^3, and laundry demand was estimated at 409 m^3, meaning that the modeled RHS was already limited by the relationship between roof area, rainfall and demand before the daily water balance was applied. Since rainwater yield is directly dependent on local rainfall patterns and catchment area, the discrepancy between the modeled result and some of the reviewed literature can likely be explained by differences in roof area per user, or catchment-to-demand ratio. Most reviewed projects were located in Sweden, meaning that although differences in rainfall pattern and local climate may contribute, they are unlikely to be the only explanation.

This suggests that the weak performance of the RHS in this study should not neccessarily be interpreted as a general limitation of rainwater harvesting but rather as a result of the limited rainwater yield available from the reference building. The selected end-use affects how this limitation is expressed, but it does not remove the underlying constraint: the available roof area is small in relation to the building's water demand. In dense multi-family buildings, the available roof area per resident can be relatively small, while the non-potable demand remains high, as suggested by Villarreal and Dixon [152]. Under these conditions, the system may be unable to supply a large share of the total water demand regardless of tank size. Increased storage capacity can reduce overflow losses, but it cannot compensate for a structurally limited annual yield.

Improving RHS performance would therefore require addressing the yield limitation. This would require either a larger catchment area or a lower demand connected to the system. In practice, increasing the catchment area may be the more relevant option, for example by connecting additional roof surfaces from the surrounding area to the same storage tank. Including other types of stormwater runoff, like in the case of Röda Oasen [149], could also increase the yield, but would likely require additional treatment due to higher contamination risks compared with roof runoff. Applying RHS in lower-density buildings with the same roof area would improve the catchment-to-demand ratio, but would not necessarily increase the absolute amount of potable water saved.

Water-efficient technologies consistently resulted in the highest total water savings in this study. The savings, ranging from 27–47% across the implementation scenarios, were somewhat higher than savings reported in the literature (22–28%). One possible explanation is that potential rebound effects related to user behavior were not included within the scope of this study. The calculations assume that reduced fixture flow rates translate directly into lower water use. In practice, users may instead partly compensate for lower flow rates by increasing the duration or frequency of use, for example by taking longer showers. This interpretation is supported by literature review findings showing that savings may decrease over time after implementation[143]. If behavioral responses were accounted for, the resulting savings may align more closely with findings from the literature.

The same uncertainty also affects the estimated energy savings for water-efficient technologies (which were the highest of any studied technology) since these are directly linked to reductions in hot water use. Any user behavior that reduces the expected water savings would therefore also reduce the associated energy savings.

The GWRS resulted in a 26% reduction in total potable water use, which is broadly consistent with the limited comparable literature identified in this study. In the HSB Living Lab study [105], the first scenario resulted in a 16.7% reduction in cold-water demand, while the third scenario resulted in a 30.6% reduction in cold-water demand. The result obtained in this study therefore falls between these two reported cold-water reductions, which is reasonable since the modeled system substitutes cold potable water used for WC flushing and laundry. This suggests that the modeled water-saving potential is not unrealistic but also that GWRS performance is highly configuration-specific. It should also be noted that the water-saving potential for GWRS in the reference building was constrained by both the selected system configuration and the available space. Due to the capacity of the selected INTEWA system, approximately 96% of the toilet flushing and shared laundry demand could be supplied with treated graywater. However, the maximum achievable water saving for these end uses is approximately 34%, assuming full coverage of the toilet flushing and laundry demand.

The energy results are more difficult to compare directly because the literature reports different energy mechanisms. The hot-water reuse scenarios in HSB Living Lab reduced energy use for hot-water production by 43.5–46.8%. These savings are linked to configurations where treated graywater is reused for hot-water applications, while the GWRS in this study does not. In this study, energy savings were instead estimated at

0.03% without heat recovery and 20% with heat recovery. The lower saving without heat recovery reflects that the system mainly substitutes cold potable water, while the larger saving with heat recovery shows the importance of recovering residual heat from graywater. The GWRS energy performance should therefore be interpreted as highly dependent on whether the system only reuses water or also recovers thermal energy from the graywater.

The results of the LCA in Table 4.1 broadly reflect the same overall pattern as the water-saving results, but they also show that water savings alone do not fully determine climate performance. This is clear from the two GWRS configurations, which achieve the same water savings but differ in GWP reduction due to differences in energy performance.

The LCA results should however be interpreted with some caution, as the absolute annual GWP differences between some alternatives are relatively small compared with the uncertainties in the assessment. The main value of the LCA is therefore not to provide a precise ranking but to show whether reductions in potable water use also translate into climate benefits once additional materials, system components and operational energy are included. In other words, the LCA helps avoid interpreting water savings as an environmental benefit by default and highlights the need to look at the system as a whole. At the same time, it is important to remember that only a partial LCA was conducted. Consequently, the LCA results should primarily be interpreted as an indicator of climate performance rather than a comprehensive measure of environmental performance, as only GWP were considered in the assessment. Additional environmental impact categories could potentially have influenced the relative performance of the alternatives, particularly as the technologies differ substantially in terms of materials, infrastructure requirements, and operational characteristics.

Looking at the GWP for the RHS, the slight increase is not necessarily surprising. The system introduces additional decentralised infrastructure into a building that is already connected to centralised systems, where large-scale treatment and distribution can benefit from economies of scale. At the same time, the RHS in this study only provides one main environmental benefit: the substitution of cold potable water. Unlike GWRS with heat recovery, it does not reduce hot-water demand or recover thermal energy. However, given the relatively small magnitude of the GWP increase, the result should be interpreted as an indication of limited climate benefit rather than as a definitive negative climate impact. Alternative configurations resulting in higher rainwater yield could potentially lead to different GWP outcomes.

The sensitivity analyses showed that, although the ranking of the technologies remained largely unchanged under the tested assumptions, the performance of the individual technologies depended strongly on the underlying conditions. The water consumption sensitivity showed that RHS was only affected to a limited extent, since its performance is mainly constrained by rainwater yield rather than demand. For GWRS, the effect was more pronounced, as the system depends on both available graywater and reuse demand. However, since the system configurations were kept unchanged, the results show how the selected systems perform under different consumption levels rather than how optimally resized systems would perform.

For water-efficient technologies, the achievable savings were particularly sensitive to the efficiency of the existing fixture stock. As increasingly efficient fixtures are installed, the marginal water-saving potential from further fixture replacement decreases.

While even lower flow rates, such as those associated with BAT fixtures, could theoretically increase the water savings further, the social assessment indicated that user acceptance may become a limiting factor. Signalisten reported complaints related to low flow rates, and previous studies have identified similar challenges. This suggests that achieving additional savings through further reductions in fixture flow rates may involve trade-offs between water savings and resident satisfaction.

In this context, GWRS and RHS may become more attractive in the future, as they can provide additional potable water savings without compromising the perceived functionality of the fixtures. However, unlike water-efficient technologies, these systems are not plug-and-play solutions and require careful planning and design. For GWRS in particular, the sensitivity analysis demonstrated the importance of balancing graywater yield and non-potable water demand, as both undersized and oversized systems resulted in less favourable outcomes.

5.2 The importance of implementation scenarios

While new construction was shown to provide the most favourable conditions for the implementation of all three technologies, by both the findings of the literature study and the interviews, this is especially true for the more complex solutions RHS and GWRS. Integrating these technologies at an early stage reduces the need for modifications to existing building infrastructure, which can be both costly and intrusive, as shown by the LCC results in Table 4.2. It also creates better conditions for system design, since spatial requirements and pipe routing can be considered from the beginning. Without the spatial constraints of pre-existing building design and plumbing system the modeled RHS or GWRS can be integrated into the building based on optimized design choices.

Retrofitting can be understood as the most difficult and constrained implementation scenario. Again, this is especially true for RHS and GWRS, but the interviews (see Section 4.2.6) show that even retrofit of water-efficient technologies can be negatively received when the user experience is perceived as noticeably deteriorated. As mentioned in Section 4.1.1.1, retrofit installations of water-efficient technologies may also involve technical compatibility issues with existing piping and can lead to an increased need for maintenance.

However, the economic results for water-efficient technologies show that a technically constrained scenario does not necessarily result in weaker economic performance. Both the LCC and calculated PBP are lower for retrofit than for new production, as shown in Table 4.2. While this may initially appear counterintuitive, it can be explained by the different baseline assumptions applied in the scenarios, both regarding the reference technology level and the allocation of costs. However, it is still interesting because it highlights that the economic attractiveness of a technology is not solely determined by the properties of the technology itself but also by what it replaces. This does not mean that water-efficient technologies are less relevant in new construction. Rather, it suggests that their value in new construction lies in prioritising efficient performance from the beginning and avoiding future retrofit needs.

For GWRS, the retrofit case is more straightforward to interpret. The LCC results and breakdown, shown in Table 4.2 and Fig. 4.2 for 3a-R and 3b-R, show substantially higher costs, with a larger share related to CAPEX. This reflects the more complex installation phase, which is also supported by findings from the literature study on the

Junehem project. The literature also indicates that limitations related to technical space, system sizing and integration with existing water and wastewater infrastructure can negatively affect implementation feasibility [99].

