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Sustainable Water Use: A Comprehensive Assessment and Reduction Strategy for Volvo Cars Facilities in Gothenburg

Master's thesis in Design and Construction Project Management

HUSSEIN KADEM

KHAIBAR POPALZAI

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2025
www.chalmers.se

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KHAIBAR POPALZAI

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

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Gothenburg, Sweden 2025

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HUSSEIN KADEM
KHAIBAR POPALZAI
Department of Architecture and Civil Engineering
Chalmers University of Technology

Summary

The automotive industry faces increasing demands to reduce its environmental footprint, with water management emerging as a critical component of corporate sustainability. Although Volvo Cars has made substantial progress in energy efficiency and carbon reduction, water use remains a significant challenge, especially given the scale and complexity of operations at the Torslanda facility in Gothenburg. The importance of sustainable water management is underscored by global frameworks such as the Sustainable Development Goals, as well as local ambitions to achieve climate neutrality and resource efficiency. This thesis investigates how Volvo Cars Torslanda can optimize its water use and implement more sustainable solutions in line with these ambitions.

The research combines a literature review with empirical data analysis and insights from interviews with both internal and external experts. The first phase of the study maps water consumption across the Torslanda facility, with a special focus on the eastern part of the site where offices, laboratories, and smaller workshops are located. This mapping reveals areas of high water use and also some inefficiencies linked to outdated metering, leaks, and limitations in data quality. The findings highlight the presence of non-revenue water, as well as the need for improved measurement and monitoring systems.

The thesis explores a range of innovative solutions that could contribute to more sustainable water use. These include sensor-based fixtures, IoT-enabled monitoring systems, and automated meter reading technologies that allow for real-time tracking of water flows and rapid detection of leaks. The potential for rainwater harvesting, considering both technical feasibility and economic viability within the Swedish industrial context. Challenges related to initial investment, organizational priorities, and relatively low water prices are discussed, along with strategies to overcome these barriers.

Through interviews and data analysis, the study identifies key opportunities for improvement, as well as practical challenges that must be addressed to achieve meaningful results. The importance of organizational engagement, reliable data, and effective collaboration is emphasized throughout the research. Ultimately, the findings suggest that a combination of technical innovation, behavioral change, and strategic investment is required to drive water efficiency at Volvo Cars Torslanda. The conclusions drawn from this thesis are intended to guide both decision-makers at Volvo Cars and other industrial actors seeking to improve their water management practices.

By addressing both the technical and organizational aspects of water use, this thesis provides a comprehensive framework for sustainable water management in a modern industrial facility. The strategies and recommendations presented here are relevant not only for Volvo Cars but also for other companies aiming to balance operational efficiency with environmental responsibility.

Keywords: water management, sustainability, automotive industry, water efficiency, digitalization, rainwater harvesting, IoT, Sweden, Volvo Cars, industrial facility

Hållbar vattenanvändning: En omfattande utvärderings- och minskningsstrategi för Volvo Personvagnars verksamhet i Göteborg
HUSSEIN KADEM
KHAIBAR POPALZAI
Institutionen för Arkitektur och Samhällsbyggnadsteknik
Chalmers tekniska högskola

Sammanfattning

Bilindustrin står inför ökande krav på att minska sitt miljöavtryck, där vattenhantering blir en allt viktigare del av företagens hållbarhetsarbete. Trots att Volvo Cars har tagit stora steg mot energieffektivisering och minskade koldioxidutsläpp kvarstår vattenanvändningen som en utmaning, särskilt med tanke på verksamhetens omfattning och komplexitet vid Torslandafabriken i Göteborg. Betydelsen av hållbar vattenanvändning understryks både av globala ramverk som de globala målen för hållbar utveckling och av lokala ambitioner om klimatneutralitet och resurseffektivitet. Detta examensarbete undersöker hur Volvo Cars Torslanda kan optimera sin vattenanvändning och införa mer hållbara lösningar i linje med dessa mål.

Arbetet bygger på en kombination av litteraturstudie, analys av empiriska data och intervjuer med både interna och externa experter. I den första fasen kartläggs vattenförbrukningen vid Torslandafabriken, med särskilt fokus på den östra delen där kontor, laboratorier och mindre verkstäder finns. Kartläggningen visar på områden med hög vattenanvändning och viss ineffektivitet kopplat till omodern mätning, läckage och brister i datakvalitet. Resultaten tydliggör förekomsten av så kallat icke-fakturerat vatten och behovet av förbättrade mätsystem och övervakning.

Examensarbetet undersöker flera innovativa lösningar som kan bidra till mer hållbar vattenanvändning. Bland dessa finns sensorstyrda armaturer, IoT-baserade övervakningssystem och automatiska mätavläsningssystem som möjliggör kontinuerlig uppföljning av vattenflöden och snabb upptäckt av läckor. Potentialen för regnvatteninsamling, med hänsyn till både tekniska och ekonomiska förutsättningar i svensk industri. Utmaningar

relaterade till initiala investeringar, organisatoriska prioriteringar och låga vattenpriser diskuteras, liksom strategier för att hantera dessa hinder.

Genom intervjuer och analys identifieras både möjligheter till förbättring och praktiska utmaningar som behöver lösas för att uppnå konkreta resultat. Arbetet understryker vikten av engagemang inom organisationen, tillförlitliga data och effektivt samarbete. Sammantaget pekar resultaten på att en kombination av teknisk innovation, beteendeförändring och strategiska investeringar krävs för att nå ökad vattentillgång och effektivitet på Volvo Cars Torslanda. De slutsatser som dras syftar till att vägleda både beslutsfattare inom Volvo Cars och andra industriföretag som vill utveckla sitt vattenarbete.

Genom att ta ett helhetsgrepp på både tekniska och organisatoriska aspekter bidrar detta arbete med en ram för hållbar vattenhantering i en modern industriverksamhet. De strategier och rekommendationer som presenteras är relevanta för såväl Volvo Cars som för andra företag som vill förena effektiv drift med ett ökat miljöansvar.

Nyckelord: vattenhantering, hållbarhet, bilindustri, resurseffektivitet, digitalisering, regnvatteninsamling, IoT, Sverige, Volvo Cars, industrifastighet

Acknowledgements

This master's thesis marks the conclusion of our studies in Design and Construction Project Management at Chalmers University of Technology. The work has been carried out during the spring of 2025 in Gothenburg, Sweden, in close collaboration with Volvo Cars.

We would like to extend our sincere gratitude to our supervisor at Volvo Cars, Jelena Maric, for her continuous support, insightful feedback, and encouragement throughout the project. Her expertise and constructive advice have been invaluable during all stages of our work.

We would also like to express our deep appreciation to our academic supervisor at Chalmers, Jesper Knutsson, for his excellent guidance and thoughtful comments. His advice on research methodology and his willingness to share his academic experience have greatly contributed to the development of this thesis.

Finally, we would like to thank everyone who participated in our interviews and discussions, and all colleagues at Volvo Cars and Chalmers who have provided their perspectives and support.

Gothenburg, 2025 June
Hussein Kadem & Khaibar Popalzai

Glossary

Acronym	English	Svenska
SCM	Sustainability Benefit-Cost Model	Hållbarhetskostnads-nyttomodell
VCT	Volvo cars torslanda	Volvo Cars Torslanda
ROI	Return of investment	Avkastning på investering
ISO	International Organization for Standardization	Internationella Standardiseringsorganisationen
NRW	Non-Revenue Water	Icke-fakturerat vatten
LEED	Leadership in Energy and Environmental Design	Miljöcertifiering
BREEAM	Building Research Establishment Environmental Assessment Method	Miljöcertifiering
WFP	Water Footprint	Vattenfotavtryck
SDG	Sustainable Development Goals	Globala målen för hållbar utveckling
CSRD	Corporate Sustainability Reporting Directive	EU:s direktiv om hållbarhetsrapportering
Esight	Monitoring system	Mätningssystem
RWH	Rainwater harvesting	Regnvattenuppsamling
AMR	Automated Meter Reading	Automatiserad mätaravläsning
IoT	Internet of Things	Sakernas internet
GI	Green Infrastructure	Grön infrastruktur
MIP	Model Industrial Park	Modellindustriområde

Content

1 1

Introduction 1

1.1 Background 1

1.2 Aim 4

1.3 Research Questions 4

1.4 Limitations 5

1.5 Outline 6

2 8

Theoretical framework 8

2.1 Introduction to Water Management in Industrial Facilities 8

2.1.1 Industrial Water Management and Sustainable Development 8

2.1.2 Balancing Industrial Water Use with Environmental Needs 10

2.2 Innovative Water-Saving Technologies 13

2.2.1 Optimizing Industrial Water Use Through IoT and Big Data 13

2.2.2 Sensor technologies for leakage detection and monitoring 17

2.2.3 Small-scale application and behavioural efficiency tools 19

2.2.4 Rainwater Harvesting and Wastewater Reclamation 20

2.3 Rainwater Harvesting Systems 21

2.3.1 Rainwater Harvesting for Sustainable Industrial Water Management 22

2.3.2 The Potential of Rainwater Harvesting in Urban Water Management 22

2.4 Benchmarking and Best Practices 23

2.4.1 Green Infrastructure for Sustainable Urban Water Management 23

2.5 Economic and Environmental Impacts of Water Management Strategies 26

2.5.1 Optimizing Water Reuse in Industrial Areas: Insights from the MIP Model 26

2.6 Challenges and Barriers 27

2.6.1 Water Leakage as a Technical and Institutional Challenge 27

2.6.2 Behavioural and Attitudinal Barriers to Sustainable Water Management 30

2.6.3 Communication Barriers in Organisational Water Management 31

3 34

Methodology 34

3.1 Research Process 34

3.2 interview study 36

3.3 empirical study 38
3.4 Confidence and Ethical Considerations 39
3.5 Discussion of Methodology 40
4 43
Results and discussion 43
4.1 Current Water Use and Identified Inefficiencies 43
4.1.1 Mapping Water Use for Targeted Sustainability Efforts 44
4.1.2 Overview of Water Distribution to Eastern Torslanda Facilities 46
4.1.3 Analysis of Unmetered Water and Identification of Inefficiencies in Eastern Torslanda 49
4.1.4 Rising Water Costs and Their Financial Implications for Volvo Cars 52
4.1.5 Analysis of Water Use and System Inefficiencies at Volvo Cars Torslanda ... 55
4.2 Evaluation of Sensor-Based Faucets Implementation through Sustainability Benefit-Cost Model 58
4.2.1 Identification of Cost and Savings Parameters 59
4.2.2 Water Savings and Economic Impact 60
4.2.3 Energy Savings Estimation 63
4.2.4 Carbon Footprint and Environmental Benefits 65
4.2.5 Payback Time Analysis and Interpretation 67
4.2.6 Exploring Water-Saving Technologies and Behavioral Strategies at Volvo Cars Torslanda 68
4.3 Potential of Alternative Water Sources: Rainwater Harvesting and Stormwater Recycling 71
4.3.1 Rainwater Harvesting: Implementation Opportunities and Challenges 71
4.3.2 Stormwater Recycling: Strategic Integration in Sustainable Facility Design 72
4.3.3 Exploring the Viability and Strategic Integration of Rainwater Harvesting and Water Recycling at Volvo Cars Torslanda 73
5 77
Conclusion 77
6 80
Recommendations for Future Water Management at Volvo Cars Torslanda 80
7 85
Future Research and Development 85
References 88
Interview Guideline 94

List of figures

Figure 1: List of Interviewees. 38
Figure 2: Share of total water consumption per facility group at Volvo Cars Torslanda East, 2023 45
Figure 3: Water Distribution Network to Eastern Torslanda Facilities 47
Figure 4: Example of current bathroom faucet conditions in PV area. 59

List of Tables

Table 1: Reported water loss in 99 Swedish municipalities from 2017 (Svenskt Vatten Utveckling, 2019). 14
Table 2: Monthly Comparison of Purchased vs. Measured Water in Eastern Torslanda (2023) 49
Table 3: Annual water tariff average rate of increase, (Svenskt Vatten, 2024) 54
Table 4: Payback time versus normalised water benefit score for the sensor-based faucet installation. 62
Table 5: Payback time versus normalised energy benefit score for the sensor-based faucet installation. 65
Table 6: Climate benefit score vs. payback time for sensor-based faucet installation. 66
Table 7: Figure X. CAPEX vs Payback Time for Sensor-Based Faucet Installation. 68
Table 8: Overview of recommendation to Volvo Cars. 80

1

Introduction

The introduction chapter provides a brief background on the topics of industrial water management, sustainability, and resource efficiency, focusing on the challenges and opportunities associated with water use in manufacturing facilities. This leads to the aim of the thesis and the formulation of key research questions related to optimizing water consumption and integrating sustainable solutions. Furthermore, delimitations and an outline of the thesis are presented.

1.1 Background

It is evident from the past that, in contrast to other key resources like energy and raw materials, water, one of our most basic resources, has not been given its due credit. With the shift in global energy and rising electricity costs, electricity consumption and atmospheric carbon dioxide levels have largely occupied the limelight while commenting on sustainable development. Notwithstanding the fact that water resources are among the most basic needs of life and industrial production, water scarcity and unsustainable use of water have tended to be taken for granted. Water scarcity is considered one of the top ten global risks over the next decade, with serious implications for industrial productivity and economic stability, particularly in water-stressed regions (World Economic Forum, 2024). In the future there is a risk of facing a major worldwide catastrophe, when water shortage and water quality degradation will be capable of influencing ecosystems, society, and mostly the economy, if failing to adopt shared responsibility for water issues and ignore them (UNESCO/UN-Water, 2020). Water usage is escalating with urbanization and industrialization, resulting in issues of excess extraction of groundwater, pollution of water resources, and ineffectual water management systems. Industry consumes much of the water worldwide; manufacturing alone is estimated to consume 20% of the world's freshwater (Weerasooriya et al., 2021). Supply of water is sometimes restricted, especially in areas of high population with no infrastructure and little precipitation, and therefore it is important to research how companies and industries can conserve water and minimize their environmental impact.

One of the many industries with high water consumption is the automotive industry, which uses a lot of water in processes like cooling, component cleaning, and surface treatment, but also for facility and staff uses, such as sanitation, hygiene, consumption and cleaning (Semmens et al., 2014). In addition to identifying new technologies, it's critical to look for opportunities to improve water management systems and reuse process water to increase water efficiency (European Commission, 2015). Being a major actor in the automotive sector, Volvo Cars has a larger need to incorporate sustainable solutions into its facilities and manufacturing processes. This will help to lower water usage and advance sustainable industrial development.

Volvo Cars has stepped up efforts at sustainability over the past few years, following the setting of goals to reduce their footprint on the environment, including water usage. The western part of the site is the Torslanda factory, one of Volvo Cars' factories in Sweden, which uses a lot of water during production. Office complexes and small workshops, including laboratories where all kinds of testing like crash testing, software verification and acoustic measurements are done, constitute the eastern part of the site. Plenty of water is used in the eastern part of the site as well, which is why it becomes important to devise working alternatives that can cut down on unnecessary usage. Herein, they can support the UN Sustainable Development Goals 6 and 12, namely "Ensure availability and sustainable management of water and sanitation for all" and "Ensure sustainable consumption and production patterns" (United Nations, n.d.).