The RHS retrofit case should be interpreted somewhat differently. As mentioned, the evaluated RHS configuration was limited to shared laundry facilities, meaning it does not represent the additional indoor distribution work that would be required if rainwater were supplied to WC flushing throughout the building. However, this does not make the scenario unrealistic. Rather, it reflects a design choice based on a limited rainwater yield. Since the available yield was effectively utilized by the selected laundry demand, expanding the distribution system to WC flushing in its place would have increased piping complexity and cost without necessarily increasing the amount of rainwater used. In this sense, the RHS scenario represents a realistic low-intervention configuration, where the system is adapted to the yield limitation rather than designed around a larger end-use that the available rainwater could not fully supply. Furthermore, the RHS LCC was strongly affected by the assumed underground tank placement which requires excavation. This was selected as a conservative solution due to assumed spatial limitations in Solna which was raised as an issue to consider in early communication with Solna Vatten AB (Solna Vatten AB, personal communication, 2026). If indoor or above-ground tank placement were feasible, the LCC would likely be lower, improving the relationship between cost and water savings for RHS.

Implementation during planned renovation is an intermediate scenario. It may not provide the same freedoms that new construction does, but it can still be less restrictive than retrofitting. Looking at the LCC (see Table 4.2) for the three technologies, there is still a clear improvement for the REN scenarios compared to retrofit.

The implementation scenario also affects the interpretation of the LCA results, seen in Table 4.1. Similar to the LCC and PBP, the climate impact is not only determined by the technology itself but also by how much additional material and installation work is attributed to the intervention. Retrofit scenarios generally carry a larger additional burden, while renovation and new construction can allocate only the additional impact beyond already planned or standard work. In other words, the LCA results, like the economic results, depend strongly on what is assumed to be additional to the baseline scenario.

5.3 Municipal perspective

From a municipal perspective, the results of this study indicate that the main challenge is not only to identify technically suitable water-saving technologies, but also to understand how these can realistically be promoted within the municipality's limited authority. The literature review and interviews show that municipalities have very restricted possibilities to directly require housing companies to implement specific building-level technologies. This is particularly relevant for systems such as GWRS and RHS, which require substantial changes to building infrastructure and are therefore difficult to justify without clear economic, technical, or strategic incentives.

The municipality has some influence through planning processes, land allocation and stormwater requirements, but this influence is mostly indirect. Requirements related to local stormwater management can create more favourable conditions for RHS, since rainwater harvesting can contribute to a second environmental improvement that was not included within the scope of this study: reduced stormwater runoff. However, the municipality cannot generally require a specific technical solution, such as a rainwater tank or graywater recycling system, in detailed development plans. Similarly, the W&WW tariff is limited as a steering instrument, since it must follow the principles of cost recovery and fair allocation. This creates a mismatch between the type of support that housing companies may need and the tools that are actually available to the municipality.

This mismatch was also visible in the interviews. Signalisten already implements water-efficient technologies in its building stock, but has not yet reached the stage where RHS or GWRS are considered realistic measures. For such systems to become relevant, economic incentives and stronger knowledge support were requested. This is understandable in relation to the results of the cost analysis shown in Table 4.2. Water-efficient technologies had short payback periods and resulted in net life cycle savings across all implementation scenarios, while RHS and GWRS generally had much weaker economic performance under the static tariff assumption. In the adjusted payback analysis, all systems reached payback within their service lifetime when increasing W&WW tariffs were included. This shows that future tariff development may substantially improve the economic feasibility of the technologies. However, it does not mean that tariffs can be relied on as the main municipal incentive. In Solna, where the current W&WW tariff is very low relative to other Swedish municipalities, the immediate economic motivation for municipal property owners will likely remain weak.

The MCDA results further support this interpretation. Water-efficient technologies achieved the highest overall scores due to their favourable environmental and economic performance, as well as their relatively low implementation and maintenance complexity. This makes them the most realistic first step from a municipal perspective, especially in existing buildings and planned renovations. At the same time, the interviews show that even these relatively simple technologies can create social and technical barriers if tenants perceive reduced flow as a deterioration or if low-flow fixtures are poorly adapted to user needs. This suggests that municipal recommendations should not focus only on maximum water reduction, but also on functionality and user acceptance and awareness. In practice, this means that replacing clearly inefficient fixtures may be more suitable, and informing tentants of the importance of water reductions, than promoting the most extreme low-flow alternatives.

For RHS, as mentioned, the municipal role may be more closely connected to stormwater management than to drinking water reduction alone. The results of this study show that the evaluated RHS had limited potable water-saving potential in the reference building, mainly due to the relationship between roof area, rainfall and demand. This makes it difficult to motivate RHS solely as a water-saving measure in dense multi-family buildings. However, if RHS is considered together with local stormwater management, its municipal relevance may increase. In new developments, the municipality can express ambitions related to sustainable water management in land allocation processes or planning dialogues, even if specific technical requirements cannot be imposed. RHS may therefore be most relevant where it can potentially serve several purposes at the same time, such as reducing runoff, supporting irrigation, and replacing potable water for selected non-potable uses.

GWRS presents a different municipal challenge. The results show that GWRS has greater water-saving potential than RHS and that the inclusion of heat recovery can improve both energy and climate performance. However, the MCDA and LCC results also show that the technology is penalised by high costs, implementation complexity and maintenance requirements, especially in retrofit scenarios. This suggests that GWRS is unlikely to become widely implemented through general municipal recommendations alone. Instead, the most realistic pathway may be targeted implementation in new construction or major renovation projects, where separate pipe systems, treatment units and space requirements can be considered from the beginning. From a municipal perspective, GWRS may therefore be more suitable as part of innovation projects or demonstration buildings than as a broadly applicable requirement.

Pilot projects may be one way to bridge the gap between municipal ambition and limited formal authority. By collaborating with Signalisten, suppliers and researchers, the municipality could help reduce both financial risk and knowledge uncertainty without imposing direct requirements. Such projects could generate local experience, improve the evidence base, and demonstrate whether RHS or GWRS are practically feasible in Solna's building context. This would also respond to the knowledge gaps identified in the interviews, where both municipal actors and Signalisten expressed a need for more examples, long-term performance data and clearer decision support. If successful, pilot projects could make future voluntary implementation more likely by showing that the technologies are technically reliable, economically feasible, and acceptable to users.

Overall, the municipal perspective points towards a gradual rather than regulatory implementation pathway. In the short term, the most realistic measure is to continue replacing inefficient water technology with well-functioning water-efficient technologies, particularly in planned renovations and new construction. In parallel, the municipality can increase knowledge and reduce uncertainty by providing guidance, communicating good examples, and formulating voluntary ambitions in land allocation processes. The example of Gotland shows how municipalities can facilitate implementation by providing practical guidance material and administrative support for property owners interested in rainwater harvesting. However, the limited uptake in Gotland also suggests that guidance alone may be insufficient if the economic incentives remain weak. More complex systems such as RHS and GWRS should therefore not be dismissed, but their implementation is likely to depend on favourable future conditions such as increasing water tariffs, stronger environmental motivation, and practical examples through pilot projects.

5.4 Limitations of the study

The study is associated with several limitations and sources of uncertainty related to methodological choices, data availability, and simplifying assumptions, which should be considered when interpreting the results.

First, the methodological choice of using a fictitious reference building limited the possibility for detailed engineering based on building-specific conditions, requiring several assumptions regarding building characteristics and system implementation. As a result, differences between renovation and new construction scenarios could not be fully reflected in the calculations. This limitation was particularly relevant for GWRS, as its implementation required more extensive construction work. Since information regarding building characteristics (e.g. dimensions, layout, and available installation space) was unavailable, it was not possible to account for additional construction work and practical challenges that may arise during implementation, such as spatial constraints. Consequently, retrofit-specific challenges could not be fully represented, which may have led to an underestimation of the costs and environmental impacts associated with GWRS implementation in existing buildings. This was reflected in the results, where identical outcomes were obtained for the GWRS renovation and new construction scenarios.

Another limitation related to the fictitious reference building concerns the use of property-level rather than building-level data. Since a single property may consist of several building units, there is a risk that the reference building dimensions were overestimated. The impact of this limitation is expected to be relatively small for water-efficient plumbing fixtures and RHS. Water-efficient technologies are installed at component level, while the modeled RHS configuration can potentially serve multiple buildings within the same property. The limitation may be more significant for GWRS, as the modeled configuration was intended for a single building unit. In practice, multiple smaller systems distributed across several buildings may be required instead of one centralized system, potentially increasing costs and environmental impacts.

One of the major limitations of the study concerns the applied top-down approach for representing water consumption, as the assumptions used in the model may not fully reflect actual building conditions. The reference case was intended to represent a conventional building connected to the municipal water network without water-efficient technologies. However, since the actual installations in the buildings from which the consumption data were obtained were unknown, the observed water consumption may already reflect a certain degree of water efficiency. This could potentially lead to an overestimation of the savings associated with water-efficient technologies. It is reasonable to assume that the majority of the buildings contain older installations, as according to the available property list only three of the buildings from which water consumption data were obtained had undergone renovations. However, since the property list is outdated, additional renovations may have taken place between 2020 and 2025. A bottom-up approach based on specific installations and user behavior would provide greater control over model parameters and could potentially have reduced this mismatch.

This limitation was addressed in part through the water consumption sensitivity analysis, which tested lower and higher consumption levels. Although this does not remove the uncertainty related to the reference building, it provides an indication of how strongly the results depend on the selected baseline consumption.

Additional uncertainty concerns the data sources used in the quantitative assessment. Construction costs were estimated using Bidcon, where material prices may be higher than actual procurement costs due to the absence of company-specific discounts and supplier agreements. This may have resulted in an overestimation of investment costs, particularly for GWRS which has the most construction work, and thereby affected the LCC and PBP results. The

A limitation concerning the qualitative assessment is the interview selection. Interviews were only conducted with representatives from Solna, where experience with graywater reuse and RHS appeared to be limited. While this highlighted existing knowledge gaps and uncertainties surrounding these technologies, additional interviews with municipalities that have worked more actively with such systems, as well as housing companies with implementation experience, could have provided a broader understanding of governance approaches and implementation barriers and thereby strengthened the ability to address the research questions. Similarly, surveys or interviews with local residents could potentially have provided a more context-specific assessment of social acceptance.

Finally, a limitation of the MCDA assessment concerns the subjective nature of the scoring process, as the weighting and scoring were determined by the authors. Greater robustness could potentially have been achieved through stakeholder involvement or expert consultation during the evaluation process. However, the MCDA was primarily intended to synthesize and summarize the results. Therefore, greater emphasis should be placed on the relative ranking and differences between systems than on the absolute scores.

5.5 Future research

Future studies could further investigate alternative local water resource approaches beyond rainwater harvesting. Considering the relatively low rainwater collection potential from rooftops in Solna and the limited economic incentives resulting from low W&WW tariffs, broader approaches may be relevant. Specifically, approaches that combine local stormwater management with residential water-saving measures may be of particular interest, as municipalities generally have greater opportunities to influence such solutions through requirements related to stormwater management under the PBL. This could include the collection and utilization of stormwater or drainage water from the entire property rather than only rooftop runoff, potentially utilizing existing underground storage infrastructure, similarly to Röda Oasen. The spatial potential for such solutions could also be investigated by mapping existing underground storage infrastructure and its proximity to multi-family buildings. GIS-based analyses could further identify areas with high stormwater collection potential and locations vulnerable to flooding, thereby supporting optimized system placement and increasing urban resilience.

In this study, the water-saving technologies were assessed in isolation, meaning that potential synergy effects of combined solutions were not considered. Future studies could therefore investigate the performance of hybrid solutions and interactions between different technologies. This may be particularly relevant as buildings progressively adopt water-efficient technologies. For example, while water-efficient technologies reduce potable water demand, they may also reduce the amount of graywater generated. Since the performance and water-saving potential of GWRS depend on the availability of graywater, this may affect system sizing and overall system performance.

Although large-scale implementation of GWRS and RHS may currently appear distant, future studies could investigate potential scale effects and their implications for municipal water systems. Improved understanding of potential system-level benefits and risks may strengthen incentives for municipalities to facilitate and support the implementation of such solutions.

6 Conclusion

This study concludes that water-efficient technologies are the most suitable first measure for reducing potable water demand in Solna's multi-family buildings. In the used reference building, they were estimated to provide the highest potential water and energy savings while also showing the best economic and environmental performance across all implementation scenarios. GWRS may offer important long-term potential, particularly in new construction or major renovation projects and when combined with heat recovery. Its estimated higher costs, climate impact from added infrastructure, and implementation complexity, however, make it more scenario-dependent. RHS showed the weakest performance as a water-saving measure in the reference building configuration. The technology can, however, still be relevant in projects where rainwater harvesting can provide additional functions, such as stormwater management, or in projects where a larger catchment area improves the balance between rainwater yield and demand. Overall, the findings provide a basis for comparing the assessed technologies in the selected Solna context. However, the used MCDA weights should be interpreted as illustrative for decision-support rather than representing a robust stakeholder consensus.

The municipality's ability to support implementation is primarily indirect. While it cannot require specific building-level solutions, it can potentially support implementation indirectly through stormwater management requirements, land allocation criteria, practical guidance, knowledge sharing and by supporting collaborative pilot projects. The main barriers to implementation are high investment costs, regulatory and technical uncertainty, and limited municipal authority, while important drivers include increasing water demand, a changing climate, planned renovations and new construction, sustainability ambitions, and rising W&WW tariffs. The main conclusion is therefore that water-saving technology can be used in Solna to support reduced potable water use, but that implementation should follow a gradual pathway. Inefficient fixtures should be prioritized in the short term, especially in planned renovations and new construction. In parallel, uncertainty around RHS and GWRS should be reduced through, for example, collaborative pilot projects. These should preferably be carried out in new construction or major renovation projects, where technical integration, cost sharing and long-term monitoring are likely more feasible than in retrofitting, and where practical knowledge can be developed and shared with property owners to encourage wider implementation.

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A Data for defining the reference building

Table A.1: Overview of selected properties from Signalisten's 2020 portfolio and input data for defining the reference building

Property	Year built	Residential area [m^2]	Commercial area [m^2]	Total area [m^2]	No. residential units	No. of floors	Water consumption 2025 [m^3]
Bagartorp 1	1961	2098	206	2304	30	4	1952
Bagartorp 2	1960	1429	49	1478	18	4	1067
Bagartorp 3	1960	2100	356	2456	30	4	4529
Bagartorp 6	1960	4877	121	4998	68	14	7429
Bagartorp 7	1959	4893	120	5013	69	14	7751
Bagartorp 8	1960	4942	49	4991	69	14	6687
Bagartorp 9	1960	4942	45	4987	69	14	8003
Bagartorp 10	1960	5272	0	5272	87	14	7183
Bagartorp 11	1960	1877	157	2034	24	5	5870
Bagartorp 12	1960	1878	148	2026	24	5	1438
Bagartorp 13	1960	1877	157	2034	24	5	1925
Bagartorp 14	1961	1457	82	1539	18	4	5015
Bagartorp 15	1961	1456	52	1508	18	4	1173
Bagartorp 16	1961	2595	63	2658	36	4	2908
Gunnarbo 2	1963	3359	2062	5421	44	8	ND
Torsken 2	1960	7754	1974	9728	106	6	ND
Torsken 3	1961	8769	3204	11973	120	7	ND
Torsken 5	1960	6347	2240	8587	78	7	ND
Biet 2	1956	2180	0	2180	37	9	ND
Getingen 1	1956	7219	87	7306	105	10	ND
Humlan 1	1956 (2014)	4266	63	4329	66	4	ND
Myggan 1	1956 (2015)	2724	22	2746	33	4	2143
Myran 3	1957	4782	840	5622	72	11	ND
Sländan 2	1956 (2015)	2346	118	2464	34	5	ND
Bollen 2	1985	3732	2531	6263	64	6	13058
Fölet 1	1952 (2012-2013)	5405	51	5456	84	7	ND
Hästen 1	1953 (2009-2010)	3332	617	3949	54	4	ND
Ponnyn 2	1952 (2011)	3411	260	3671	54	5	4016
Ridskolan 1	1953 (2009-2010)	3626	129	3755	56	4	ND
Nordan 18	1971	15918	969	16887	219	16	63728
Nordan 20	1971	15658	1044	16702	217	16	
Hallen 8	1992	4548	3525	8073	72	7	18892
Hallen 9	1992	6225	230	6464	86	5	18785
Hallen 10	1992	5904	265	6169	81	5	ND

Property	Year built	Residential area [m^2]	Commercial area [m^2]	Total area [m^2]	No. residential units	No. of floors	Water consumption 2025 [m^3]
Kaptenen 1	1969	3017	0	3017	43	11	4257
Motorn 11	1982	8735	388	9123	114	8	ND
Rudviken 5	1985	2074	103	2177	35	5	3002
Blåhäggen 4	1951 (2003)	2507	175	2682	36	4	ND
Hängbjörken 1	1949 & 1951 (2001)	536	5186	5722	8	8	13985
Krönet 2	2005	4462	260	4722	59	7	8625
Krönet 3	1949 (1998)	6622	5	6627	98	6	10867
Körsbärsträdet 5	1949 (1995)	6625	185	6738	99	8	6901
Ripan 1	1959 (2001-2002)	12284	1905	14189	175	7	ND
Syrenen 1	1951 (2003)	1668	115	1783	24	5	1765
Utsikten 1	1949 (1997)	4894	53	4947	71	7	8269
Turkosen 1	1979 & 2011	12015	3239	15254	150	5	ND
Platån 19	1971	4164	2314	6478	60	11	22163
Platån 20	1971	6337	2228	8565	103	11	
Platån 21	1971	5698	2024	7722	81	11	ND
Platån 22	1971	2943	3196	6139	48	11	ND
Palsternackan 3	2019	4446	73	4519	77	8	ND

B INTEWA rainwater harvesting system

Figure B.1: Illustration of "Flat underground tank HD, 15.000 liters" by INTEWA [191]. Reproduced with permission from INTEWA.