Torslanda is one of the key positions in Volvo Cars' global production network. The factory, which was founded in Gothenburg in 1964, is one of the biggest and most modern production halls of Volvo. Torslanda's built-up area is over 450,000 square meters and has a daily capacity of approximately 1,250 automobiles (Volvo Cars, n.d.). The Torslanda plant has undergone significant upgrading as part of Volvo Cars' global sustainability program to reduce its impact on the environment. Volvo Cars key environmental ambition is to reach net zero greenhouse gas emissions for the whole value chain by 2040. Volvo Cars also hopes to progress incrementally towards a circular and more resource-efficient use of resources production process and lower its carbon footprint per car by 65 to 75 percent by 2030 (Volvo Cars, 2022). Volvo Cars' first climate-neutral car factory, Torslanda has been run by climate-neutral energy since 2008 and also uses climate-neutral heating from 2020 (Volvo Cars, 2020). One of its objectives towards sustainability in 2030, Volvo Cars aims to reduce CO_2 emissions per vehicle by 75 percent, energy consumption in operations by 40 percent, and water consumption by 50 percent, each against 2018 benchmark (Volvo Cars, 2023). The firm also targets at least 30 percent recycled material in the fleet and 99 percent reuse or recycling of operational waste.

Even though energy efficiency and lower carbon emissions have received a lot of attention, water usage is still a significant component of Volvo Cars' overall sustainability efforts. Although cooling, surface treatment, and cleaning are the primary uses of water in factory production, the eastern portion of Torslanda also uses a significant of water. Office buildings and labs where numerous testing and quality controls are conducted are in this section of the complex, which also has high water consumption. Water usage in the office area is related to daily operations and cleanliness, and it is also utilized for material testing, chemical testing, and other research procedures in the laboratory. The eastern part of Torslanda site accounts for 30% of the total water consumption. Although both the eastern and western parts have approximately 6500 employees each, water consumption is higher in the western part. This is due to the presence of more water-intensive manufacturing operations on the western side.

Volvo Cars has already implemented sustainable water management globally, but there are opportunities for further optimization of water usage in Torslanda by analysing and developing new solutions. Efficient use of water is one of the most significant factors for making the company more sustainable and resource efficient. By investigating improvement opportunities in the eastern part of the plant, Volvo Cars can decide solutions that save water not only but also support the company's long-term environmental goals. The purpose of this study is, therefore, to identify how Volvo Cars Torslanda can enhance its water management by means of consumption analysis, possibilities for water recycling, and decision on implementation of more environmentally conscious water management systems. Opportunities like rainwater harvesting and other new technologies are examples that can fall into this category. Apart from minimizing its footprint on the environment, Volvo Cars can set the pace for sustainable resource management that other company buildings can follow by optimizing water usage.

1.2 Aim

This thesis aims to explore how water management at Volvo Cars Torslanda can be improved through a detailed analysis of current practices, monitoring systems, and sustainability strategies. The primary focus lies on the eastern part of the site, which includes offices, laboratories, and restaurants, and does not involve the manufacturing operations located in the western area. The aim is to support Volvo Cars future sustainable objectives by enhancing water efficiency in non-production facilities.

1.3 Research Questions

The main research question explores how Volvo Cars' Torslanda facility can optimize water management for efficiency and sustainable. To address this, several sub-questions have been formulated, focusing on current water use, potential water-saving technologies, sustainable water supply solutions, and implementation feasibility.

Main research question:

- How can the facilities at Volvo Cars Torslanda optimize water management to ensure efficient use and promote sustainable resource utilization?

Sub-Questions to Address the Research Question:

Current Water Use:

- What are the existing water uses and consumption patterns, and where are the inefficiencies at Volvo Cars Torslanda?

Water-Saving Opportunities:

- What technologies or practices can improve water efficiency in the facility?

Sustainable Water Supply:

- How can Volvo Cars integrate sustainable practices such as rainwater harvesting or stormwater recycling into their water management system?

1.4 Limitations

This thesis addresses sustainable water management within an industrial context, specifically examining strategies for optimizing water usage and implementing water-saving technologies at Volvo Cars' Torslanda facility in Gothenburg, Sweden. The research explicitly focuses on the eastern section of the facility, which comprises offices, laboratories, and restaurant operations, rather than the western side where manufacturing processes occur. While the findings may be informative for other industrial or commercial settings with similar characteristics, the scope is explicitly tailored to the specific challenges and opportunities within the eastern part of the Torslanda site. This spatial limitation was strategically chosen to enable practical and manageable data collection and analysis within the timeframe of a master's thesis.

The research does not seek to create an entirely new water management system but evaluates existing strategies, technologies, and best practices aimed at enhancing sustainability within non-process water use such as office environments, laboratories, and support facilities. Emphasis is placed on assessing the potential for rainwater harvesting, water recycling, and digital monitoring solutions. Although financial considerations such as investment costs and payback periods are briefly explored, the study does not engage in detailed financial modelling or comprehensive cost-benefit analysis at the organizational scale.

Moreover, the thesis concentrates primarily on internal water management practices at the industrial facility level and does not extensively address municipal or regional water management. Recommendations are confined to practical insights applicable to facility-level operations. Regulatory aspects are mentioned primarily from a compliance perspective, without conducting an exhaustive legal analysis of water management regulations.

Finally, recognizing that sustainable water management is influenced by continuously evolving technology, regulations, and climatic conditions, the thesis findings are based on current practices and available data. The conclusions provided are intended as a contribution to ongoing discussions and to serve as a foundation for future research rather than definitive solutions.

1.5 Outline

This thesis is structured to systematically explore sustainable water management at Volvo Cars' East facility. Following this introduction, which provides context, research aims, and questions, the theoretical framework (Chapter 2) reviews existing literature relevant to industrial water management, digital monitoring technologies, rainwater harvesting, and water-saving innovations.

Chapter 3 describes the research methodology, outlining the data collection methods, which include quantitative water usage data and qualitative interviews, and the analytical approaches utilized. Chapter 4 combines empirical findings with detailed discussions organized explicitly around the three research questions, providing a comprehensive analysis that integrates quantitative data with qualitative insights from stakeholder interviews.

Chapter 5 succinctly presents conclusions by directly addressing and summarizing the answers to each research question. Chapter 6 provides concrete recommendations aimed at guiding Volvo Cars in implementing effective water management strategies, prioritized by practical feasibility and impact. Chapter 7 highlights future research directions, identifying opportunities for further exploration and advancement in sustainable water management practices within industrial settings.

The research progresses through three distinct phases: mapping current water consumption and inefficiencies, examining technological solutions and behavioural strategies for water efficiency, and evaluating the feasibility of integrating sustainable practices such as rainwater harvesting and water recycling. This phased approach ensures a structured and evidence-based investigation, clearly aligning with the research questions and objectives.

2

Theoretical framework

This chapter presents the main concepts and theories used to understand and assess sustainable water utilization in Volvo Cars Torslanda. It includes cases of previous studies on industrial water reuse, efficiency improvement, and combined water systems. The aim is to give insightful background for the analysis and findings subsequent in the report.

2.1 Introduction to Water Management in Industrial Facilities

Water scarcity has become a serious worldwide concern, and industrial processes are one of the major reasons behind this. Industrial operations consume approximately 20% of all fresh water consumed worldwide, and this rate will go up with continuous industrialization, population growth, and urbanization (FAO, 2016). The increasing pressure on water resources necessitates an urgent requirement for sustainable water consumption in industries, where considerable volume of water is utilized in process activities, cooling, and sanitation.

2.1.1 Industrial Water Management and Sustainable Development

Reducing industrial water footprints is mostly dependent on water conservation technologies. Innovative approaches to treating industrial wastewater, like adsorption filtration and hydrodynamic cavitation, have shown promise in allowing businesses to recover and reuse water inside their buildings (Sabia et al., 2023). Businesses can lower their overall water withdrawals and lessen their reliance on outside water sources by implementing closed-loop systems. But even with these developments, industries continue to have a difficult time implementing sustainable water practices.

With growing water demand, industries are increasingly being pressured to align their water management practices with international sustainability agendas, including the UN Sustainable Development Goals (SDGs). SDG 6 stands for clean water and sanitation; SDG 12, responsible consumption and production; and SDG 9, the role of innovation for industrial sustainability. As such, the integration of WFP information into various business practices has been found useful in reducing water consumption and thereby enhancing sustainability efforts. Once water footprint analyses are completed, industries can reduce water consumption through various means, including stormwater recycling, rainwater collection, and developing advanced wastewater treatment plants (Liu & Jensen, 2018).

Water-saving technologies are also needed to reduce industrial water footprints. Emerging technologies such as hydrodynamic cavitation and adsorption filtration have proven useful in wastewater treatment for industry, enabling industries to recycle and reuse water within their facilities (Sabia et al., 2023). With the use of closed-loop systems, organizations can reduce their consumption of external water sources and decrease their overall water withdrawals. But with these innovations, even then, industries are still facing huge challenges in adopting sustainable water practices.

The primary obstacles include high initial costs, technological limitations, and institutional barriers (Ocal et al., 2023). Many industries, particularly in developing countries, lack the financial resources and technical expertise to implement advanced water conservation measures. Additionally, in regions where water pricing is low, there is little economic incentive for industries to invest in water-saving technologies (Sabia et al., 2023).

Overcoming these challenges requires a multidimensional approach that includes policy measures, capacity building, and inter-border cooperation. Global initiatives like the Water Footprint Network and inter-border agreements like the Paris Agreement have assisted in compelling industries to adopt sustainable water management systems (Liu & Jensen, 2018). In Europe, Sweden has a tendency to set stronger environmental standards than EU requirements. For instance, although the EU Urban Wastewater Treatment Directive provides some minimum standards for treatment, 97% of Sweden's urban wastewater is treated to these minimum standards, higher than the EU average of 76% (European Commission, n.d.). Sweden has also designated its entire area as sensitive areas, and this makes it harder to remove nitrogen and phosphorus from the wastewater discharges. However, Sweden has been accused of granting blanket exemptions to the EU Water Framework Directive, including to hydropower operations, to some degree, which others believe may jeopardize the health of its freshwater ecosystems (WWF, 2022). Access to water is a prerequisite for economic growth, but global water crisis has deepened due to accelerated industrialization and urbanization. Another study (Santos et al., 2020) showed how these impacts developing countries in general, as industrial growth results in a rise in the quantity of waste water that is typically highly contaminated with strongly contaminated contaminants. The heavy nutrients, heavy metals, and salts make it more difficult to implement therapies by traditional methods.

Corporates will be able to gain from co-operative business agreements with local governments, research institutions, and charities for coming up with tailored solutions for water reusing and conserving (Sabia et al., 2023). Companies such as Volvo Cars that possess extensive industrial factories in the urban layout are most likely to make use of synchronized water control mechanisms that help both the industrial production requirements and urban sustainable actions (Sabia et al., 2023).

Integrated reuse concepts seek to decouple freshwater use by integrating industrial and municipal water flows. A good practical case from Sweden is the supply of treated effluent from Ryaverket to a battery plant in Gothenburg, which reuses it for cooling purposes and then is integrated into the district heating system (Gryaab, 2022; Göteborg Energi, 2022). It shows that industrial–urban water cooperation is feasible.

For Volvo Cars, reuse model analysis is applicable regarding the use of alternatives to freshwater in cleaning and cooling processes. While bigger concepts such as IU-WA-RE and SEMIZENTRAL were initially designed for greenfield developments (Bauer et al., 2020; Liu & Jensen, 2018), their modularity can inspire future solutions that can be applied in mature sites such as Torslanda. Local collaboration and regulatory adjustments would be a precondition for feasible implementation (Sabia et al., 2023).

2.1.2 Balancing Industrial Water Use with Environmental Needs

Despite the promising benefits of industrial water reuse, several challenges must be addressed to make it feasible in the long run. Membrane fouling in reverse osmosis (RO) membranes is one of the most important challenges and occurs when contaminants such as calcium sulfate, organic matter, and microbial growth adhere to membrane surfaces and reduce the effectiveness of filtration (Ocal et al., 2023). Over time, fouling leads to decreased flow rates, increased energy expenditure, and maintenance, and RO system operation becomes less efficient. To avoid these, pre-treatment steps such as anti-scalant chemicals, UV treatment, and sedimentation filtration are increasingly being utilized to enhance membrane life and filtration performance (Ocal et al., 2023).

Aside from the technical issues, industries also need to consider the cost-effectiveness of water reuse systems. In settings such as Sweden, where municipal water is low in cost, the imposition of high up-front cost for on-site wastewater treatment and reuse can be hard to argue for industries despite long-run sustainability benefits (Sabia et al., 2023). However, when considering long-term cost savings from reduced water purchase, lower wastewater discharge fees, and compliance with environmental regulations, the economic case for industrial water reuse becomes stronger (Sabia et al., 2023). Besides, companies that adopt sustainable water management can develop their corporate reputation, raise investors, and become leaders in competitive advantages in industries where sustainability is a key differentiator.

Another important concern is the integration of water sustainability assessments into business decision-making. In the past, industries have been focusing on short-term operational efficiency at the expense of considering their broader water footprint through indirect water consumption in supply chains (Sabia et al., 2023). A life-cycle approach to water management, which considers water consumption not only at the point of production but also material removal, distribution, and product end-use, can provide a more accurate picture of an industry's water footprint (Liu & Jensen, 2018). For Volvo Cars, this could involve examination of water-using processes in the automotive supply chain, opportunities for water savings at the stages of manufacturing parts, and implementation of sustainable purchasing policies.

Local water availability and climatic variability also decide the viability of water reuse schemes to a large extent. Rainfall and groundwater recharge fluctuations seasonally in arid and semi-arid areas might affect water supply for reuse (Sabia et al., 2023). Even though Gothenburg is not marked by severe water shortage, it does face seasonal variations in water usage and rainfall, and these must be taken into account for long-term water planning (Liu & Jensen, 2018). For manufacturing sites like Volvo Cars Torslanda, the integration of climate modeling and hydrology information into water planning may be used to ensure that measures for sustainability are resilient to changing environmental conditions (Ocal et al., 2023).

Furthermore, stakeholder involvement and regulatory compliance are crucial to the success of industrial water sustainability initiatives. Effective water management entails coordination between industries, policymakers, and local communities to ensure that water reuse initiatives align with regional sustainability objectives (Sabia et al., 2023). Public-private partnerships can be particularly valuable for investment cost sharing of infrastructure, knowledge exchange, and for ensuring industrial water reuse systems fulfill the local water quality standards (Liu & Jensen, 2018). For Volvo Cars, engaging in partnerships with city governments in Gothenburg can enable co-development of new water reuse initiatives, e.g., joint investments in wastewater treatment plants or pilot projects for urban-industrial water recycling.

Going forward, digitalization and technological innovations are likely to impact the sustainability of industrial water. The efficiency of industrial water can be significantly enhanced by integrating real-time monitoring systems, sensor-based analysis, and AI-based water optimization (Sabia et al., 2023). For instance, smart water grids offer automated leak detection, predictive maintenance, and data-driven decision-making, which reduce unnecessary water losses and operational costs (Liu & Jensen, 2018). The development of next-generation filtration membranes that have higher rejection rates, better energy efficiency, and longer operating lifetimes is also expected to be significant to the advancement of sustainable industrial water management (Ocal et al., 2023).

Moreover, regulatory policies will only get stricter in the coming years, further pressurizing industries to invest in water-efficient technologies and practices. Companies that get ahead of the curve by adopting sustainable water management systems will not only be in compliance with future regulation but also gain strategic advantages by demonstrating environmental stewardship (Sabia et al., 2023). For instance, Volvo Cars can utilize its water sustainability initiatives to connect with the European Green Deal, which strives to promote industries to use resources in a responsible manner (Liu & Jensen, 2018).

The importance of sustainable water management in industries cannot be overstated. As water scarcity intensifies with population growth, climate change, and industrialization, industries must transition to circular water systems with emphasis on conservation, reuse, and efficiency (Sabia et al., 2023). The IU-WA-RE framework and advances in filtration technologies and integrated urban-industrial water planning provide a pathway for sustainable industrial water use (Liu & Jensen, 2018).

For firms like Volvo Cars, adopting water reuse strategies, incorporating green infrastructure, and working with stakeholders in collaboration holds the key to reducing their water footprint while improving corporate sustainability. While challenges regarding economic feasibility, regulatory policies, and technological barriers remain, continued investment in research, policy efforts, and digital innovation will drive the future of sustainable water management in industrial operations (Ocal et al., 2023).

2.2 Innovative Water-Saving Technologies

As businesses come under increasing pressure to reduce freshwater consumption and enhance sustainability, emerging water conservation and treatment technologies have come to the fore. This chapter will cover some of the groundbreaking solutions enabling more effective and resilient industrial water management. Digital solutions through IoT and sensor-enabled monitoring and decentralized solutions like rainwater harvesting and wastewater reuse. Together, these technologies provide workable solutions in terms of conserving water, fixing leakages, enhancing energy efficiency, and promoting general environmental objectives.

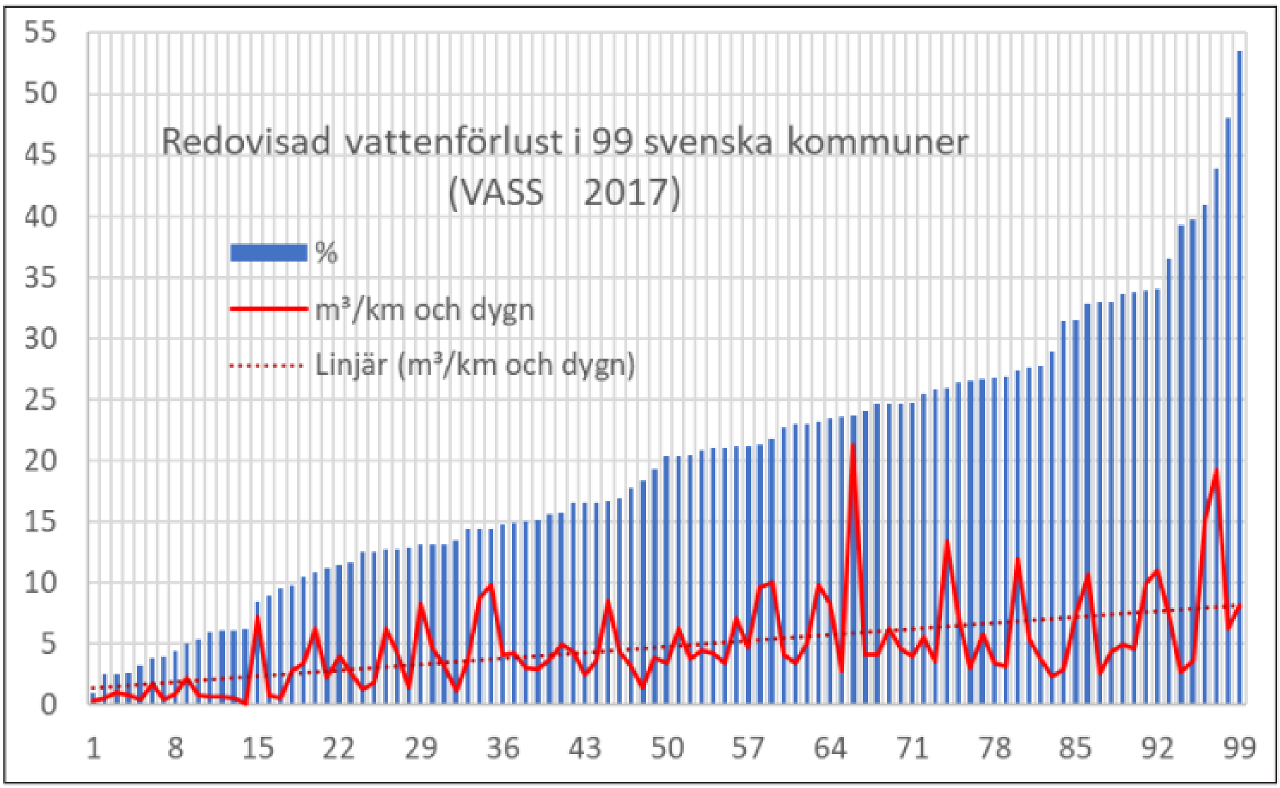
2.2.1 Optimizing Industrial Water Use Through IoT and Big Data

The convergence of Internet of Things (IoT) and Big Data analytics has transformed industrial water management by enabling real-time monitoring, predictive analysis, and automated decision-making. The technologies rectify the shortcomings of conventional water distribution systems troubled by aging infrastructure, overconsumption of water, and loss due to concealed leaks (Koo, Piratla, & Matthews, 2015). In an industrial environment like Volvo Cars' Torslanda plant, IoT and Big Data solution deployment for optimizing water consumption can greatly help improve operational efficiency, minimize water losses, and uphold sustainability targets.

One of the most significant risks facing industrial water management is non-revenue water (NRW), which is potable water lost through leaks, pipe ruptures, or unauthorized use. In industrial practice, e.g., big drinking water distribution systems, water leakage, or NRW as it is also called, is still a prominent problem for sustainable water management. In Sweden, distribution system losses are estimated to correspond to about a fifth of the total drinking water produced. Statistics Sweden reports that 20–25% of treated water was lost on the way to consumers in 2015 (Cirkulation, 2018), which is in line with international proportions. Koo, Piratla, and Matthews (2015) also state that NRW stands at approximately 17% of treated water in public distribution systems, which speaks to the enormity of the problem.

In Sweden, water losses in municipal water distribution systems have been a top issue to be tackled by utilities. Based on statistics from 2017, the total water loss in 99 municipalities was around 20%, and the respective municipalities had reported water loss ranging from 1% to 50%, see *Table 1*. (Svenskt Vatten Utveckling, 2019). This concerns variations between municipalities, where the range of 1–50% refers to the lowest and highest measured water losses locally. To detect and minimize such losses, more advanced technical solutions are being adopted, including smart water meters and IoT-based monitoring systems (Koo, Piratla, & Matthews, 2015). With the application of intelligent metering, remote data collection, and real-time analysis, utilities can identify leaks early in large pipeline systems without costly excavation. This active digital surveillance facilitates fast responses to leakage events, thereby reducing non-revenue water and conserving water resources and cost savings (Koo, Piratla, & Matthews, 2015).

Table 1: Reported water loss in 99 Swedish municipalities from 2017 (Svenskt Vatten Utveckling, 2019).



Inefficiency in water distribution processes not only leads to additional operating expenditure but also adds to the carbon footprint of water treatment and transportation processes (Zang et al., 2021). Further, water demand variability and system breakdowns can halt industrial processes and hence the need for forward-looking water management by industries such as

Volvo Cars (Stefanakis, 2019). IoT and Big Data technologies present groundbreaking solutions for real-time water monitoring and decision-making. IoT refers to a network of intelligent devices and sensors connected and which provide real time data on water flow, pressure, temperature, and consumption patterns (Koo, Piratla, & Matthews, 2015). These data are processed using Big Data analytics so that facility managers can detect abnormalities, recognize inefficiencies, and enact focused conservation efforts (Zang et al., 2021).

At Volvo Cars' Torslanda factory, IoT-enabled sensors in production lines, cooling systems, and pipelines can be used for early detection of leaks, minimizing water wastage, and proper distribution of water (Stefanakis, 2019). The solution makes operations more reliable and shields industrial processes from disruption due to water supply failures.

One of the highest value applications of IoT is Automated Meter Reading (AMR), which offers real-time water consumption readings without the need for intervention (Koo, Piratla, & Matthews, 2015). AMR infrastructure already sees widespread application in commercial and residential sectors, proving feasibility and scalability for industrial applications. AMR can be embedded in current water infrastructure for tracking water consumption patterns, identifying unusual consumption, and initiating customized conservation measures (Zang et al., 2021).

IoT-enabled pressure sensors in pipes are another beneficial use, as it allows monitoring the flow of water in real time to identify the changes that indicate leaks, damage to pipes, or inefficiencies in the system (Stefanakis, 2019). With this real-time monitoring of data, maintenance personnel can prioritize repairs and allocate resources accordingly, reducing the chances of costly emergency repairs.

Predictive analytics also enhance industrial water management by using trending historical data to forecast system performance. For instance, when the water use increases unexpectedly within a particular area, predictive models can be applied to determine whether the issue is with operations change, an unseen leak, or water use inefficiency (Koo, Piratla, & Matthews, 2015).

Industrial cooling of processes, water transport, and treatment all use a lot of energy and account for a large portion of the total energy used and carbon emissions of a plant (Zang et al., 2021). IoT and Big Data systems can optimize energy use by making pump usage more efficient, eliminating unnecessary heating or cooling of surplus water, and providing water only where and when needed (Stefanakis, 2019).

For example, real-time flow information allows facility managers to dynamically optimize pump speeds so that pumps operate at their most efficient levels rather than always operating at levels that waste energy (Koo, Piratla, & Matthews, 2015). The following strategy can minimize energy costs and carbon footprint associated with water delivery and cooling systems.

Despite their numerous advantages, IoT and Big Data adoption in industrial water management is not without its drawbacks. Upfront high costs of sensor placement, data processing infrastructure, and network setup may act as a deterrent for some industries (Zang et al., 2021).

These costs can, nevertheless, be offset by long-term cost savings through reduced water losses, improved energy efficiency, and lowered maintenance (Stefanakis, 2019). The other crucial issue is cybersecurity since IoT networks connecting industrial water systems to the cloud or centralized data centers are vulnerable to hacking and data theft (Koo, Piratla, & Matthews, 2015). Strong security features such as encryption of data, access controls, and real-time monitoring are crucial to protect against sensitive water management data (Zang et al., 2021).

The success of IoT and Big Data in water management is heavily dependent on stakeholder involvement. Increasing the awareness of employees, facilities managers, and policymakers about the benefit of digital water monitoring can boost adoption and effectiveness in implementation (Stefanakis, 2019).

Incorporating IoT-based water-saving programs into corporate sustainability planning can help align operational efficiency with environmental responsibility (Koo, Piratla, & Matthews, 2015). Moreover, collaboration with government organizations and technology providers can facilitate access to funding, incentives, and knowledge-sharing initiatives that encourage smart water management solutions (Zang et al., 2021).

IoT and Big Data technologies offer a transformativ approach towards industrial water management, which facilitates real-time monitoring, predictive maintenance, and energy-efficient operations. By embracing these technologies, industries can prevent wastage of water, maximize the use of resources, and reduce the environmental footprint (Koo, Piratla, & Matthews, 2015).

For Volvo Cars' Torslanda factory, the use of IoT-enabled water management systems provides the opportunity for enhanced sustainability performance, lower operation costs, and assisting broader water-saving practices (Stefanakis, 2019). While initial investment costs and cybersecurity risks must be approached cautiously, the long-term benefits of smart water technologies place them as a critical weapon for the success of sustainable industrial processes (Zang et al., 2021).

2.2.2 Sensor technologies for leakage detection and monitoring

A growing area within innovative water-saving technologies is the use of sensor systems for real-time monitoring and leakage detection in both municipal and industrial water networks. In Sweden, two recent developments exemplify the potential of digital tools to support proactive water management.

One example of an emerging sensor innovation is currently under development by IVL Swedish Environmental Research Institute, as described in a recent press release. The organization presents a patent-pending system for non-contact measurement of water quality and flow in stormwater and wastewater networks (IVL, 2023). The solution combines laser technology, camera imaging, and AI-driven analysis to detect changes in flow patterns and early signs of blockages or contamination, all without the sensor being submerged. Although the technology is still in its early stages and has not yet been implemented on a large scale, it illustrates the potential of non-invasive, AI-supported monitoring systems. While primarily aimed at municipal infrastructure, the approach also highlights possible future applications in industrial settings where low maintenance and operational reliability are crucial. A field test within the LoV-IoT project showed that the sensor, referred to as the "Turbinator," could successfully measure turbidity and water level in stormwater wells without coming into contact with water, confirming its suitability for dirty environments where contact-based sensors often fail (IVL, 2020).

In parallel, researchers at KTH Royal Institute of Technology have developed a new generation of sensors designed to identify both leakage and potential contamination in drinking water systems with high accuracy (KTH, 2024). This technology utilizes pressure waves and acoustic signals to pinpoint changes in water movement caused by leaks or foreign substances. The system has been tested in pilot environments and demonstrated the ability to detect even minor anomalies in plastic pipes and complex network layouts. Its application in early warning systems could significantly reduce water losses and limit the spread of pollutants, which are challenges particularly relevant in industrial facilities with extensive piping networks.

Together, these two Swedish innovations illustrate how combining smart sensor technology, artificial intelligence, and advanced data analytics can enable more efficient and sustainable water use. By adopting such digital solutions, industries can transition from reactive to predictive maintenance strategies, reduce water-related risks, and achieve greater control over their consumption and environmental impact. These technologies offer promising pathways for implementing scalable, cost-efficient, and environmentally responsible water-saving practices in the industrial sector.

The SmartVA project in the municipality of Kristianstad exemplifies how digital monitoring is applied in modern wastewater management. With the implementation of more than 500 sensors across the municipal sewer system, the network enables real-time tracking of flow volumes, water levels, and anomalies (Kristianstads kommun, 2024). The purpose of this system is to enhance operational control and reduce risks related to flooding, environmental degradation, and abnormal system behavior. The collected data helps identify variations caused by factors such as groundwater infiltration or stormwater overload, allowing for faster responses and more efficient allocation of resources.

SVU Report emphasizes that such technical solutions must be integrated with long-term planning and infrastructural adaptation to remain effective over time (Svenskt Vatten Utveckling, 2018). The report suggests that pipelines should be designed for a technical lifespan of at least 100 to 150 years, which requires careful selection of materials, high installation quality, and adequate maintenance. To reduce the need for extensive excavation work, methods such as cathodic protection and trenchless rehabilitation, including pipe lining, are highlighted as viable alternatives. These techniques must be tailored to local conditions such as soil type and pipe material, while also being feasible in municipalities with limited financial and technical resources.

The combination of real-time monitoring technologies described by Kristianstad Municipality (2024) and the long-term renewal strategies outlined in Svenskt Vatten Utveckling (2018) illustrates how the integration of digital systems with structured planning efforts can improve the resilience and performance of water and wastewater infrastructure.

2.2.3 Small-scale application and behavioural efficiency tools

Yet another sensor-activated water-saving device is displayed in a test at California State University, Sacramento (2016), which compared the water efficiency of automatic with that of manual faucets in the public toilets. Three different setups were used: a manual faucet, an automatic faucet with 1.9 Liters per minute flow rate, and another with 1.3 Liters per minute. The results showed that the 1.9 l/min sensor faucet conserved between approximately 32 percent and the manual one, with the 1.3 l/min model yielding an even greater conservation of approximately 54 percent (Harmon, 2016). These findings show the significant water-conserving capabilities of sensor-controlled well-calibrated faucets, particularly in heavy-use environments.