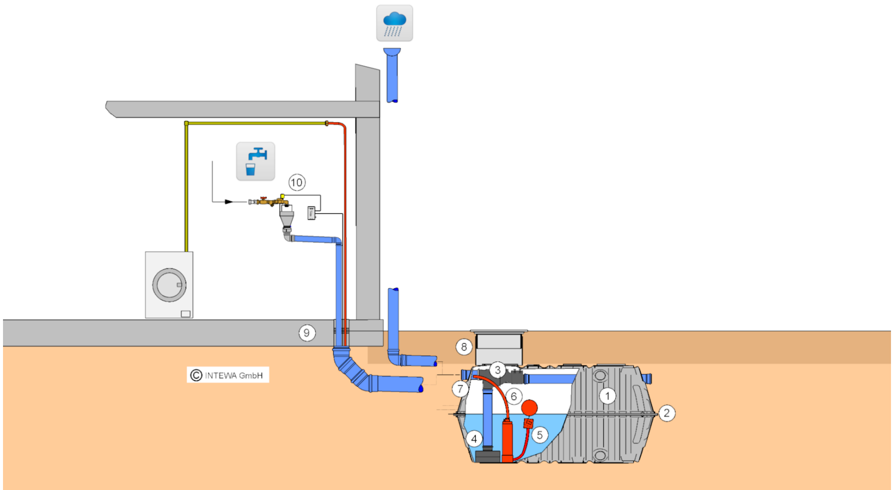


Figure B.2: Illustration of "Rainwater harvesting House-Basic-Kit 2.000 liter" by INTEWA [192]. Adapted with permission from INTEWA.

C LCA input data

Municipal water system

Table C.1: Energy consumption and GWP of the municipal water system per m^3 water

Service	**Energy consumption [kWh/m^3]**	**GWP [kg CO_2eq/m^3]**	**Source/Comment**
Water production (Norrvatten)	0.511	0.05	*
Water distribution (Solna Vatten)	$4.16 \cdot 10^{-4}$	$1.4 \cdot 10^{-6}$	** GWP was calculated based on Vattenfall's electricity mix.
Wastewater collection (Solna Vatten)	0.05	$1.75 \cdot 10^{-4}$	** GWP was calculated based on Vattenfall's electricity mix***.
Wastewater treatment (Käppala)	-0.06	0.19	Energy consumption was calculated based on the average net energy balance for the period 2020-2024 [23], [24], [25], [26], [27]. GWP was estimated using system expansion, where the environmental credit from the co-product compressed biogas was subtracted from the plant's total emissions of 2230100 kg CO_2eq [23]. This credit stems from the avoided emissions when biogas substitutes conventional diesel fuel in buses. In 2024, the plant generated 35,89 GWh of energy from biogas (3700000 Nm^3 with an energy content of 9.7 kWh/Nm^3 [193]) [23]. The emission factors used in the calculation were 2.52 kg CO_2eq/MWh for compressed biogas and 324 kg CO_2/MWh for diesel [194].
District heating (Norrenergi)	NA	$5.83 \cdot 10^{-5}$	Based on [195] and an assumed energy requirement of 60 kWh/m^3 for water heating [11].

* (Norrvatten, personal communication, February 14, 2026)
** (Solna Vatten AB, personal communication, February 11, 2026)
*** Vattenfall's electricity mix: 64% nuclear, with an emission factor of 3 g CO_2/kWh, and 36% hydro, with an emission factor of 4 g CO_2/kWh [196].

LCA data for the assessed technologies

Table C.2: LCA inventory data and assumptions for water-efficient technologies

Component/Process	Amount	GWP [kg CO_2eq/FU]	Comment/Source
1-R			
Production			
Plumbing fixtures	67 pcs. of each	183	see "production phase assumptions and modeling"
Installation/Construction			
Disposal of plumbing fixtures	67 pcs. of each	12.9	[110], [111], [112], [197], [198]
Installation	67 pcs. of each	1	Bidcon; no environmental impact from installing showerheads
Operational phase			
Avoided emissions (water savings)		-852.6	Calculated based on reduced water demand
Avoided emissions (energy savings)		-312.8	Calculated based on reduced energy demand for heating water
1-REN			
Operational phase			
Avoided emissions (water savings)		-852.6	Calculated based on reduced water demand
Avoided emissions (energy savings)		-312.8	Calculated based on reduced energy demand for heating water
1-N			
Operational phase			
Avoided emissions (water savings)		-486.6	Calculated based on reduced water demand
Avoided emissions (energy savings)		-192.5	Calculated based on reduced energy demand for heating water

Table C.3: LCA inventory data and assumptions for the RHS

Component	Amount	GWP [kg CO_2eq/FU]	Comment/Source
2-R, 2-REN, 2-N			
Production			
INTEWA RHS (tank, pump, filter)	1 pcs.	54.7	see "production phase assumptions and modeling"
Backfill material	53.5 m^3	6.4	[199]
Installation/Construction			
Excavation	76.7 m^3	2.2	Volvo EC300E [199]
Pipes	25 m	1.5	Bidon
Operational phase			
Pumping	217 h/yr	0.7	Power: 0.9 kW [200]
Avoided emissions (water savings)		15.6	Calculated based on reduced water demand

Additional assumptions used in LCA for GWRS:

- A floor-to-ceiling height of 2.5 m was assumed.
- The graywater pipe from the shower was assumed to be 2 m per bathroom.
- The treated water pipe connected to the toilet was assumed to be 1 m per bathroom.
- For bathrooms not containing a shaft wall, an additional pipe length of 0.5 m was assumed.
- The wastewater branch pipe connecting the shower to the horizontal wastewater collection pipe in the floor was assumed to be 0.5 m.

Table C.4: LCA inventory data and assumptions for the GWRS

Component	Amount	GWP [kg CO_2eq/FU	Included in	Comment/Source
Production				
INTEWA AL-GW5400	1 pcs.	69.2	all	See production phase assumptions and modeling.
Heat exchanger Geiser AT 8455	152 kg	12.2	3b	Alfa Laval heat exchanger T21-BFM/AQ8T-BFM used as proxy [201].
Shaft wall	119.4 m^2 / 31 m^2	60.3 / 15.7	R / REN, N	Bidcon.
Shaft pipes (graywater)	105 m	2.9	all	Modeled with PP Nordic pipe [202], diameter: 75 mm.
Shaft pipes (treated water)	105 m	4.1	all	Pipes modeled with LK PAL pipe [203], insulation modeled with stone wool [204], diameter: 20 mm incl. 50 mm insulation.
Distribution pipe to laundry	25 m	3.6	all	Modeled with LK PAL pipe [203], diameter: 32 mm incl. 10 mm insulation.
Main collection pipe (graywater)	35 m	0.4	all	Modeled with PP Nordic pipe [202], diameter: 110 mm.
Main distribution pipe (treated water)	35 m	2.1	all	Modeled with LK PAL pipe [203], diameter: 32 mm incl. 10 mm insulation.
Graywater shower pipe (in bathroom)	150 m / 116.5 m	4.2 / 3.2	R / REN, N	Modeled with PP Nordic pipe [202], diameter: 75 mm.

Component	Amount	GWP [kg CO_2eq/FU	Included in	Comment/Source
Treated water pipe (in bathroom)	83 m	1.5	R	Modeled with Altech chrome plated copper pipes [205], diameter: 12 mm.
Floor (building material)	268 m	173.2	R	Bidcon.
Floor drains	67 pcs.	2.7	R	Bidcon.
Installation/Construction				
Waste disposal shaft walls	84.9 m^2	0.9	R	Wall composition: gypsum board x2 [206], plywood [207], steel studs [208], insulation [204].
Waste disposal tiles (floors and walls)	387.4 m^2	1.8	R	Modeled with VitrA Karo floor tile [209].
Waste disposal walls	34.5 m^2	0.4	R	Wall composition: gypsum board [206], plywood [207], steel studs [208], insulation [204].
Waste disposal floors	268 m^2	11.7	R	Floor composition: waterproofing membrane [210], screed [211], EPS cement [212].
Waste disposal grout (floors and walls)	3.9 kg	0.02	R	0.5 kg/m^2 [106]; modeled with LIP Rustic Grouts [213].
Waste disposal patching material (floors and walls)	1549.4 kg	0.2	R	4 kg/m^2 [214], modeled with Höganäs patching material [215]
Waste disposal wastewater pipe (in bathroom)	33.5 m	0.9	R	Wastewater pipe modeled with PP Nordic pipe (75 mm) [202].
Waste disposal toilet pipe (in bathroom)	83 m	0.002	R	Modeled with Altech chrome plated copper pipe [205], diameter: 12 mm.
Waste disposal floor drains	67 pcs.	1.2	R	Modeled with Purus floor drain Brage [216].
Demolition hammer	335 h	0.04	R	5 h/bathroom (Bidcon), modeled with Hilti TE 1000-AVR (1.6 kW) [217].
Vacuum suction truck	74 h	59.6	R	1 h/bathroom [106], modeled with Relita 55 (fuel consumption 12.5 L diesel/h) [218].

Component	Amount	GWP [kg CO_2eq/FU	Included in	Comment/Source
Industrial vacuum cleaner	333 h	0.03	R	~5 h/bathroom [106], modeled with KÄRCHER WD 7 Control PS (1.4 kW) [219].
Dust trap	444 h	0.02	R	6.6 h/bathroom [106], modeled with Pullman Ermator A2000 (0.75 kW) [220].
Mixer	55.5 h	0.007	R	0.8 h/bathroom [106], modeled with Collomixer XQ6 (1.75 kW) [221].
Material pump	55.5 h	0.02	R	0.8 h/bathroom [106], modeled with Nordic 5.5 (5.5 kW) [222].
Operational phase				
INTEWA AL-GW5400		6.6	all	Energy consumption: 1 kWh/m^3 [162].
Pumping		15.6	all	Modeled with Nuvos110S (1.1 kW) [223], VDF (40% average energy savings) [224].
Avoided emissions (water savings)		-468.6	all	Calculated based on reduced water demand.
Avoided emissions (energy savings)		-7.8 / -95.6	3a / 3b	Calculated based on reduced electricity demand for heating water / reduced district heating demand for heating water.

Production phase assumptions and modeling

Water-efficient technologies

The cradle-to-gate impacts of water-efficient plumbing fixtures were estimated based on EPDs for specific products. Although a specific product may not be fully representative of all plumbing fixtures within a given category, it was considered sufficient for providing an approximate estimation. The total GWP amounted to 183 kg CO_2/yr, which would only be added as an environmental burden in the retrofit scenario. Table C.5 presents the climate impacts from the production phase (A1–A3) of all plumbing fixtures in the apartments of the reference building, together with the EPDs the values are based on.

Table C.5: LCA cradle-to-gate phase based on EPDs for water-efficient fixtures

Plumbing fixture (67 pcs.)	kg CO_2eq/FU	Based on	Source
Bathroom basin	29	Mora MMIX II Eko+ Basin chrome	[110]
Kitchen sink	30	Damixa core kitchen mixer	[111]
Shower head	6	New Tempesta 100 II hand shower	[112]
Toilet	118	Laufen bathrooms sanitary ceramic, Gustavsberg duroplast toilet seat	[197] [198]
Total	**183**		

RHS

The material composition of the RHS was associated with high uncertainty due to limited available data. The tank, filter and pump were included, which in a single-household RHS accounts for approximately 62% of total embodied carbon according to Parkes et al. [40]. To partially address missing components, a conservative assumption was made by applying a higher GWP value for the PE tank. Table C.6 presents the included components and how they were modeled. The total GWP amounted to approximately 55 kg CO_2eq/yr.

Table C.6: LCA cradle-to-gate phase based on bill of materials for RHS

Component	Main material	Weight [kg]	GWP [kg CO_2eq/FU]	Modeled with	Database/Source
Tank	PE	802	40	15000 L underground PE tank incl. concrete shell	[40]
PURAIN filter	PP	1.95	0.1	(1) PP resin (2) Plastic injection moulding; PP, HDPE and PE	(1) Plastics Europe [225] (2) GaBi [226]
Pump (submersible)	EPDM, stainless steel	11.8	14.6	Generic pump (electromechanical)	[40]
Total			**54.7**		

GWRS

The GWP of the cradle-to-gate phase of GWRS was based on bill of materials for the INTEWA AL-GW5400 system. However, only the main material of each component could be estimated, and the assessment covered approximately 84% of the total system mass. As a result, the precision of the estimate is low, and the calculated value is likely an underestimation of the actual climate impact. The lower bound was estimated to be approximately 69 kg CO_2eq/yr. The bill of materials and estimated GWP for each component are presented in Table C.7, while the service life used to relate the GWP to the FU for each component is presented in Table C.8.

Table C.7: LCA production phase (lower bound) based on bill of materials for the INTEWA AL-GW5400 graywater system

Component	Main material	Weight [kg]	GWP [CO_2eq/FU]	Modeled with	Database / Source
Graywater system (INTEWA AL-GW5400)					
Bioreactor storage tank	HDPE [227]	240 [227]	10.6	(1) HDPE granulates (2) Blow moulding; PET, HDPE and PP	GaBi [226]
PURAIN filter	PP [162]	7.4 [162]	0.4	(1) PP resin (2) Plastic injection moulding; PP, HDPE and PE	(1) Plastics Europe [225] (2) GaBi [226]
AQUALOOP membrane station	PVC [162]	37,5 [228], [162] (3 pcs.)	1.7	(1) Suspension PVC (2) Film extrusion (blowing); PP, PE, PVC, PET and PS	(1) Plastics Europe [225] (2) GaBi [226]
Membrane cartridge	PE [162]	28,8 [162] (18 pcs.)	6.9	(1) LDPE granulates (2) Extrusion with blowing agent; LDPE and EPS	GaBi [226]
Pipe diffuser	EPDM [229]	18 [229]	1.3	Ethylene propylene diene elastomer (EPDM)	GaBi [226]
Sludge pump	PP [230]	4 [162]	0.2	(1) PP resin (2) Plastic injection moulding; PP, HDPE and PE	(1) Plastics Europe [225] (2) GaBi [226]
Growth bodies	HDPE (recycled) [162]	65 [162]	1.5	(1) Recycled HDPE granulate (2) Plastic injection moulding; PP, HDPE and PE	(1) Ecoinvent v3.10 [231] (2) GaBi [226]
Clear Water tank	HDPE [232]	98 [232]	4.3	(1) HDPE granulate (2) Blow moulding; PET, HDPE and PP	GaBi [226]
I-CONNECT system control	Sheet steel [162]	18 [162]	3.2	Control panel (electromechanical)	[40]
AL-BL200 Blower	Cast iron [233]	25 [162] (3 pcs.)	2.2	Cast iron	[234]
Pump (Nuvos 110S)					
Pump	NA	30 [223]	36.9	Generic pump (electromechanical)	[40]
Total			**69.2**		

Table C.8: GRWS component service life for the INTEWA AL-GW5400

Component	Service life [yrs]	Source
HDPE water tank	50	[41]
Membrane station	50	[233]
Purain filter	50	Assumption[a]
Growth bodies	50	Assumption[b]
Aeration system (pipe diffusor)	50	[233]
Controls	25	[233]
Air blower	15	[233]
Membrane cartidge	10	[162]
Pump	10	[233]

[a] While checkups are required, the product website [235] does not state that replacement is necessary.
[b] No information indicating that replacement of the growth bodies would be needed was found.

D LCC input data

The utility prices presented in Table D.1 were used to estimate operational costs and savings associated with reduced water consumption and hot water demand.

Table D.1: Utility tariffs and prices used for operational cost and savings calculations

Parameter	Price	Source
Variable W&WW tariff	19.30 SEK/m^3 delivered water	[30]
Variable electricity price	1.73 SEK/kWh	Calculated based on the electricity spot price [236], grid fee [237], and electricity tax [238].
District heating price	498.5 SEK/MWh	Weighted annual average price based on [239]

Construction-related investment costs were primarily estimated using Bidcon. Detailed screenshots of the Bidcon calculation sheets are included at the end of this appendix for transparency. Additional investment, maintenance, and reinvestment cost components not covered by Bidcon are presented separately in Table D.2. The presented investment and reinvestment costs are expressed as absolute values and have not been annualized using the annuity method.

Table D.2: Additional investment, maintenance, and reinvestment cost components not covered by Bidcon

Component	Inv. costs [SEK]	Maint. costs [SEK/yr]	Reinv. costs [SEK]	Source
Water-efficient technologies (67 pcs. of each)				
Bathroom faucet	97331			Average price of the five most water-efficient bathroom faucets in [117]
Kitchen faucet	151782			Average price of the five most water-efficient kitchen faucets in [117]
Shower	25829			Average price of the five most water-efficient showerheads in [118]
Toilet	308493			Price based on a 4/2 flush toilet [240]
RHS				
INTEWA RHS	115050			excl. VAT [192]
Excavation	86337			[241]
Submersible pump			5171	Cost per replacement (is replaced 4 times) [242]
GWS				
INTEWA AL-GW5400	525000			Price range 500000-550000 SEK, incl. pump (Graytec, personal communication, April 8, 2026)
Heat exchanger	230000			Geiser AT 8455 (Armatec, personal communication, April 16, 2026)
Installation cost	41600			(Graytec, personal communication, April 8, 2026)
Maintenance cost		20000		[14]
Sludge pump			2185	Cost per replacement (is replaced 4 times) [242]
Novus pump			34011	Cost per replacement (is replaced 4 times) [242]
Blowers			14438	Cost per replacement (are replaced 3 times) [242]
Control system			175515	Cost per replacement (is replaced 1 time) [242]
Module membranes			202804	Cost per replacement (are replaced 4 times) [242]

Bidcon: Cost items (in Swedish)