Although the technology itself is not leaking detection or water quality monitoring specifically, it forms part of a wider trend in which automated behavior and digital control systems are increasingly being incorporated into everyday water management. As industries look to new solutions for water efficiency, such smart faucets demonstrate the possibility that small-scale interventions can form part of smarter water usage within institutional and commercial settings.

These results were complemented by a master's thesis at the Chalmers University of Technology wherein atomization-based nozzles with sensor-activated faucet technology produced by Altered were combined with touch-free and manual modes of functionality (Tahric, 2023). The nozzles have the potential to be installed into existing taps and can achieve up to 98 percent water savings depending on use mode. The Dome nozzle, which is for public areas, flow rate is 0.4 Liters per minute and saves as much as 96 percent. The Dual Flow Pro model consists of two modes – mist and spray – with water savings of 98 and 85 percent respectively. The study emphasized that this type of technical improvement can significantly reduce water consumption without compromising user experience, especially when backed by user-improving features that facilitate behavioural change. Furthermore, the functionality of users being able to switch between manual mode and sensor-based mode was deemed vital in inducing sustainable patterns of use from the onset.

2.2.4 Rainwater Harvesting and Wastewater Reclamation

The increasing pressure on freshwater resources has triggered the exploration of decentralized water systems as an alternative to the traditional, centralized system. Zang et al. (2021) offer a sustainability assessment of decentralized systems with specific emphasis on integrating rainwater harvesting (RWH) and wastewater reclamation to enhance water use in semi-arid environments. Contrary to massive water treatment plants relying on extensive distribution networks, decentralized systems offer localized solutions, which can be of effectiveness in industrial setups like Volvo Cars' Torslanda factory.

Decentralized systems of water management can even be autonomous or run parallel to municipal water supply systems so that industries and urban communities can harvest, store, and treat water on site. This localized approach reduces dependence on external freshwater sources and improves water security in areas with seasonal variation. The study by Zang et al. (2021) demonstrates that an integrated RWH and wastewater reclamation system can significantly decrease the use of potable water by recycling treated water for non-potable purposes such as cooling processes, flushing toilets, and cleaning facilities.

For Volvo Car, the installation of a hybrid system in Torslanda would complement existing measures for water conservation through rainwater harvesting for direct use and treatment of process wastewater for reuse in industry. Integration within existing plants guarantees that sustainability goals are realized without disrupting production or requiring significant redesign of facility plans.

A good example of the above application is found in western Sweden, where chemical company Perstorp has partnered with the municipality of Stenungsund to recycle treated wastewater from a municipal treatment plant into its own production processes (Vaguiden, 2023). Instead of pumping treated wastewater into the ocean, the water is recycled and recycled in manufacturing, reducing the company's reliance on potable water as well as its environmental footprint. The first phase of the project consists of 650,000 cubic meters of treated water diverted to the company's cooling system from autumn 2023. At full production, the system will be saving 1.1 million cubic meters of freshwater annually, as quoted by project representative Eva Gunnergård (Vaguiden, 2023). The real-world application of this case highlights how cooperation between sectors and local reuse of water can initiate both environmental and operational advantages. It also highlights the feasibility of implementing decentralized water solutions in existing industrial environments, in turn supporting the argument that the models are scalable as well as transferable to different industries.

Zang et al. (2021) bring attention to three key aspects that matter when assessing decentralized water systems: their environmental impact, financial implications, and the potential benefits for society. On the environmental side, these systems can reduce the need to draw fresh water and help limit how much wastewater ends up in the environment. For a large industrial site like Torslanda, that could ease the pressure on local water infrastructure and contribute to a more balanced water use overall.

When it comes to cost, the initial investment is often high. But if the system is well planned, it may pay off in the long term. Lower water bills, reduced treatment costs, and greater independence from external providers are all factors that could make it worthwhile. It would be reasonable for Volvo Cars to explore whether this kind of system could offer real savings over time.

There's also the social dimension. If industries become more self-sufficient and use less drinking water, that can improve availability for nearby communities (Zang et al., 2021). Showing that a company takes water issues seriously might also have a positive effect on how it is perceived by the public.

Still, it's not something that can be rolled out overnight. Setting up decentralized systems requires technical know-how, time, and the ability to navigate a fair number of regulations (Zang et al., 2021). To get around these obstacles, companies need to be practical. They can start by using proven technologies like membrane filtration or UV disinfection, adapt new systems to what's already in place, and work with experts and authorities to make the process smoother.

2.3 Rainwater Harvesting Systems

As freshwater grows ever more under stress, rainwater harvesting (RWH) has become a sound option for improving water sustainability in urban and industrial sectors. In this chapter, we showcase several applications of RWH, ranging from industrial reuse at large volumes to decentralized systems in the urban environment. Through recycling and harvesting rainwater for non-potable uses, industries and municipalities can minimize their reliance on municipal supplies, stormwater runoff, and improve climate resilience. Subsections cover filtration and storage technological innovations, integration with current infrastructure, and regulatory and financial considerations affecting wider adoption.

2.3.1 Rainwater Harvesting for Sustainable Industrial Water Management

Rainwater harvesting (RWH) has risen to the top of priorities as a method of sustainable water management in industrial and urban settings. In industries where there are extensive roof areas, RWH appears to be an option for conserving drinking water for non-priority applications such as cooling, sanitation, and irrigation. The literature shows that a high percentage of the water requirement in such applications is obtainable through RWH supplemented with proper storage and simple filtration (Aleksic et al., 2019; Engvall, 2021).

In the Swedish industrial environment, Engvall (2021) demonstrated that an RWH system at Sandvik AB could potentially provide over half of a building's cooling water demand. Although not directly applicable, the application demonstrates that such a project is viable at Volvo Cars' Torslanda plant, where there is large roof area and non-potable water demands within office and test environments.

Aleksic et al. (2019) also investigated the use of RWH in the automotive industry. In their study, they concluded that the use of rainwater harvesting, and pre-installed treatment plants has the potential to reduce municipal water usage by up to 72 percent. This suggests that there is more potential for automobile companies to utilize RWH as part of their sustainability strategy, especially when coupled with wastewater recirculation. This, for Volvo Cars, would mean complementing traditional water usage with locally harvested rainwater for cleaning, cooling, or flushing.

While RWH is economically and environmentally advantageous, viability depends on local policy, seasonal levels of precipitation, and local need. Where local water usage is high and sustainability is the focus area, for instance, in areas like Torslanda, RWH can be an effective step towards greater water efficiency with little requirement for extensive alteration of underlying line production processes.

2.3.2 The Potential of Rainwater Harvesting in Urban Water Management

Rainwater harvesting (RWH) is currently being promoted as a sustainable technology in urban and industrial areas. Industrial establishments have large roof surfaces that provide opportunity for rainwater harvesting, which can be recycled for non-potable uses like washing, sanitation, or cooling. Engvall (2021) answers this through a case study at Sandvik AB, where rainwater was employed to supply more than half of the cooling water requirements of a plant. This is characteristic of how RWH can effectively minimize freshwater utilization in water-efficient operations, and this can be adopted in such factories as Volvo Cars Torslanda.

In the automobile industry, RWH has been investigated to help attain sustainability objectives through municipal water dependence reduction. Aleksic et al. (2019) show that 15 percent or even more of the total water requirement of an industrial plant can be satisfied with harvested rainwater, based on regional rainfall intensity and roof space availability. Hybrid rainwater with current water recycling treatment also increases resource productivity.

Though the two cannot be eliminated entirely, Govindan's (2018) contention brings forth the fact that they are bound by law and by a cost of investment too. Inconsistencies across jurisdictions exist at the municipal level, as found by Engvall (2021), which can make large-scale uptake problematic. Govindan (2018) also finds economic incentives to be pertinent, particularly in nations such as Sweden where water is inexpensive. Nonetheless, the potential to save operating expenses and increase long-term durability renders RWH a viable industrial water management practice.

2.4 Benchmarking and Best Practices

To foster water sustainability in urban and industrial areas, best practices from cities and organizations that have been successful in adopting forward-thinking strategies must be investigated. This section reviews the incorporation of green infrastructure in urban water management based on international benchmarking. Through examination of approaches in cities like Singapore, Berlin, and Melbourne, this study discusses how context-specific strategies, concerted institutional efforts, and multifunctional design enable water resilience, minimal environmental footprints, and the integration of infrastructure development into broader sustainability objectives.

2.4.1 Green Infrastructure for Sustainable Urban Water Management

Using five prominent world cities as their subject, Liu and Jensen (2018) focus on the role of green infrastructure (GI) in urban water management: Singapore, Berlin, Melbourne, Philadelphia and the Sino-Singapore Tianjin Ecocity. This enables them to represent different approaches to urban water management with a focus on the integration of green infrastructure to achieve more sustainable water management. The study offers a detailed overview of the contributions of green infrastructure to water conservation, to environment protection, and to overall urban sustainability, and gives insights into both its potential and its challenges.

The article (2018) stresses the need for a shift from conventional linear models to integrated systems that bring together supply, drainage, and the environment as linked components of a larger system. Green water management plays a key role in this shift by replicating the natural water cycle and providing key ecosystem services such as infiltration, evapotranspiration, and retention. Examples of green water management are green roofs, rain gardens, bio-retention ponds, wetlands, and permeable surfaces, which are designed to manage stormwater locally, reduce water consumption, and improve the city.

To compensate for the fact that Singapore has to rely very much on imported water, water supply is improved through garden irrigation and the creation of reservoir parks; Berlin uses riverside filtration and artificial recharge to maintain water quality, Melbourne concentrates on the use of non-conventional sources for irrigation in public gardens, while Tianjin is determined to use sewage water and sludge for watering the large expanses of inland and coastal flora, and reduce CSOs. Challenges related to urban water management that were encountered in the different cities chosen, such as lack of water supply, pollution, CSOs and climate adaptation.

One of the strongest forthcoming themes of the research (2018) is the multifunctionality of GI. Beyond water management, GI enhances biodiversity in cities, supports recreational and cultural use, and enhances property value. For example, GI in Singapore brings not just stormwater management but also recreation and city identity. Similarly, Melbourne parks reflect no utilisation of potable water while promoting urban biodiversity and public health. This multifunctionality then positions GI as a principal tool in addressing broader sustainability goals such as climate change adaptation and resource efficiency.

The study emphasizes the importance of aligning GI strategies with specific urban challenges and development agendas. Each city formulates its strategy based on its own context. For example, cities with significant water supply concerns, such as Singapore and Tianjin Eco-city, have employed GI quite extensively to cope with water shortages. The Philadelphia and Berlin cities are less interested in coping with water scarcity but more interested in environmental conservation and improving water quality through measures such as permeable surfaces and nitrate-phosphorus control measures.

Despite its advantages, GI deployment is confronted by numerous challenges. Institutional challenges such as insufficient cross-sector coordination and delayed development of site-specific guidelines are barriers to GI adoption. Technical challenges in terms of expensive installation and maintenance costs, alongside interference with current infrastructure, also act as a hindrance. Space limitations in high-density cities also constrain the feasibility of mega-scale GI projects. The research calls for both top-down and bottom-up strategies in addressing these obstacles and ensuring GI efforts are properly coordinated and involve a wide range of stakeholders.

The five cities examined prove that effective GI implementation must be done through a mix of pilot projects, city-level strategies, and public participation. For example, Berlin's "Urban Ecology Model Projects" show creative solutions at the local scale, but Singapore brings GI into its overall water management strategy to allow for scalability. Public awareness campaigns and incentives are also required to engage the private sector and get buy-in from the community.

For facilities management, the outcome of this research has relevance to water efficiency and conservation. Use of GI for local stormwater capture and reuse can be used to reduce potable water use in buildings, for instance, for irrigation, flushing toilets, or cooling in cooling systems. Furthermore, the inclusion of GI features like green roofs and permeable pavements in building plans enhances stormwater management and reduces the building's environmental footprint. These interventions are very much in congruence with the broader desires for sustainability and resource use efficiency, demonstrating that GI can be an efficient and effective solution for urban infrastructure in the modern world.

The study by Liu and Jensen (2018) provides a significant knowledge regarding the capacity of green infrastructure to transform urban water management towards sustainability, resilience, and multipurpose functionality. Despite existing challenges, what the five cities in this study have undertaken is a model for the integration of GI into city planning and facility operation that conserves and utilizes efficiently water resources. The study emphasizes the adoption of GI solutions to specific urban environments and ensuring coordination among stakeholders to harness its full potential.

2.5 Economic and Environmental Impacts of Water Management Strategies

With industries under growing pressure to reduce their use of freshwater, learning more about the broader impact of water reuse has become highly important. This chapter presents some selected results from comparison-modelling studies on how different reuse scenarios can affect environmental and economic performance in industry. After the Model Industrial Park (MIP) example by Boysen et al. (2020), focus is placed on key findings in terms of reuse efficiency, cost evolution, and life cycle impacts. While not all may be directly useful to Volvo Cars, the core principles are sufficient to inspire future water management decisions.

2.5.1 Optimizing Water Reuse in Industrial Areas: Insights from the MIP Model

Industrial wastewater recycling has also been the focus of growing interest as a wise approach towards water saving, particularly in industrial applications where freshwater is scarce. Boysen et al. (2020) offer an MIP-based modelling method that approximates different alternatives of wastewater recycling and identifies the economic and environmental effects thereof. The research demonstrates that it can minimize freshwater withdrawal and discharge with efficiency by raising the reuse rate from 5% to 14% without compromising the water quality for non-potable uses such as irrigation, toilet flushing, and cooling (Boysen et al., 2020).

One of the major lessons of the MIP model is that there is a compromise between initial investment and future savings. Even though investment in water reuse facilities at the time of construction is costly, unit cost of the reused water decreases with increasing volume of reuse by the scale economies. For instance, unit cost per cubic meter decreased from €0.25 to €0.18 when reuse rate improved from 5% to 14% (Boysen et al., 2020). The research indicates that high-end reuse systems are economically feasible in certain situations, especially where there is a water shortage or high environmental conservation.

Environmental-wise, Boysen et al. (2020) undertook a life cycle assessment that indicated that increased reuse leads to lower greenhouse gas emissions and lower nutrients flushed into the water bodies. This would mean that higher reuse mechanisms not only enhance operating effectiveness but also lower the environmental cost associated with industrial operations. Volvo Cars Torslanda's direct reuse rates and facilities in the MIP model may not apply directly at first glance, but overall conclusions hold true. This research presents the potential of water reuse plants to become more resource-efficient in consumption, especially with the integration of continuous water treatment technologies. All these concepts can be applied to future planning and programs for sustainability at Volvo and other companies like Volvo manufacturing plants.

2.6 Challenges and Barriers

Despite increasing access to new technologies and best management practices, numerous barriers remain on the path to sustainable industrial and urban water use. These range from technical barriers such as hidden leakage and aging infrastructure to institutional and financial concerns affecting reinvestment capabilities and maintenance. Moreover, behavioural mind-sets and dysfunctional internal communication systems have the tendency to undermine even optimal-designed strategies. This section explores these key challenges in depth, highlighting how technology, policy, and coordination within need to work collectively to facilitate meaningful improvement in water management.

2.6.1 Water Leakage as a Technical and Institutional Challenge

The most critical among the sustainable water management challenges in industrial and urban settings is water leakage. In Sweden, 15 to 20 percent of produced drinking water goes to waste in distribution systems, amounting to approximately 150 to 200 GWh energy loss each year (Rothman et al., 2013), this is a national average or estimated range for Sweden as a whole. Most of these leakages are undercover, in that the water seeps into the ground undetected and without ever reaching customers. Such losses contribute not only to economic loss but also to initiate erosion, flooding, as well as environmental concerns by affecting groundwater and surface water systems (Najar & Persson, 2023). This is a very complex issue in aging pipe networks where material degradation, soil conditions, and inadequate maintenance intersect.

According to Rothman et al. (2013), application of new technologies such as Doppler radar presents significant potential to detect hidden leaks, such as in plastic pipes or big diameters where traditional acoustic methods are ineffective. Doppler radar works on the principle of sending radio waves into the ground, which reflect off objects like pipes and moving water. Upon reflection off them, their frequency could have changed. This is known as Doppler shift and can be used to determine the motion of water in a leak. The technology makes it possible for very precise detection, even in noisy areas where the use of traditional means is not appropriate. Pilot project results indicate the potential of this method, but further study is needed to up-scale to various local conditions and pipe materials.

While technological progress is a key factor, Najar and Persson (2023) mention certain fiscal and organizational challenges that hinder effective leak management. Based on their studies, only four percent of Sweden's water utilities attain a sustainable level using the national sustainability index. A major concern is the low pipeline infrastructure replacement rate because of limited budgets and politically driven decisions in favour of new construction over reuse of installed pipelines. The effect could be increased stress on distribution systems and treatment plants, leading to flooding, soil instability, and the transmission of dirty water to sensitive water ecosystems.

This is further complicated by variations in local financial conditions. According to SVU-report 2024, the financial capacity of Swedish municipalities to act about water infrastructure maintenance and leakage varies significantly (Svenskt Vatten, 2024). While the overall investment per capita in pipeline infrastructure is approximately 1,400 SEK annually, the report also identifies significant gaps across the country, with some municipalities investing relatively lower amounts of capital, making sustainability over the long term difficult to accomplish. In parallel, the average drinking water tariff in Sweden is 17 SEK per cubic meter, while wastewater services average 22 SEK per cubic meter, resulting in a combined average of 39 SEK per cubic meter. This figure is based on a standard single-family household (Typ A) with an annual consumption of 270 m^3 and a total water-related cost of 10,515 SEK in 2024 (Svenskt Vatten, 2024). Although regional tariff levels vary considerably, they are designed to reflect actual operational and investment needs, with no profit margins allowed. Still, the alignment between local tariff setting and long-term reinvestment capacity may differ depending on financial and political priorities. This distortion implies that some municipalities struggle to generate the revenue necessary to recapture infrastructure, especially in low-density or rural municipalities where economies of scale are more difficult to achieve. Smaller municipalities with fewer than 10,000 subscribers have more per capita expenses, showing structural fragility in making sustainable water management financially feasible for low-density areas.

Additional contribution is provided by Svenskt Vatten Utveckling (2013), stressing the need to develop practically applicable and reliable techniques for leak detection in water supply systems. The study experimented with various technologies, including acoustic techniques, pressure correction, and sensors, to determine their performance under different soil conditions and pipe material. A central part of the research was developing guidelines on how water utilities can select the most appropriate method according to local conditions. An example is that the research contrasted how different leak detection methods perform in loose soils, bedrock, or urban areas with high levels of interference from infrastructure. It also underscored the importance of applying methods that do not require highly technical expertise or significant financial investments to apply. By laying down a step-by-step and practical framework on how municipalities and other stakeholders can implement these methodologies as part of their normal operations, the report provides helpful insights regarding how the water losses can be addressed in an organized and cost-effective way.

All three studies together demonstrate that technical solutions such as Doppler radar and innovative leak detection must be supplemented by long-term maintenance planning, strategic investment, and organizational readiness to be able to effectively reduce water loss through leakage in urban and industrial settings. Only a holistic approach can enable sustainable use of water as well as the Agenda 2030 targets (United Nations, 2015).

Apart from studies at the academic level, industry groups have also pointed to water leakage as an emerging societal problem in Sweden. In a joint commentary in 2023, Maskinentreprenörerna CEO Anders Robertsson, Swedish Association of Pipe Wholesalers (Svenska Rörgrossistföreningen VVS) CEO Joacim Nordh, and VVS Manufacturers Council (VVS-Fabrikanternas råd) CEO Jonny Hellman emphasized that several hundreds of leaks in the municipal water and sewage system were reported last year. They warned that the lack of extended investment in maintenance and renewal heavily threatens the operation of such systems at a time when climate change will doubtless put added pressure on infrastructure near the end of their life (Dagens Samhälle, 2023).

The authors had spoken of a widening gap between demand for infrastructural provisions and funds and called for united national action to avoid water supply being eroded. They indicated that political will, regulation, and more open governance were needed to achieve leakage of water being addressed in a systematic and proactive manner, particularly to deliver climate and sustainability targets and protect one of our most valuable natural assets.

It completes the deficiencies of existing scientific work by emphasizing collaboration among industry players and government action towards the achievement of technical and organizational changes proposed here. It also shows that water leakage is not a technical issue but rather a well-established problem that includes institutional and governance-related issues, which necessitate intervention at societal levels.

2.6.2 Behavioural and Attitudinal Barriers to Sustainable Water Management

One very important element of sustainable water management is human behaviour and attitude towards water conservation. In a study by Lee and Tansel (2013), the Miami-Dade County, Florida, implemented a grand-scale water-conservation retrofit program aimed at low-income and older residents who were residing in single-family dwellings built before 1996. The program involved free replacement of high-efficiency showerheads, faucets, and toilets in participating homes with the aim of reducing the daily amount of water consumed both through technological advancements and behaviour adjustments.

Each home was to be replaced with up to two high-efficiency toilets, two showerheads, and one faucet aerator kit. The improvements equated to estimated daily water savings of approximately 131.4 Liters per household for toilets, 106 Liters per day for showerheads, and 35.2 Liters per day for aerators (Lee & Tansel, 2013). In addition to the technical measures, a telephone survey of 121 households with an achieved response rate of 64 respondents was conducted to assess programme satisfaction and behavioural changes.

The findings showed that 65.5 % of respondents had changed their water-consuming habits. Unsurprisingly, the most common changes were taking shorter showers (33.9 %) and switching off the tap while brushing teeth (32.2 %). Furthermore, 76.6 % of respondents indicated a reduction in their water bills, while a vast majority (81.3–89.1 %) indicated a favourable attitude toward the incentive scheme and the equipment installed (Lee & Tansel, 2013). The above findings underscore user satisfaction and its significance to facilitate behavioural change as well as provide measurable water savings.

Demographically, the sample was 82.8 % of senior households and 68.8 % of two to three-person households. The respondents were predominantly high school or lower educated, but the researchers found no significant correlation between education level and perceived water savings, which means that strategies for participation might be more effective than education levels.

Unexpectedly, 64.1 % of the homes belonged to the medium water-saving potential category (approximately 273 to 545 liters per home per day). Despite technical potential, perceived water savings did not exhibit the same range, with only the lowest level of water-saving potential (less than approximately 273 liters per day) reporting positive results. This inconsistency highlights the generic conservation program limitation: the disparity between technical advances and user perceptions of saved costs, which may be due to behavioural rebound effects and inconsistent awareness (Lee & Tansel, 2013).

The research by Lee and Tansel (2013) aligns with bigger studies in highlighting that technological intervention alone is not sufficient unless behavioural assumptions are addressed. For instance, Hage et al. (2009) point out that individuals' propensity to take up environmental behaviour, including water-saving measures, largely relies on perceived behavioural control, personal norms, and situational variables. This highlights the point that effective water management strategies are not only in need of understanding how to install efficient technologies but also establishing an environment that encourages and sustains behavioural change.

Overall, the case study illustrates the need for integrating technical retrofits with behavioural engagement to bring about meaningful and sustained reductions in water consumption. It illustrates that technical measures must be complemented by people-centred approaches that allow individuals to become active participants in fulfilling water conservation goals.

2.6.3 Communication Barriers in Organisational Water Management

While technical limitations and behavioural factors represent significant barriers to sustainable water management, a third barrier is inherent in the communication systems which govern the way knowledge, risks, and strategies are shared within an organisation. Cross-departmental and cross-stakeholder group communication is a central precondition for facilitating integrated and unified responses to water issues, particularly in large and complex industrial systems.

Covello et al. (2007) point out that well-designed risk and crisis communication is not only critical during the acute phase of emergencies but also plays a basic role in long-term organizational preparedness, strategic alignment, and trust building. One of the key tools discussed is message mapping, which is a methodical process of ensuring that communication is consistently clear, consistent, and credible at different stakeholder levels. This structured messaging enables quicker and more aligned responses, which, in water activities with multiple departments holding joint responsibility for monitoring, risk assessment, and strategic planning, is particularly useful.

Similarly, Castro et al. (2023) illustrate how poorly aligned communication structures between actors can hinder collaboration and delay the implementation of effective water management strategies. Their network analysis of integrated water governance in Houston, Texas, reveals a striking gap between stakeholders stated ambitions to cooperate and the fragmented reality of the existing communication system. This misalignment underscores the need to institutionalize communication channels that not only connect departments but also promote clarity in roles, responsibilities, and mutual expectations. Through participatory modelling and fuzzy cognitive mapping, the study shows how improved communication structures can foster adaptive learning and a shared understanding of both risks and opportunities in water management.

These studies highlight that successful water governance depends not only on technical systems or behavioural change but also on the relational and communicative infrastructure that supports coordinated action. In a large organization such as Volvo Cars, where water-related responsibilities may span across departments like facility operations, environmental management, and finance, the establishment of shared language, clear ownership, and reliable communication pathways is essential. Improving this internal alignment could significantly enhance the organisation’s ability to manage water efficiently, identify risks early, and implement sustainable solutions in a unified manner.

3

Methodology

This chapter outlines the methodological approach used in this study, detailing the research process, data collection methods, interview study, empirical analysis, and ethical considerations. The chosen methodology aims to provide a comprehensive and structured approach to investigating water consumption at Volvo Cars' eastern Torslandas facilities and identifying sustainable and cost-efficient solutions for reducing water usage.

A combination of qualitative and quantitative methods has been used to ensure a holistic understanding of the problem. The study incorporates interviews, literature review, benchmarking of best practices, field visits, and financial modeling using Volvo's *Sustainability Benefit-Cost Model* (SCM). These methods allow for a multi-faceted analysis that integrates technical, financial, and sustainability aspects into the proposed solutions. By combining both qualitative and quantitative research it strengthens the validity of findings by allowing for triangulation, where multiple sources of data contribute to a comprehensive understanding of the research problem (Bryman & Bell, 2017).

3.1 Research Process

The study is designed to identify high-consumption areas, explore potential solutions for reducing water use, and assess the feasibility of implementing sustainable water management practices. The process consists of three distinct phases, each building upon the insights gained from the previous stage to form a well-grounded and actionable set of recommendations. Through a systematic approach to research design, as mentioned by Bryman & Bell (2017), this report ensures that data collection and analysis remain coherent aligned with the objectives of the study.

The first phase focuses on mapping current water consumption by gathering and analyzing quantitative data from Volvo Cars' internal monitoring systems, specifically using eSight. Esight is Volvo's own internal site for viewing water data using installed water meters in buildings that send data on consumption. By assessing historical consumption patterns, this phase identifies which facilities have the highest water usage and where inefficiencies may exist. The goal is to establish a clear baseline that allows for meaningful comparisons and targeted interventions. This phase also examines discrepancies between purchased and measured water to detect possible leaks or unaccounted-for losses. With the use of quantitative data, it is essential for identifying trends and variations over time, providing a factual foundation for further analysis (Bryman & Bell, 2017).

The second phase is centered on identifying optimization opportunities by exploring potential efficiency measures that could be implemented within the studied facilities. This involves conducting interviews with key stakeholders at Volvo Cars, including environmental coordinators, facility managers, and engineers, to gain insights into existing water management strategies and challenges. Additionally, benchmarking best practices from similar industries and reviewing relevant literature help contextualize the findings and highlight proven methods for reducing water consumption. Site visits to other companies with successful water-saving initiatives further contribute to understanding the practical implementation of different technologies and management approaches. Interviews and benchmarking, which is a part of the qualitative methodology, provides valuable context and depth to numerical data by helping to understand why specific patterns emerge (Bryman & Bell, 2017).

The third phase expands the study beyond reducing consumption to investigating how additional water can be sourced in a sustainable manner. This part of the research focuses on assessing the feasibility of implementing rainwater harvesting at Volvo Cars' eastern Torslanda facilities. The goal is to evaluate whether rainwater collection systems could be integrated to supplement existing water supplies, reduce dependence on municipally supplied water, and contribute to sustainability goals. This phase involves analyzing local rainfall patterns, storage and filtration requirements, and potential applications for harvested water, such as toilet flushing, irrigation, or cooling systems.

The research approach in this study combines elements of both inductive and abductive reasoning. Inductive reasoning is applied in the initial phases, where patterns and trends in water consumption are identified from the collected data without prior assumptions. By analyzing the data and drawing conclusions based on observed usage patterns, the study builds an understanding of existing inefficiencies and opportunities. The abductive approach comes into play when identifying potential solutions, as the study moves beyond purely data-driven conclusions to exploring plausible explanations and innovative interventions that could address the identified issues. Research methodologies have received a lot of attention from Bryman and Bell (2017), who note that abductive reasoning is helpful in applied research since it allows for creativity while maintaining evidence-based solutions to problems. By incorporating both approaches, the research remains open to discovery while ensuring that findings are grounded in empirical evidence and aligned with practical applications.

This structured research process ensures that the study is both methodologically sound and aligned with Volvo Cars' operational and sustainability objectives. By integrating data analysis, stakeholder insights, and feasibility assessments, the research lays a solid foundation for developing realistic and effective strategies to optimize water use and explore sustainable alternatives for water sourcing.

3.2 interview study

To gain a deeper understanding of water management practices and identify feasible solutions for reducing water consumption at Volvo Cars' eastern Torslanda facilities, a qualitative interview study has been conducted. The selection of interviewees has been carefully considered to ensure that the collected insights cover both internal perspectives from Volvo Cars and external expertise from companies specializing in sustainable water management. These interviews provide a broader contextual understanding of existing water usage patterns, potential efficiency measures, and best practices that could be applicable in Volvo's operations. One of the importance of qualitative interviews is the gain of rich and detailed insights that may not be captured through only quantitative approaches (Bryman & Bell, 2017).

The interview study follows a semi-structured format, allowing for both predefined key questions and open-ended discussions. This flexible approach ensures that important topics are covered while also providing interviewees with the opportunity to share their own insights and expertise. Since the research aims to explore both technical and organizational aspects of water management, maintaining an open dialogue is crucial for identifying practical, innovative, and cost-effective solutions that align with Volvo's operational framework. Semi-structured interviews allow researchers to examine unexpected but relevant questions that come up during discussions while also finding a balance between consistency and adaptation (Bryman & Bell, 2017).