Benämning	Mängd	S:a Mängd	Enhet	Aktiv	Material [../enh]	Material [..-tot]	Tid (S) [tim/enh]	Tid [tim/enh]	Tid [tim-tot]	UE [../enh]	UE [..-tot]	Kostnad [../enh]	Kostnad [..-tot]	kg CO2e [..-tot]
Nettokalkyl -				☑		603			385.2		0		173,966	21
Demontering/återmontering toalettstol	67.00	67.00	st	☑	5.00	335	1.40	1.400	93.8	0.00	0	635.00	42,545	12
Demontering/återmontering blandare	67.00	67.00	st	☑	2.00	134	0.85	0.850	57.0	0.00	0	384.50	25,762	5

Figure D.1: Retrofit cost items for Water-efficient technologies

Name	Actual Quantity	Unit	Active	Material Cost/Unit	Material Total Cost	Time (h) /Unit	Time Total (h)	Labour Cost/Unit	Labour Total Cost	Net Cost /Total	Note
Kompositrör PAL Universal Xtra A32x3,0mmx25m ring PN10 max +70°C PE-...	25.00	m	☑	327.00	8,175	0.000	0.0	0.00	0	8,175	pipe to laundry room

Figure D.2: Cost items for RHS

Name	Actual Quantity	Unit	Active	Material Cost/Unit	Material Total Cost	Time (h) /Unit	Time Total (h)	Labour Cost/Unit	Labour Total Cost	Net Cost /Total	Note
Net Sheet -			☑		374,706		69.3		31,196	405,902	
Avloppsrör plast Nordic 75x3m PP grå Pipelife	105.00	m	☑	188.31	19,773	0.000	0.0	0.00	0	19,773	shaft
Kompositrör PAL Universal Xtra A20x2,5mmx50m ring PN10 max +70°C PE-...	105.00	m	☑	132.00	13,860	0.000	0.0	0.00	0	13,860	shaft (obs 10 mm...
Kompositrör PAL Universal Xtra A32x3,0mmx25m ring PN10 max +70°C PE-...	25.00	m	☑	327.00	8,175	0.000	0.0	0.00	0	8,175	pipe to laundry room
Kompositrör PAL Universal Xtra A32x3,0mmx25m ring PN10 max +70°C PE-...	35.00	m	☑	327.00	11,445	0.000	0.0	0.00	0	11,445	horizontal branch...
Avloppsrör plast Nordic 110x3m PP 1muff grå Pipelife	35.00	m	☑	334.97	11,724	0.000	0.0	0.00	0	11,724	horizontal branch...
Badrum 4m² - Spillvattenledningar i tak PP Nordic Pipelife	35.00	st	☑	4,583.58	160,425	0.975	34.1	438.75	15,356	175,782	Renovation/New...
Badrum 4m² - Spillvattenledningar i tak PP Nordic Pipelife	32.00	st	☑	4,665.74	149,304	1.100	35.2	495.00	15,840	165,144	Renovation/New...

(a) Pipes

Name	Actual Quantity	Total Quantity	Unit	Active	Material Cost/Unit	Material Total Cost	Time (h) /Unit	Time Total (h)	Net Cost /Unit	Net Cost /Total	CO2 Total	Note	Weight Total
Net Sheet -				☑		237,006		321.7		381,774	3,798		11,168
Våtrumsvägg med stålregel, säker vatten	30.98	30.98	m2	☑	1,576.57	48,842	2.140	66.3	2,539.57	78,676	783	Renovation/New...	2,302

(b) Shaft wall

Figure D.3: Renovation/new construction cost items for GWRS

Name	Actual Quantity	Unit	Active	Material Cost/Unit	Material Total Cost	Time (h) /Unit	Time Total (h)	Labour Cost/Unit	Labour Total Cost	Net Cost /Total	Note
Net Sheet -			☑		750,767		115.7		52,045	802,812	
Badrum 4m² - Spillvattenledningar i tak PP Nordic Pipelife	35.00	st	☑	4,665.74	163,301	1.100	38.5	495.00	17,325	180,626	
Badrum 4m² - Spillvattenledningar i tak PP Nordic Pipelife	32.00	st	☑	4,747.90	151,933	1.225	39.2	551.25	17,640	169,573	
[211.C] Badrum 4m² - Synlig rördragning för tappvatten	35.00	st	☑	2,180.72	76,325	0.345	12.1	155.25	5,434	81,759	
[211.C] Badrum 4m² - Synlig rördragning för tappvatten	32.00	st	☑	2,327.24	74,472	0.518	16.6	232.88	7,452	81,924	
Golvbrunn Balder 75 P 150x75mm bottenutlopp insats & sil i plast rostfritt stål...	67.00	st	☑	3,280.00	219,760	0.000	0.0	0.00	0	219,760	
Rivning avlopp	67.00	st	☑	0.00	0	0.040	2.7	18.00	1,206	1,206	
Rivning ledningar	35.00	st	☑	0.00	0	0.080	2.8	36.00	1,260	1,260	
Rivning ledningar	32.00	st	☑	0.00	0	0.120	3.8	54.00	1,728	1,728	
Avloppsrör plast Nordic 75x3m PP grå Pipelife	105.00	m	☑	188.31	19,773	0.000	0.0	0.00	0	19,773	shaft
Kompositrör PAL Universal Xtra A20x2,5mmx50m ring PN10 max +70°C PE-...	105.00	m	☑	132.00	13,860	0.000	0.0	0.00	0	13,860	shaft (obs 10 mm...
Kompositrör PAL Universal Xtra A32x3,0mmx25m ring PN10 max +70°C PE-...	25.00	m	☑	327.00	8,175	0.000	0.0	0.00	0	8,175	pipe to laundry room
Kompositrör PAL Universal Xtra A32x3,0mmx25m ring PN10 max +70°C PE-...	35.00	m	☑	327.00	11,445	0.000	0.0	0.00	0	11,445	horizontal branch...
Avloppsrör plast Nordic 110x3m PP 1muff grå Pipelife	35.00	m	☑	334.97	11,724	0.000	0.0	0.00	0	11,724	horizontal branch...

(a) Pipes

Name	Actual Quantity	Total Quantity	Unit	Active	Material Cost/Unit	Material Total Cost	Time (h) /Unit	Time Total (h)	Net Cost /Unit	Net Cost /Total	CO2 Total	Note	Weight Total
Net Sheet -				☑		237,006		321.7		381,774	3,798		11,168
Våtrumsvägg med stålregel, säker vatten	119.35	119.35	m2	☑	1,576.57	188,164	2.140	255.4	2,539.57	303,098	3,015	Retrofit	8,867

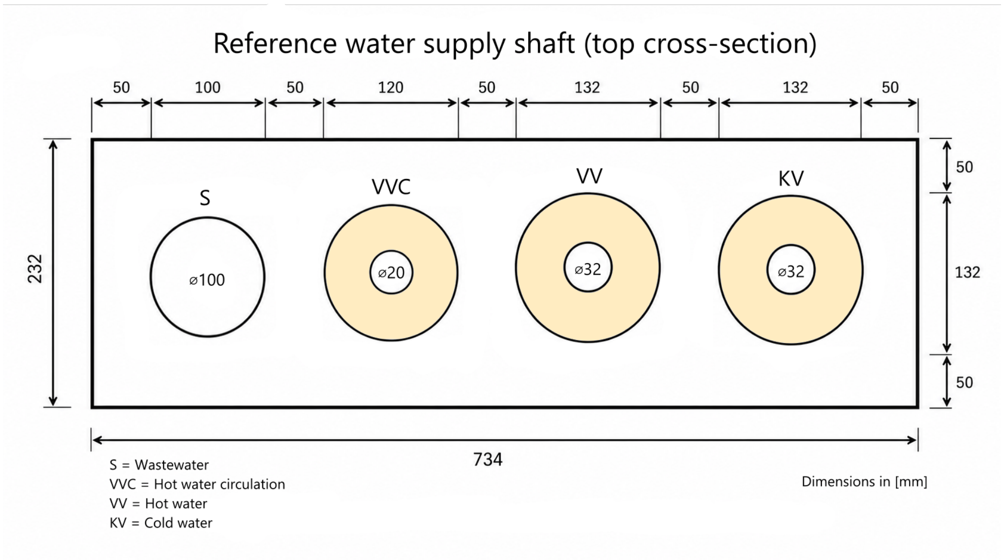
(b) Shaft wall

Name	Actual Quantity	Total Quantity	Unit	Active	Material Cost/Unit	Material Total Cost	Time (h) /Unit	Time Total (h)	Net Cost /Unit	Net Cost /Total	CO2 Total	Note
Net Sheet -				☑		743,263		899.1		1,147,878	8,658	
Rivning klinker på golv, ytor < 8 m2	*268.00*	268.00	m2	☑	15.30	4,100	0.500	134.0	240.30	64,400	0	
Rivning fuktisolerande golvmassa i våtutrymme	*268.00*	268.00	m2	☑	255.00	68,340	0.350	93.8	412.50	110,550	0	
Rivning överbetong i större utrymmen (maskinellt)	*268.00*	268.00	m2	☑	102.00	27,336	0.400	107.2	282.00	75,576	0	
Ytskikt, keramiska plattor på golv våtzon 1, tätskiktsklass VTgF	*268.00*	268.00	m2	☑	1,311.97	351,608	1.130	302.8	1,820.47	487,886	3,515	
Fiberförstärkt avjämning 4320 (flytspackel), t=20 mm, med pump	*268.00*	268.00	m2	☑	388.50	104,118	0.090	24.1	429.00	114,972	2,514	
Undergolv av EPS-cement	*268.00*	268.00	m2	☑	682.88	183,013	0.520	139.4	916.88	245,725	2,630	
Rivning innervägg med regelstomme	34.48	34.48	m2	☑	28.90	996	0.720	24.8	352.90	12,168	0	demolition wall
Rivning innervägg med regelstomme	84.88	84.88	m2	☑	44.20	3,752	0.860	73.0	431.20	36,600	0	demolition shaft wall