Internal interviews focus on key stakeholders within Volvo Cars, including environmental coordinators, facility managers, and engineers who work directly with infrastructure, sustainability initiatives, and operational efficiency. These interviews aim to identify the main water-related challenges within the organization, understand ongoing efforts to optimize water use, and explore areas where improvements could be made. Additionally, these discussions help clarify technical constraints, financial considerations, and organizational priorities that may influence the implementation of new water-saving measures. By engaging with individuals who have hands-on experience in Volvo's water consumption and management, the study ensures that its findings remain relevant and actionable within the company's operational environment.

External interviews are conducted with companies and experts specializing in water efficiency technologies and industrial water management. These external stakeholders provide valuable benchmarking opportunities, offering insights into best practices, technological advancements, and successful strategies implemented in other industries. By learning from companies that have effectively reduced their water footprint, the study can assess which methods and innovations could be adapted for Volvo's specific needs. These interviews also help in understanding the cost-benefit implications of various water-saving solutions and evaluating their feasibility in an automotive manufacturing and office facility context.

The interviews are conducted both in person and via Microsoft Teams, depending on the availability of the respondents and logistical considerations. On-site interviews allow for a more immersive understanding of water-related challenges within Volvo's facilities, while virtual interviews provide flexibility in engaging with external experts across different locations. Regardless of format, all interviews are documented and analyzed thematically to identify recurring patterns, challenges, and opportunities for improvement. Thematic analysis, a systematic method for examining qualitative data by spotting repeated themes and patterns in interviews, is something that Bryman and Bell (2017) suggest.

A complete list of interviewees, along with their roles and affiliations, is presented in *Figure 1*, providing transparency regarding the selection process while maintaining confidentiality where necessary.

Label	Company	Role	Location
A1	Volvo Cars	Project Leader	On-site
A2	Volvo Cars	Sustainability Analyst	On-site
A3	Volvo Cars	Graduate	Teams
A4	Volvo Cars	Workplace Sustainability	On-site
A5	Volvo Cars	Environmental Coordinator	On-site
A6	Volvo Cars	Environmental Coordinator	On-site
A7	Volvo Cars	Head of Media and Resource Utilization	Teams
B1	Volvo Group Real Estate	Sustainability Manager	Teams
C1	Skanska	Climate and Sustainability Manager	On-site
C2	Steptura	Project Manager	Teams
C3	Consultant	Stormwater Consultant	Teams
C4	Smartvatten	Account Manager	Teams
C5	Prowash Sverige	Business Manager	Teams

Figure 1: List of Interviewees.

3.3 empirical study

The empirical analysis in this study integrates quantitative data from Volvo Cars' water monitoring systems, financial assessments, and benchmarking of best practices to evaluate the efficiency and feasibility of proposed water-saving solutions. In addition, an inventory of water-consuming installations was conducted with a focus on sensor-based faucets, supported by internal Excel documentation used to quantify the number of toilets and associated handwashing stations across the facility.

By analyzing historical water consumption data from eSight, the study identifies high-usage areas, potential inefficiencies, and discrepancies between purchased and consumed water. This data-driven approach provides a clear understanding of where reductions can be made and helps prioritize the most impactful interventions. In the field of business, statistical analysis facilitates objective pattern discovery and well-informed decision-making, while reliance on quantitative data strengthens the credibility of a conclusion (Bryman & Bell, 2017). Regarding to the internal data analysis, the study incorporates benchmarking against industry best practices to compare Volvo Cars' current water management strategies with those of other organizations. This comparison helps identify successful implementations of water efficiency measures and assess their applicability in an automotive and office facility context. This is further emphasized by Bryman and Bell (2017), who contend that benchmarking is an effective tool for assessing an organization's performance in relation to outside norms and identifying areas in need of improvement.

To ensure that proposed solutions are both financially viable and sustainable, the Sustainability Benefit-Cost Model (SCM) is applied, which is Volvo's own internal investment tool. This methodology allows cost-benefit analysis, payback period calculations, and long-term economic impact assessments of different water-saving initiatives. By combining data-driven insights, industry benchmarking, and financial modeling, the empirical analysis provides a comprehensive foundation for developing practical, cost-effective, and sustainable water management strategies at Volvo Cars. In business research, financial modeling is essential because it helps businesses evaluate the viability of interventions by calculating predicted returns on investment and benefits (Bryamn & Bell, 2017).

3.4 Confidence and Ethical Considerations

Ensuring the credibility, reliability, and ethical integrity of this study is essential to producing valid and applicable results. To enhance trustworthiness, the research applies multiple strategies such as methodological triangulation, transparency in procedures, and respondent validation. Ethical principles are also emphasized, particularly in relation to data confidentiality and informed consent.

Methodological triangulation is achieved by combining quantitative and qualitative methods, including water consumption data from eSight, stakeholder interviews, and financial assessments. This integration enables cross-verification from multiple perspectives and strengthens the validity of findings by minimizing bias (Bryman & Bell, 2015). Transparency is maintained through clear documentation of data collection, analysis, and interpretation. Interview procedures are designed to ensure neutrality, and respondent validation is applied by sharing preliminary findings with key stakeholders for feedback, reducing the risk of misinterpretation (Bryman & Bell, 2017).

Ethical considerations are central to the research process. All interview participants were informed of the study’s purpose, how their input would be used, and their right to anonymity. Special care was taken to protect sensitive corporate data related to internal strategies or financial performance. Upholding confidentiality is crucial when collaborating with corporate entities (Bryman & Bell, 2017). Findings are presented objectively, independent of stakeholder interests or preferred solutions. Limitations related to data collection or analysis are acknowledged to promote academic integrity and critical reflection (Bryman & Bell, 2017).

Together, these measures support the credibility and ethical foundation of the research, ensuring that its conclusions are both academically sound and practically relevant for sustainable water management at Volvo Cars.

3.5 Discussion of Methodology

The chosen methodology provides a structured and comprehensive approach to analyzing water consumption and identifying efficiency improvements at Volvo Cars' eastern Torslanda facilities. By combining quantitative data, qualitative insights, and financial analysis, the study captures both measurable patterns and contextual understanding relevant to operational water use. This mixed-methods approach is well-suited for applied research, where practical implementation is as important as analytical accuracy (Bryman & Bell, 2017).

A key strength of the methodology is its integration of diverse data sources. Historical water consumption data from eSight forms the empirical foundation, while interviews with stakeholders add operational and behavioral context. Benchmarking against external organizations offers comparative insight into best practices, and the use of the Sustainability Benefit-Cost Model (SCM) introduces financial analysis to evaluate the economic feasibility of interventions. As part of our methodological approach, we decided to include an investment analysis focusing on sensor-based faucets. This decision emerged early in the study when we, based on our own experience of working in the Volvo Cars factory environment over the past six years, noticed a clear absence of such faucets in both the western and eastern parts of the Torslanda site. This observation led us to reflect on whether a relatively small technical change could generate unexpectedly large sustainability benefits over time. We therefore chose to investigate sensor-based faucets as a concrete case, assessing both their financial viability and sustainability value using SCM.

Despite these strengths, some methodological limitations must be acknowledged. Water usage patterns can fluctuate due to seasonal effects, varying facility operations, or undetected leaks, which may complicate interpretation of short-term consumption data. Moreover, while interviews provided valuable perspectives, their subjective nature poses a risk of bias. These challenges were addressed through methodological triangulation and validation of findings across multiple data sources, in line with best practices recommended by Bryman and Bell (2017).

Overall, the methodology effectively supports the research objectives by balancing technical data with human insight and economic reasoning. It lays a solid foundation for developing practical, evidence-based strategies for sustainable water management at Volvo Cars.

4

Results and discussion

This chapter presents the main findings and analysis based on both quantitative data from Volvo Cars internal water monitoring system (eSight) and qualitative insights from interviews with internal stakeholders and external experts in water sustainability. Together, these sources provide a detailed understanding of current water consumption patterns, identified inefficiencies, and opportunities for improvement at the Torslanda facility.

The chapter is structured into a series of thematic subsections, each of which addresses one or more of the study's research questions. While the primary focus within each section is on presenting empirical results, the final part of each subsection includes a more in-depth analytical discussion. In these discussion segments, relevant academic and industry literature from the study's theoretical framework is brought in to interpret and contextualize the findings. This structure allows for a fluid integration of results and discussion, where each theme is explored both through practical insights and scholarly perspectives.

4.1 Current Water Use and Identified Inefficiencies

This section presents and discusses the measured water consumption patterns within Volvo Cars' facilities in the eastern part of Torslanda. A systematic approach was applied to map and interpret water usage data from the year 2023, retrieved from Volvo's internal monitoring system, eSight. The aim is to identify areas with significant consumption and inefficiencies, serving as a basis for further analysis and evaluation of potential optimization strategies. By categorizing and analyzing the distribution of water use, this section provides essential insights that support future sustainability initiatives and improvements in water management.

4.1.1 Mapping Water Use for Targeted Sustainability Efforts

To address the overall aim of optimizing water use at Volvo Cars' eastern Torslanda site, it was important to begin with a thorough understanding of how water is currently used across different parts of the site. The data used for this analysis was collected through Volvo's internal system, eSight, and covers the year 2023. Rather than listing every single number, the goal here is to highlight key insights and areas with potential for improvement.

The buildings have been grouped into two main areas: the PV area, which includes several offices, lab, and testing buildings, and Other East where various support and technical facilities are located. These groupings help to clarify where the largest shares of water are used and what kinds of activities are driving that use.

One clear result from the analysis is that the cooling tower in the PV area uses by far the most water. This is not surprising since cooling towers work by circulating large volumes of water to control temperature, especially in summer when the need is highest. Because of the nature of this process, it's not realistic to expect major reductions in water use here. Even solutions like rainwater harvesting would not be able to meet this demand, especially during the dry summer months when the system is under the most pressure. In addition, using rainwater in such a process would require advanced treatment to ensure the right water quality, which adds both cost and complexity.

Instead, it's more realistic to look for water-saving opportunities in other parts of the site. Several buildings showed moderate to high consumption levels that may not be tied to essential processes in the same way the cooling tower is. These could be labs, test facilities or administrative buildings where small changes, like upgrading fixtures or adjusting routines, might make a real difference. This is where we have the most room to explore efficiency improvements.

It makes it easier to see where the largest shares are and where smaller but still significant amounts of water are being used. Note that the buildings included in *Figure 2* below represent how water use was distributed across the various buildings on site during 2023.

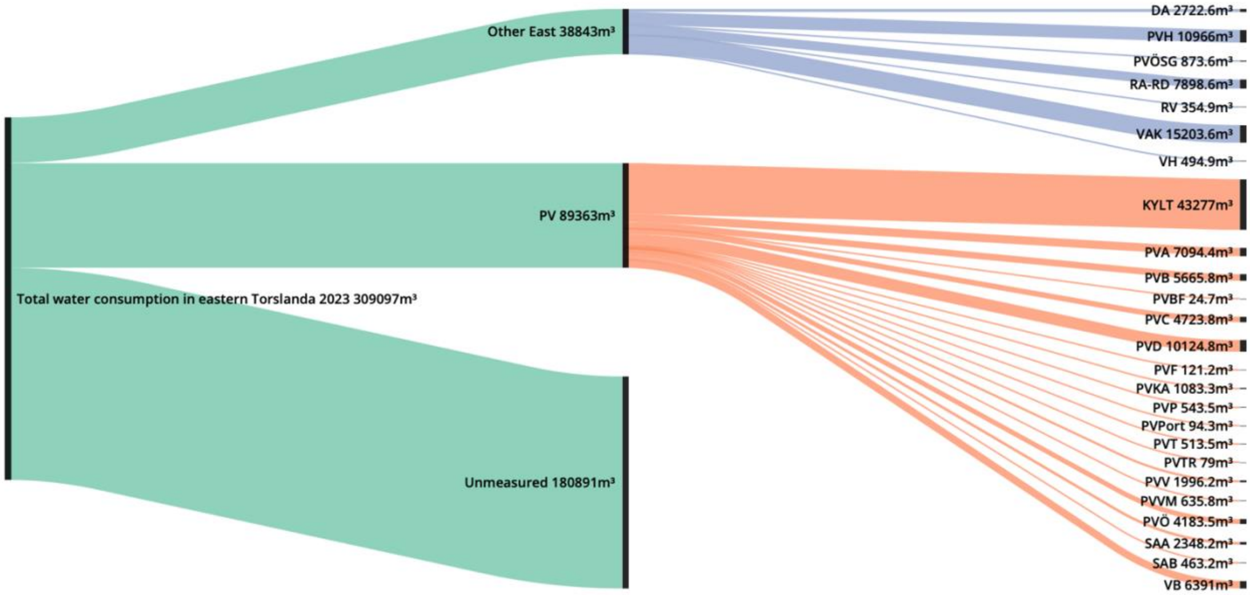


Figure 2: Share of total water consumption per facility group at Volvo Cars Torslanda East, 2023

PV accounts for 28.9% of the total water consumption, while the other eastern facilities represent 12.6%. Additionally, the cooling tower alone makes up 33.8% of PV's total usage. What this also reveals is that 58.5% of the total water consumption in 2023 remains unmeasured. The purpose of mapping out water use in this way is to gain a clearer understanding of how water is distributed across major facilities and to help identify buildings with consumption levels that fall outside reasonable expectations. The facilities represent a mix of offices, laboratories, restaurant spaces, and technical buildings. This mapping also allows for ongoing comparison of usage patterns over time and across facility types, supporting future benchmarking and targeted efficiency measures.

Another insight from this analysis is that not all buildings are equal when it comes to water-saving potential. For example, administrative buildings with frequent use by staff and visitors could be good candidates for upgrades like sensor-based faucets, while process-heavy facilities may require more tailored solutions. What this analysis shows is that while some of the biggest water users on site may be difficult to change, there are still many opportunities to make improvements elsewhere. By focusing on buildings and areas where change is both possible and realistic, Volvo Cars can start moving toward its water efficiency goals without affecting core operations.

This section builds the foundation for the rest of the work in this report. It helps us decide where to direct our efforts and what kinds of solutions might make sense in different contexts. While we may not be able to transform water use in the cooling tower, there are still many other ways to reduce overall consumption and support long-term sustainability goals at the site.

4.1.2 Overview of Water Distribution to Eastern Torslanda Facilities

All incoming water to the eastern part of the Volvo Cars Torslanda site is supplied by the water supplier and is first received at the central pumping station known internally as Hundgården. This facility does not consume water itself but instead functions as a key distribution hub. At Hundgården, flow meters monitor all incoming water before it is pumped onward to the site's main reservoir, which has a storage volume of 1,000 cubic meters and is located nearby. The same main supply line is used for the entire eastern area, which means that if a disruption occurs at or after Hundgården, water delivery to the entire eastern part of the site would be affected. The internal allocation of water to specific facility clusters, such as PV and other eastern areas, is managed beyond the main distribution point and is primarily relevant for internal monitoring and analysis.

To better clarify the internal monitoring coverage, *Figure 3* presents an overview of which buildings within the eastern part of the Volvo Cars site are equipped with water metering. Rather than illustrating the flow of water through the pipe network, this figure highlights the facilities that are currently included in the measurement system. By mapping out the connection points for metering, it becomes easier to see where data is being collected and where potential blind spots exist.

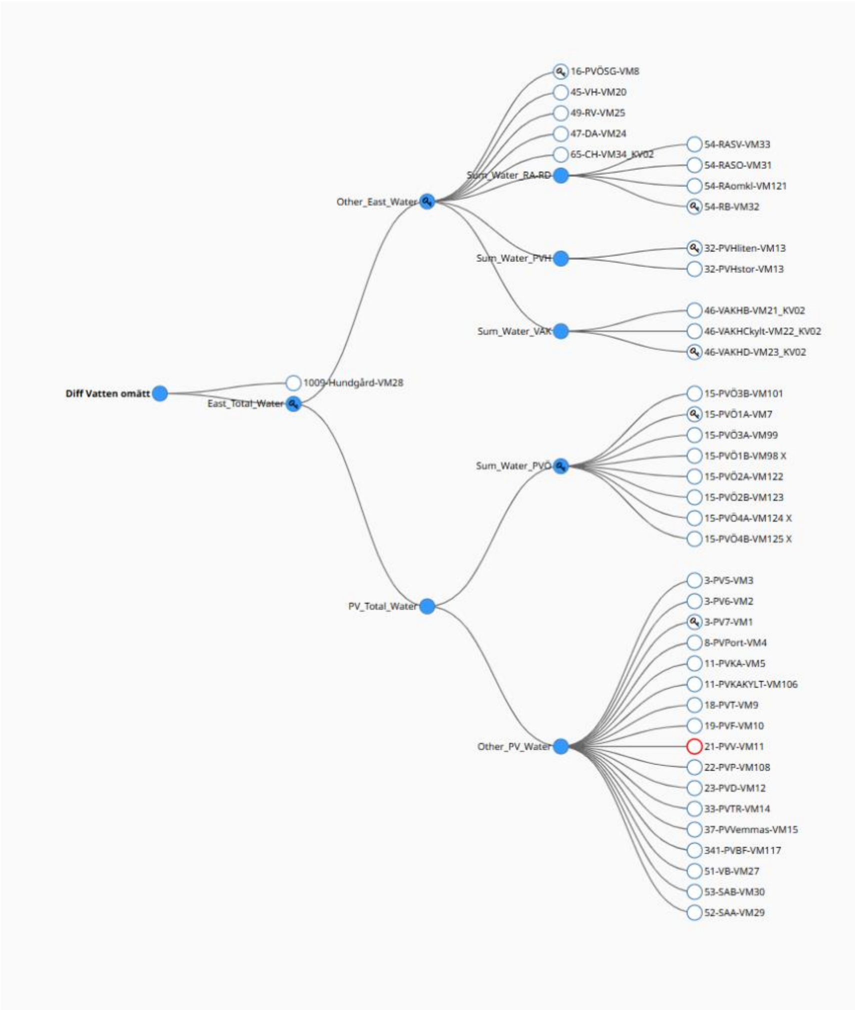


Figure 3: Water Distribution Network to Eastern Torslanda Facilities

Once water enters the Volvo-managed infrastructure from Hundgården, it passes through a network that is monitored using several metering points. All official water meters are owned and operated by the water supplier, and these meters provide the basis for both billing and internal monitoring of water consumption across the eastern area. This means that any physical adjustments or repairs to the network outside the buildings require coordination and agreement with the water supplier. Although Volvo pays for the water usage, they cannot independently modify or upgrade the external network. Instead, solutions to problems such as leaks, or pressure issues must be developed together through dialogue and mutual planning between Volvo Cars and the supplier. This division of responsibility underscores the importance of good communication and close collaboration in maintaining a functional and reliable water system.

While the metering system offers valuable data for tracking usage, certain challenges remain. One notable issue is the placement of fire hydrants before some of the official meters. These hydrants can be accessed temporarily during construction or maintenance work. If water is withdrawn from these points without proper documentation, that usage will not be captured in the official records, leading to underestimation of total consumption. Even relatively small but repeated, undocumented withdrawals can distort the accuracy of water usage data and complicate efforts to identify inefficiencies or losses.

In some areas of the eastern site, there are still buildings or facility connections where water meters are missing, outdated, or not integrated into the central monitoring system. For example, a few buildings have planned meter replacements, while others have water lines that are currently not covered by any meter at all. There are also cases where meters are installed but not fully connected to the main digital system used for internal monitoring. In addition, certain customers have direct agreements with the water supplier and are therefore not included in Volvo’s own data. Although these gaps exist, their overall impact on total water consumption and water loss is minimal. Nevertheless, it is important to be aware of these exceptions when interpreting water data, since they can help explain a small proportion of the unmeasured volumes and should be excluded when estimating potential leakage or inefficiency.

Another important point is that daily water data is in fact available through existing systems. The real challenge lies not in the lack of data, but in how consistently it is followed up and utilized to identify and address irregularities in water use. Several participants suggested that the responsibility for monitoring and acting on irregularities in certain areas, particularly those beyond the internal network, should partly lie with the external water supplier. As A6 mentioned, “There’s no point in collecting daily data if no one is actively reviewing it. And in some cases, it’s not even clear who should act.

To address this, the external stakeholder C4, a representative from Smartvatten, offered both context and potential solutions. According to C4, “Volvo’s situation is far from unique. Many industrial sites in Europe face similar losses. The key is not just measuring, but smart measuring.” Smartvatten offers a clamp-on sensor system that can be easily installed on existing pipes without interrupting operations. “It takes about 15 minutes to install per meter, and we can cover entire zones with real-time tracking,” C4 said. One of the key advantages of the Smartvatten system is that it does not require extensive infrastructure changes. The solution provides automated leak alerts, consumption pattern analysis, and remote access through a cloud-based platform.

However, it is important to note that these sensors are not certified for invoicing purposes. Since they are mounted externally and rely on ultrasonic measurements, they do not meet the accuracy standards required for official billing, which typically relies on permanently installed, certified meters provided by the water supplier. Instead, Smartvatten’s system is designed to complement existing metering by offering detailed monitoring, operational insights, and early leak detection.

4.1.3 Analysis of Unmetered Water and Identification of Inefficiencies in Eastern Torslanda

Accurate measurement and monitoring of water consumption are essential for effective water management and sustainability, particularly within complex industrial and office environments. At Volvo Cars’ eastern Torslanda site, one key issue identified through data collected in 2023 is the substantial gap between the total volume of water purchased from the water supplier and the volume measured within the facilities.

Table 2: Monthly Comparison of Purchased vs. Measured Water in Eastern Torslanda (2023)

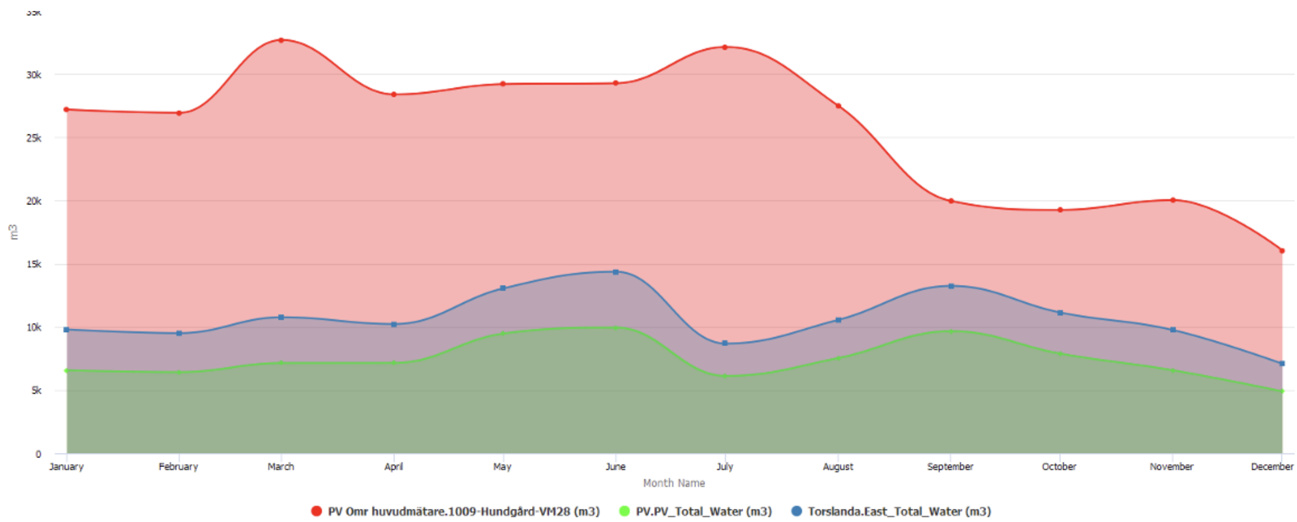


Table 2 illustrates the monthly variations throughout the year 2023, clearly highlighting the differences between purchased water (represented by the red line) and the total measured water consumption (represented by the blue line) within eastern Torslanda facilities. Throughout the observed period, there is a consistently large volume of water unaccounted for, indicating systemic issues in either measurement accuracy, leakages, or infrastructure inefficiencies. As noted by respondent A6, who works with building operations and utility planning, “we’re

paying for water we can’t trace, and that’s not sustainable from either a business or environmental point of view.” What makes this even more pressing is the fact that water prices have been rising sharply in recent years

The average monthly discrepancy between the purchased water and the measured consumption in 2023 is clearly significant, with an average difference of approximately 15,000 cubic meters each month. The gap is especially noticeable during the first half of the year, peaking between March and July. During this period, on-site distribution losses consistently remain high and, in several cases, exceed 15,000 cubic meters. One contributing factor is the increased use of cooling systems, which are water-based and operate intensively during the summer months. Although most cooling tower water consumption is measured and included in the data, there are periods when the towers are stopped for maintenance or other reasons.

During these stops, direct cooling occurs without being captured by the metering system, which explains part of the gap seen in the summer months. For example, in July, the elevated difference between purchased and measured volumes coincides with peak cooling activity and periods of unmetered direct cooling. Additionally, the periods with the largest discrepancies also coincide with a confirmed water leak that occurred earlier in the year, further contributing to the losses. From September to December, however, the situation is noticeably different. This period is characterized by a more stable water balance and no known major leakages, making it a valuable baseline for evaluating the effectiveness of future improvements.

One of the most consistently raised concerns by all internal respondents was the persistent issue of unmeasured or “unaccounted-for” water. Respondent A4, an environmental coordinator, highlighted this challenge early in our interview, noting that “every year since at least 2018, we’ve been dealing with significant water loss. It’s hard to find a single year without a leak somewhere. This long-term pattern of recurring issues adds weight to the financial impact and supports the argument for stronger monitoring, clearer internal routines, and faster response systems going forward.

To manage this, one method that has been used is relining. This involves inserting a new plastic pipe inside the old one, which allows for the internal repair of damaged sections without the need to excavate and replace the entire pipe. Relining offers a faster and less invasive solution, making it particularly suitable in areas where maintaining water access is essential. While this method has been employed in specific areas within Torslanda, it is not without limitations. For instance, the new lining always has a smaller diameter than the original pipe, which can reduce water flow capacity.

Technologies such as those offered by companies like Smartvatten are increasingly being adopted to provide real-time monitoring and automatic alerts when abnormal patterns are detected. These technologies can serve as a critical tool in mapping water flows, improving data accuracy, and enhancing early detection of anomalies before they escalate into large-scale water loss. Cost-wise, C4 explained that "for a facility the size of eastern Torslanda, covering all the critical water lines, the annual cost would be between 800,000 and 1.2 million SEK, including software licensing, maintenance, and real-time support".

This estimate refers to the recurring operational costs and does not include any potential upfront investments in hardware or installation, which were not specified. Without knowing the full installation cost, it is not possible to calculate an exact return on investment. However, C4 emphasized that for a site currently losing more than 4 million SEK annually due to unmetered water, there is significant potential to reduce losses through improved monitoring. Although the precise payback period remains unclear, the scale of existing inefficiencies suggests that the investment could offer considerable long-term value, both financially and operationally." This point resonated strongly with internal stakeholders who had expressed frustration about how difficult it was to justify investments in water-saving solutions due to the relatively low cost of water. "It's only about 1 percent of our total utility cost," noted A6, "so historically, it has not been prioritized, but that thinking is changing".

In fact, internal resistance to water-focused investments appears to be fading considering stricter corporate sustainability goals and pressure from external actors. As A5 explained, "We must report on waste, energy, and water usage globally. Water used to be the least developed of the three, but that's no longer acceptable." A5 mentioned that Volvo's sustainability strategy includes a target to reduce water withdrawal by 26 percent and water use per car produced by 50 percent by 2030. "We won't meet those targets unless we can actually measure what we use, and where we lose it," they added.

Smartvatten's approach, according to C4, includes addressing these exact coordination issues. Their platform offers cross-user access with customized dashboards for operations teams, environmental officers, and financial controllers. “It’s not just a meter it’s a tool for collaboration,” said C4. One of their clients, a major logistics firm in Finland, reportedly reduced their unaccounted water by over 65 percent within 18 months of adopting the system. “The client didn’t change the pipes, they changed how they monitored them,” C4 added.

Internally, there’s growing recognition that smart solutions like these are no longer optional. As A6 summarized, “When you look at how much water is disappearing from the system, and how much we’re paying for it, you realize that it’s a leadership issue. We either take control or we keep leaking money”. Leakage itself is another area of significant concern. All internal respondents emphasized the scale and persistence of leakage problems over the past six years. A4 mentioned that “we’ve had years where we’ve found three or four different leaks, some of them running for months before detection.” These leaks are often difficult to identify due to the complexity and underground nature of the water network.

From a sustainability perspective, the current leakage rates are incompatible with global and local goals for resource efficiency. Given that water treatment and distribution also carry a carbon footprint, reducing leakage is aligned with broader climate and environmental targets. Furthermore, increasing transparency and data quality in water use enhances the ability to track progress, report accurately, and align with frameworks like CSRD.

4.1.4 Rising Water Costs and Their Financial Implications for Volvo Cars

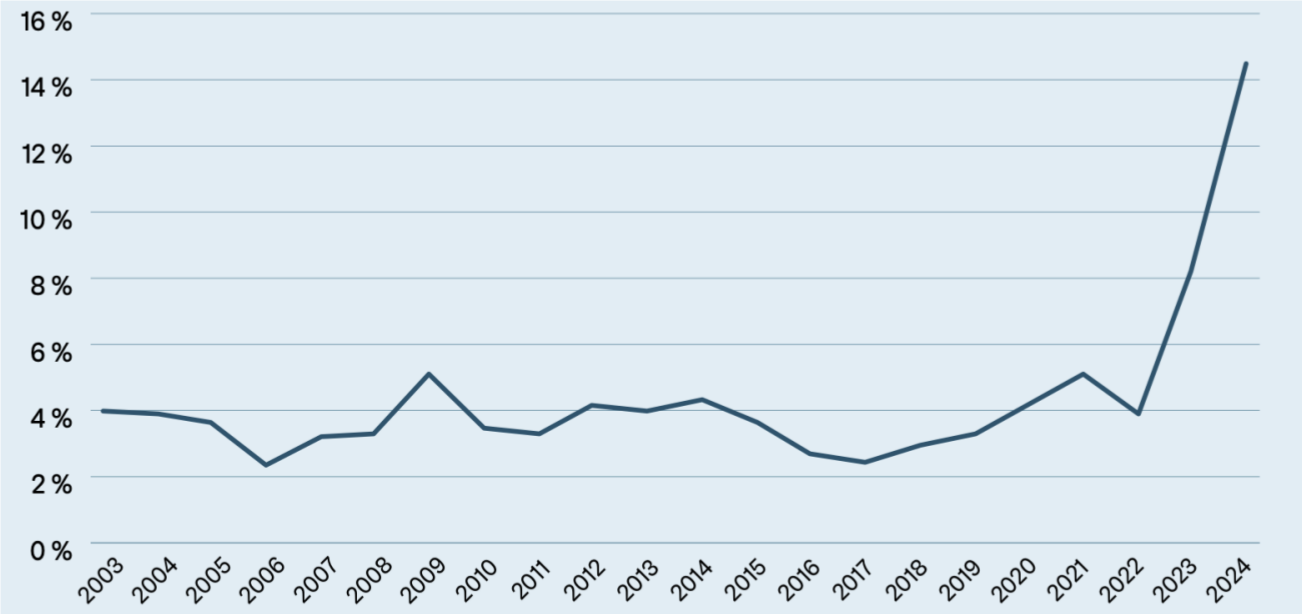
A key aspect of water management at Volvo Cars’ Torslanda site is the growing cost of water, which presents both economic and strategic challenges. Volvo Cars is likely one of the largest industrial customers of the water supplier in the Gothenburg region. Volvo is therefore significantly affected by water price increases, especially given the scale of its operations.