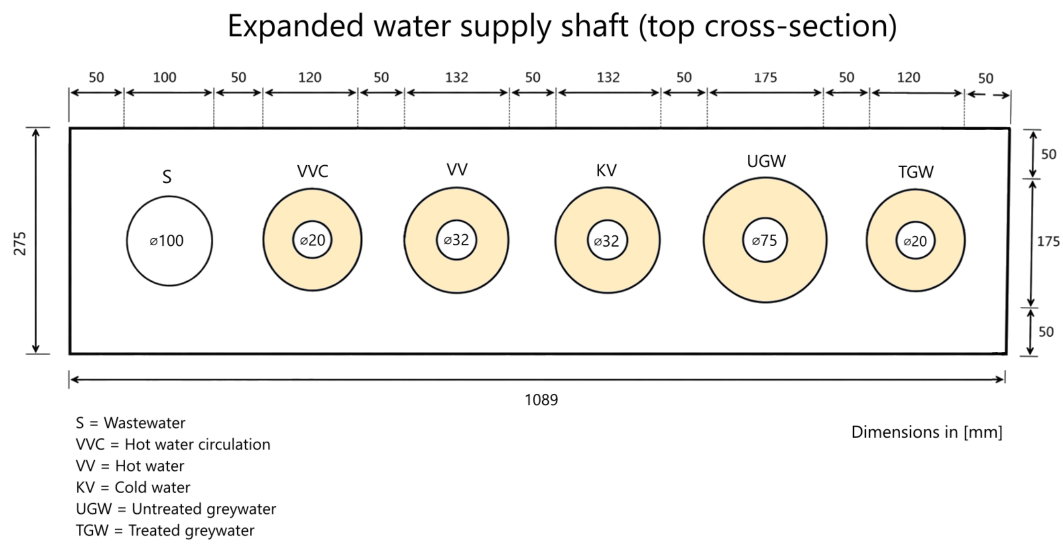
(c) Construction

Figure D.4: Retrofit cost items for GWRS

E Reference building drawings and assumed system layouts

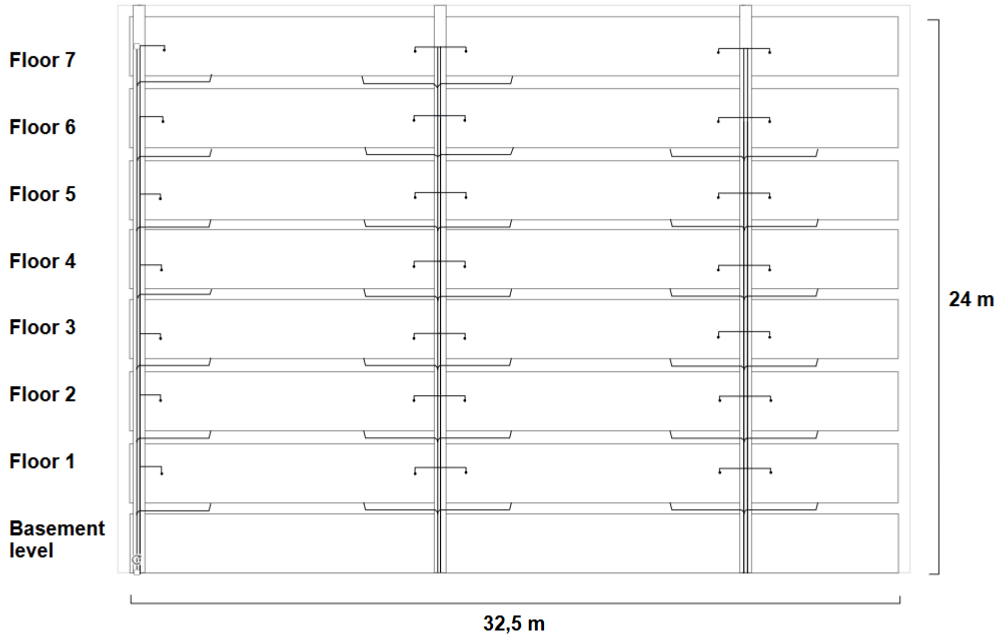


(a) Water supply shaft before expansion

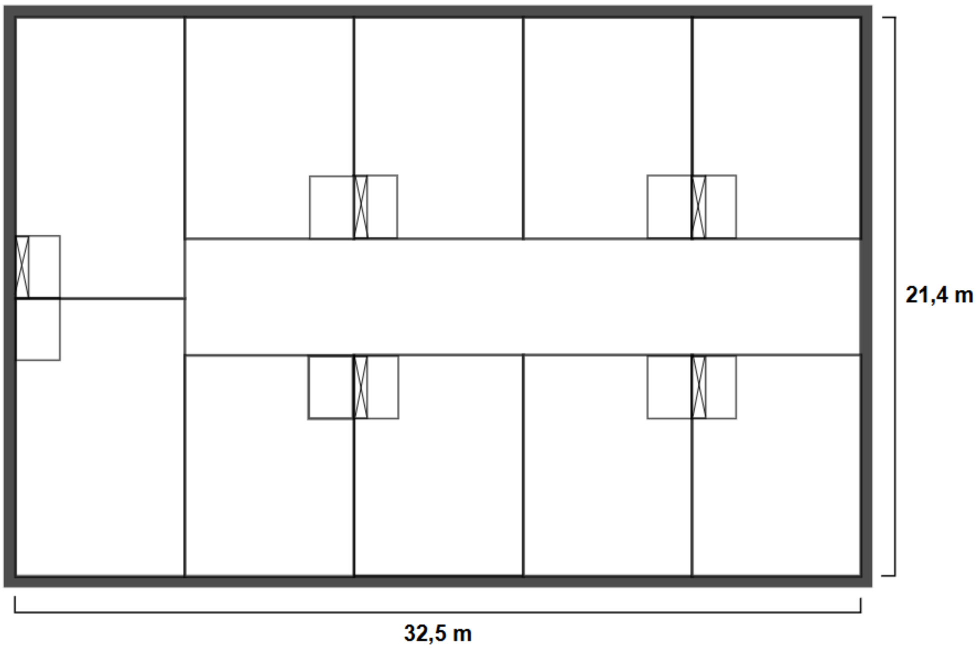


(b) Water supply shaft after expansion for GWRS installation

Figure E.1: Schematic illustration of the water supply shaft before and after expansion to accommodate the extra GWRS pipes.



(a) Cross-sectional view of the building



(b) Simplified floor plan of a typical level with ten apartments, including proposed locations of the shafts and bathrooms. The shaft area is not shown to scale.

Figure E.2: Schematic illustrations of the reference building, including cross-sectional layout and typical floor plan with key dimensions.

F Calculation of the number of washing machines

According to Hyresgästföreningen, while access to laundry facilities is required, there are no legal requirements regarding the number of washing machines in rental buildings. However, a general guideline is one washing machine per 10–15 households, assuming each household has access to the laundry room once per week [243]. To estimate the required number of washing machines in the reference building, Signalisten's laundry rules were used, which resulted in a requirement of approximately six machines (see Table F.1). This aligns with Hyresgästföreningen's general guideline.

Table F.1: Required number of washing machines for the reference building

Parameter	**Value**	**Note**
Maximum no. of laundry slots per household/month	10	[244]
Daily operating hours	15 h	[244]
Slot duration	3 h	[244]
Total monthly demand (slots)	670	$10 \cdot 67$
Slots per machine per day	5	$15/3$
Slots per machine per month (theoretical max capacity)	150	$5 \cdot 30$
Utilization rate	70%	Assumption
Slots per machine per month (realistic capacity)	105	$150 \cdot 0.7$
Required number of machines	~6	$670/105$

G Interview templates and MCDA survey

Interview template for interviewee I_1 at the building committee

Building permit

1. Is building permit or building notification required when installing graywater or rainwater harvesting systems?
2. How does the placement of the installation (e.g., indoors vs. outdoors or above vs. below ground) influence whether a building permit is required?
3. Does the requirement for a building permit differ depending on whether the system is implemented in an existing building, during renovation/pipe replacement, or in new construction?
4. If permits are necessary, how complex would you say the permitting process is for a property owner or company wanting to install a graywater recycling or rainwater harvesting system?
   (a) Is it easier for either of these alternatives?
   (b) Approximately how long would the permitting process for such a case take?

Juridical barriers

5. What factors in today's regulatory framework or permitting processes would you say hinder the implementation of graywater and rainwater harvesting systems in multi-family buildings, and what changes would be necessary to facilitate their implementation in the future?

Municipal governance

6. What tools does the municipality have to encourage or support the implementation of water-saving technologies in new construction projects?

Interview template for interviewee I_2 and I_3 at the technical service department

The municipality's overall attitude toward sustainability solutions

1. What is the municipality's overall attitude toward sustainability solutions and water-saving technologies?
   (a) Are water-saving technologies primarily viewed as an opportunity (e.g. strengthening the sustainability profile) or as a challenge (e.g. due to cost, user acceptance, or technical complexity)?

Implementation in existing buildings

2. What water-saving technologies are currently implemented in municipal buildings?
3. In your opinion, what water-saving technologies are suitable to implement in existing buildings?
4. What barriers and drivers exist for implementing water-saving solutions in existing buildings?

Feasbility in renovation/new construction projects

5. What factors usually determine whether new technology is implemented or not?
6. Does the prioritization between sustainability and cost differ depending on the implementation scenario (existing buildings, renovations, or new construction)?

Questions sent to interviewee I_4 at the environment and health committee

Environmental regulation and permitting

1. What permits or requirements are generally required for the installation of graywater recycling and rainwater harvesting systems in multi-family buildings?
   a) Are there specific treatment or water quality requirements for recycled/reused water before it can be used?
   (b) How do the requirements differ depending on the intended end use, for example toilet flushing, shower or tap water, laundry or dishwashing, irrigation, or other external uses?
2. What are the general conditions for getting graywater recycling and rainwater harvesting systems approved in multi-family buildings? Are the conditions generally favorable, limited, or difficult, and which factors are usually the most decisive (avgörande) in the assessment of whether such a system can be approved?
   a) Do the conditions for approval differ depending on whether the system is implemented in an existing building, during renovation/pipe replacement, or in a new construction?
   (b) Do the conditions for approval differ depending on how the recycled/reused water will be used?
   (c) Are there any specific health or environmental risks that the municipality needs to take into special consideration when assessing such systems?
3. If permits are necessary, how complex would you say the permitting process is for a property owner or company wanting to install a graywater recycling or rainwater harvesting system?
   (a) Is it easier for either of these alternatives?
   (b) Approximately how long would the permitting process for such a case take?

Juridical barriers

4. Do you have experience managing cases concerning graywater recycling or rainwater harvesting systems in multi-family buildings? If so, what are the greatest challenges?
5. What factors in today's regulatory framework or permitting processes would you say hinder the implementation of graywater and rainwater harvesting systems in multi-family buildings, and what changes would be necessary to facilitate their implementation in the future?

Interview template for interviewee I_5 at the urban planning department

Overall strategy and sustainability work in the municipality

1. In your view, how is water management prioritized compared to other sustainability issues within the municipality?
2. How common is the use of underground stormwater tanks for local stormwater management? What do these look like, and is there any information available regarding these systems (e.g., their locations)?
   (a) What is the potential for utilizing existing or planned underground stormwater tanks as a water supply resource for nearby multi-family buildings?

Barriers and drivers

3. What do you see as the main barriers to implementing water-saving tech in multi-family buildings?
4. In your view, can lower household water usage help postpone or minimize the need for capacity upgrades in the water and sewage infrastructure?

Municipal governance

5. How can the municipality promote water-saving technologies in residential buildings, especially in municipal housing? For instance, through mandatory requirements or land allocations?

Questions sent to interviewee I_6 at Signalisten

Overall strategy and current sustainability work

1. What is Signalisten's overall attitude toward sustainability solutions and water-saving technologies?
   (a) Are water-saving technologies primarily viewed as an opportunity (e.g. strengthening the sustainability profile) or as a challenge (e.g. due to cost, user acceptance, or technical complexity)?
2. What water-saving technologies are you currently using in Signalisten's properties? Are water-efficient fixtures standard in new constructions?
3. How common is local stormwater management using underground stormwater tanks on Signalisten's properties? If it is common, is there any information available regarding their design, capacity, and location?

Barriers and drivers

4. What barriers and drivers exist for implementing water-saving solutions in existing buildings/new constructions (please give an answer for each system alternative)
5. How is sustainability weighed against cost when implementing sustainable water system solutions in existing buildings? Are there other factors that influence the decision-making process (e.g., space constraints for such technologies, impact on the resident experience, acceptance, etc.)?
6. If Signalisten were planning a new housing project today, what changes would be necessary for you to seriously consider implementing graywater and rainwater solutions?

Municipal support

7. What incentives, policy instruments, or municipal regulations would, in your opinion, have the greatest impact on Signalisten's decision to implement water-saving technologies?

MCDA survey sent to the selected interviewees (in Swedish)

OBS! Läs först
Nedan presenteras 9 kriterier som kan vara relevanta vid beslut om att implementera en **vattenbesparande teknisk lösning**, vid **nybyggnation** eller i **befintlig byggnad**. Du har totalt 100 poäng att fördela mellan de 9 kriterierna (alltså 100poäng för Fall 1, och 100poäng för Fall 2). Fördela poängen utifrån hur viktiga du bedömer att de olika aspekterna är i ett sådant beslut. Ett högre värde innebär att kriteriet anses väga tyngre i beslutsprocessen.

Poängen kan fördelas fritt mellan kriterierna, men den totala summan ska vara 100 (se den gröna rutan). Det finns inga rätt eller fel svar, syftet är att fånga din bedömning av kriteriernas relativa betydelse. När du är nöjd med din poängfördelning **i de två olika fallen** laddar du ner excelfilen och mailar den till oss.

För mer information om vad en Multikriterieanalys innebär, och hur den kan användas, se följande länk: https://vattenbokhandeln.svensktvatten.se/produkt/svenskt-vatten-utveckling/wiser-ett-verktyg-for-beslutsstod-inom-dricksvattensektorn/

Namn:	Fyll i här
E-postadress:	Fyll i här

Fall 1 – Nybyggnation

Kriterium	Beskrivning av kriterium [möjlig enhet]	Antal poäng
Energibesparing	Mängden energi som kan sparas m.h.a. lösningen (netto). [ex. kWh/år]	
Vattenbesparing	Mängden dricksvatten som kan sparas m.h.a. lösningen. [ex. m3/år]	
Växthusgasutsläpp	Lösningens klimatpåverkan (netto). [ex. CO2e/år]	
Livscykelkostnad (LCC)	Den totala kostnaden för systemet under dess livstid, inklusive investering, drift och underhåll. [ex. tKr/år]	
Ekonomisk besparing	Den ekonomiska vinningen till följd av minskad vatten- och energianvändning. [ex. Payback time]	
Acceptans	Acceptans för den vattenbesparande lösningen bland användare och boende. [ex. upplevd komfort eller hälsorisk]	
Komplexitet (implementer	Teknisk svårighetsgrad vid installation av lösningen. [ex. Omfattning av installationsarbete, utrymmesbehov]	
Komplexitet (underhåll)	Tekniska krav på underhåll. [ex. underhållsfrekvens, hur komplicerad underhållsprocess]	
Komplexitet (juridik)	Juridiska förutsättningar som påverkar möjligheten att installera lösningen. [ex. Krav på tillstånd, möjlighet att erhålla tirstånd, ansökningsens längd och komplexitet]	
Summa poäng (ska vara 100 när allt ovan är ifyllt):		0

Fall 2- Befintlig byggnad

Kriterium	Beskrivning av kriterium [möjlig enhet]	Antal poäng
Energibesparing	Mängden energi som kan sparas m.h.a. lösningen (netto). [ex. kWh/år]	
Vattenbesparing	Mängden dricksvatten som kan sparas m.h.a. lösningen. [ex. m3/år]	
Växthusgasutsläpp	Lösningens klimatpåverkan (netto). [ex. CO2e/år]	
Livscykelkostnad (LCC)	Den totala kostnaden för systemet under dess livstid, inklusive investering, drift och underhåll. [ex. tKr/år]	
Ekonomisk besparing	Den ekonomiska vinningen till följd av minskad vatten- och energianvändning. [ex. Payback time]	
Acceptans	Acceptans för den vattenbesparande lösningen bland användare och boende. [ex. upplevd komfort eller hälsorisk]	
Komplexitet (implementering)	Teknisk svårighetsgrad vid installation av lösningen. [ex. Omfattning av installationsarbete, utrymmesbehov]	
Komplexitet (underhåll)	Tekniska krav på underhåll. [ex. underhållsfrekvens, hur komplicerad underhållsprocess]	
Komplexitet (juridik)	Juridiska förutsättningar som påverkar möjligheten att installera lösningen. [ex. Krav på tillstånd, möjlighet att erhålla tirstånd, ansökningsens längd och komplexitet]	
Summa poäng (ska vara 100 när allt ovan är ifyllt):		0

Figure G.1: MCDA survey for criteria weighting

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