These price changes are not only reflective of inflation but also of necessary investments into Gothenburg’s aging water infrastructure. According to the national tariff statistics, water prices have increased steadily in recent years (Svenskt Vatten, 2024). Municipalities across Sweden are raising water tariffs to finance extensive maintenance and upgrades of water distribution systems, which in many cases, like in Torslanda, date back to the 1960s. The growing fixed costs related to meter rentals, emergency services, data delivery, and network maintenance have become increasingly significant, now amounting to over 16.4 SEK million annually for the Torslanda site alone. This translates to approximately 1.4 million SEK per month regardless of actual water usage. The monthly total cost for water is approximately 2.5 million SEK, 1.1 million SEK attributed to variable consumption and the rest to fixed fees. Even a modest rise in water prices could add hundreds of thousands of kronor annually to the company's utility costs.

Although Swedish legislation prohibits municipalities from profiting on water services, the reality remains that rising maintenance costs and the pressure to upgrade aging infrastructure continue to push water prices upward. As a result, industries such as Volvo Cars must adapt their sustainability strategies not only for environmental reasons but increasingly to manage escalating operational costs.

The economic justification for investing in smart water-saving measures becomes stronger when viewed against this backdrop of rising prices. Even if water currently accounts for less than 1% of Volvo Cars' total operational costs, the combination of increased prices and continuous water loss makes it a critical area for improvement. From a strategic standpoint, Volvo Cars must weigh future investments such as sensor-based monitoring systems and rainwater harvesting not only on their environmental benefit but on their potential for cost savings and long-term resilience against rising tariffs.

Table 3: Annual water tariff average rate of increase, (Svenskt Vatten, 2024).



In Torslanda, Volvo Cars currently pays 22.72 SEK per cubic meter of water in 2025, including only consumption water not the fixed prices. Table 3 shows historical trends which shows a continued average annual increase of 5 percent from 2025 onwards, we can estimate future water prices with simple equation like the equation 1. By 2030, the price per cubic meter may reach approximately:

$$22.72 \times 1.05^5 = 28.98\ SEK/m^3 \tag{1}$$

This would represent a 27.6 % increase compared to the 2025 rate. If price growth follows the more aggressive trajectory of recent years, for example 8 percent per year, the 2030 price could exceed 33 SEK/m³, nearly a 50 % increase over five years. Regardless of the exact rate, the upward trend is clear and likely to continue.

4.1.5 Analysis of Water Use and System Inefficiencies at Volvo Cars Torslanda

Volvo Cars Torslanda is a large-scale industrial facility with multiple buildings and operational zones that depend on water for a variety of purposes, including technical processes, cooling systems, and sanitation. However, as the results of this study show, the facility is currently facing considerable inefficiencies in its water distribution network. In 2023 alone, approximately 182,530 cubic meters of incoming water in the eastern section of the site remained unmetered, representing nearly 58.5% of the total annual inflow to that part of the facility. This substantial amount of non-revenue water is indicative of systemic leaks, inadequate metering, and possible unauthorized water use across the site.

The economic implication of this inefficiency is particularly significant. With an average water price of 22.7 SEK per cubic meter in 2025, the cost of unaccounted-for water is estimated at over 4.1 million SEK. In the context of rising water tariffs throughout Sweden, as shown in national tax statistics (Svenskt Vatten, 2024), this figure is expected to increase sharply in the coming years unless mitigative actions are taken. The situation at Volvo Cars Torslanda thus reflects a broader trend seen in both municipal and industrial water systems in Sweden, where aging infrastructure and insufficient monitoring capabilities have led to persistent water losses (Svenskt Vatten Utveckling, 2019; Najar & Persson, 2023).

The most prominent technical issue identified is the recurring leakage within the facility's water network. Interviews with Volvo representatives revealed that large-scale leakages have occurred almost annually for the past six years, a pattern likely linked to the aging infrastructure originally built in the 1960s. Similar findings have been reported in studies of Swedish utilities, where degraded pipe materials and insufficient maintenance regimes have been shown to contribute significantly to water losses (Rothman et al., 2013; Malm et al., 2020). These leakages not only cause direct financial damage but also pose risks to soil stability, flooding, and the long-term reliability of water delivery systems.

Addressing this issue requires a combination of technological capacity and proactive management. One digital tool already in use at Volvo Cars is eSight, a platform capable of monitoring water consumption across different facility zones. Although the system is in place, several interviewees suggested that its full potential has yet to be realized, particularly in terms of its alert functions and real-time anomaly detection. By activating features such as automated notifications and threshold-based alarms, the system could help identify deviations more quickly and enable faster responses to leak or irregular consumption patterns. This aligns with findings in the literature on IoT-based water management, where integrated sensor systems and automated alerts have been shown to improve responsiveness and operational efficiency (Zang et al., 2021; Koo et al., 2015). High-resolution consumption data, when actively monitored and linked to responsive protocols, can play a central role in minimizing water losses and supporting more efficient facility management.

One of the most fundamental challenges in managing water losses at Volvo Cars Torslanda is the lack of sectionalization within the internal distribution network. Currently, water meters are mainly installed inside individual buildings, which means that the broader infrastructure between buildings does not have direct oversight. This absence of clearly defined subzones makes it difficult to detect leaks or irregularities in the underground supply lines, since anomalies observed in overall consumption data are often impossible to attribute to a specific area. Both the interviews and the academic literature emphasize that dividing the network into smaller, measurable segments would greatly enhance leak detection, allow for faster response, and make maintenance planning more effective. Research by Bauer et al. (2020) and Najar and Persson (2023) shows that implementing this kind of segmentation enables facility managers to compare inflow and outflow at the zone level, making it much easier to identify and address discrepancies that would otherwise remain hidden in a non-segmented system.

Applying these insights into the context of Volvo Cars suggests that the introduction of additional metering points outside the buildings would be a necessary improvement. By installing meters at key nodes within the external piping system, particularly in locations where multiple buildings are grouped together, the company could begin to monitor water flows across broader parts of the network. This would provide a more complete picture of how water is being distributed and consumed throughout the site, while also revealing deviations that might signal the presence of leaks or inefficiencies.

Improving visibility into the network in this way would not only support more accurate fault detection but also strengthen the collaboration with the external water supplier. When both internal and supplier-side data can be compared across specific segments of the infrastructure, it becomes easier to assign responsibility, prioritize action, and implement targeted repairs. The absence of such segmentation today means that water losses are often detected too late or remain unresolved due to the inability to identify their location.

Moreover, the results from the interviews indicated that temporary water connections such as those made during construction work or emergency repairs may be contributing to the volume of unmetered water. These connections often bypass permanent monitoring infrastructure and are difficult to track unless specifically measured. Similar patterns have been observed in other industrial sites, where unauthorized or undocumented water usage can distort overall consumption data and complicate water audits (Boysen et al., 2020). Introducing portable flow meters or requiring strict documentation of temporary water usage could mitigate this source of inefficiency.

In addition to these technical and infrastructural shortcomings, there is a behavioral and institutional dimension to the problem. As highlighted in the study by Lee and Tansel (2013), behavioral factors such as low awareness, lack of incentives, and insufficient internal motivation can hinder efforts to conserve water, even when efficient technologies are available. The case of Volvo Cars shows similar tendencies, where the lack of metering and monitoring is not just a result of technical limitations but also of organizational routines that have not prioritized water management. Overcoming these behavioral barriers will require stronger internal policies, employee engagement programs, and alignment with sustainability goals that elevate the importance of water conservation across all departments.

Beyond the internal efforts within Volvo Cars, regional and national frameworks play an important role. The Swedish context offers a strong regulatory and technical foundation for sustainable water management, but as several studies note, there are gaps between policy and practice (WWF, 2022; European Environment Agency, n.d.). Volvo Cars, as a major industrial actor, is well-positioned to take a leadership role in demonstrating how private-sector innovation can align with public sustainability goals. Partnerships with municipal, could facilitate shared infrastructure investments and knowledge exchange, particularly in advanced water reuse and leakage prevention systems (Göteborg Energi, 2022; Gryaab, 2022).

4.2 Evaluation of Sensor-Based Faucets Implementation through Sustainability Benefit-Cost Model

As a part of the sustainability strategy at Volvo Cars Torslanda, an evaluation was conducted to assess the feasibility of implementing sensor-based faucets across office buildings and production-related facilities. This initiative is aimed at significantly reducing water consumption, operational expenses, and associated environmental impacts. The evaluation was performed through a structured Sustainability Benefit-Cost Model (SCM), a financial and sustainability-oriented framework designed to assess investments based on economic performance, energy efficiency, and environmental improvements. The model, developed by Volvo's internal sustainability team, integrates factors such as capital and operational expenditures, water and energy savings, waste reductions, and carbon emission mitigations, ultimately providing a clear overview of the investment's economic and sustainability merits.

According to A1, who serves as a project manager, the primary objective of the inventory was to support upcoming renovation plans while also contributing to ongoing sustainability initiatives. The facilities assessed ranged in function from office buildings to technical workshops, and many of the fixtures were found to be outdated or inefficient. "We've identified a clear need for modernization," A1 noted, referencing the visual and structural wear observed in multiple installations. Many of the toilets and washbasins were installed more than two decades ago and were not equipped with water-saving features, such as dual-flush systems or sensor-based taps.

This detailed mapping provided an essential foundation for further analysis. Using the photographic and inventory material supplied by A1, the research team conducted a review to determine where sensor-based faucets could be feasibly implemented. After consolidating the findings, it was determined that a minimum of 350 washbasins within the PV facilities could be equipped with sensor-based water systems. These sinks were found in restrooms and common areas that are frequently used by staff and visitors, suggesting a high potential for water savings.

As illustrated in *Figure 4*, the current condition and design of the faucets vary significantly across the facilities in the PV area. This variability underscores the importance of implementing standardized, sensor-based faucet systems. Furthermore, there is already an established maintenance plan in place aimed at renovating the bathroom facilities throughout these buildings, scheduled to begin at the upcoming turn of the year. Leveraging this planned maintenance schedule presents an opportune moment for transitioning to sensor-based faucets, ensuring the renovations are conducted efficiently and cost-effectively. This strategic alignment between regular maintenance and sustainability initiatives offers both economic and logistical advantages, further reinforcing the feasibility and attractiveness of the proposed investment.

Description	Type	Plan	Zone	Buildi	Priorit	Plant	Net Ar	Comm
	Toilet	2	D	PV	1	26	2.56	*Very old standard

Figure 4: Example of current bathroom faucet conditions in PV area.

4.2.1 Identification of Cost and Savings Parameters

To effectively use the SCM model, several cost parameters and expected financial savings needed to be clearly defined and calculated. Firstly, the investment included both initial capital expenditure (CAPEX) and recurring operational expenditure (OPEX). For the CAPEX component, the primary investment consisted of purchasing the sensor-based faucets themselves, estimated conservatively at 4,000 SEK per unit, thus yielding a total equipment cost of approximately 1,400,000 SEK for the 350 faucets.

OPEX components were thoroughly analyzed to reflect ongoing costs accurately. According to standard industry practice and historical data from comparable projects, annual maintenance costs, inclusive of routine inspections, battery replacements, sensor adjustments, and minor repairs, were estimated at 15,000 SEK per year. Additionally, replacement and minor upgrades of electrical equipment components were accounted for with an estimated annual OPEX of 5,000 SEK. Thus, the total annual OPEX amounted to 20,000 SEK, representing a conservative estimation to ensure all potential costs were comprehensively captured.

4.2.2 Water Savings and Economic Impact

One of the critical assumptions within the SCM analysis involved accurately estimating annual water savings associated with sensor-based faucets compared to conventional, manually operated faucets. Traditional faucets typically result in excessive water usage, primarily due to inefficiencies and human behaviors, such as faucets being left running unnecessarily or activated longer than required. These inefficiencies lead to elevated water consumption and increased operational expenses. To address this issue, sensor-based faucets have been identified as a potential solution due to their automatic shut-off features, which minimize unnecessary water flow. In a comparative field study conducted at California State University, Sacramento, automatic faucets equipped with aerators providing a standard flow rate of approximately 1.89 liters per minute demonstrated a substantial reduction in water usage, averaging about 32% compared to traditional manual faucets (Harmon, 2016). Given the parallels between this university environment and the office and workshop areas within Volvo Cars' premises, the savings rate of 32% was adopted as a conservative yet robust assumption in this analysis.

The process of estimating potential water savings began by defining clear assumptions reflective of typical usage patterns within Volvo Cars' facilities. To establish a realistic baseline, the following parameters were determined in consultation with facility management and based on industry standards:

- Number of faucets: 350 units
- Average activations per faucet per day: 20 activations (typical for office/workshop environments)
- Operational days per year: 260 (corresponding to standard working days)
- Average activation duration per faucet: 15 seconds per activation (typical user behavior)
- Standard water flow rate: 6 liters per minute (industry-standard faucet flow rate)

Based on these assumptions, the total annual water consumption for the current conventional faucets was initially calculated. Each faucet, activated for 15 seconds at a rate of 6 liters per minute, consumes approximately 1.5 liters per activation. Consequently, with 20 activations daily per faucet, the daily water usage per faucet totals 30 liters. Extrapolating this figure across the entire set of 350 faucets and the 260 operational days annually, equation 2 resulted in a total water consumption estimate of:

$350 faucets \times 30 liters/day/faucet \times 260 days/year = 2{,}730{,}000 liters/year (2{,}730 m3)$ (2)

Applying the 32% reduction factor derived from Harmon's (2016) field study, the expected annual water savings associated with replacing conventional faucets with sensor-based alternatives were calculated as the following equation 2.1:

$$2{,}730 m3/year \times 0.32 = 873.6 m3/year \qquad (2.1)$$

Thus, the realistic and clearly justified annual water savings estimate was determined to be approximately 874 cubic meters.

To contextualize this saving, it is essential to relate it to the total water consumption within Volvo Cars' Torslanda facilities. In 2023, the total measured water consumption in the PV area alone was approximately 89,363 cubic meters annually. Therefore, the annual water savings achieved through this specific measure of installing sensor-based faucets equate to about 1% of the PV area's total annual water consumption.

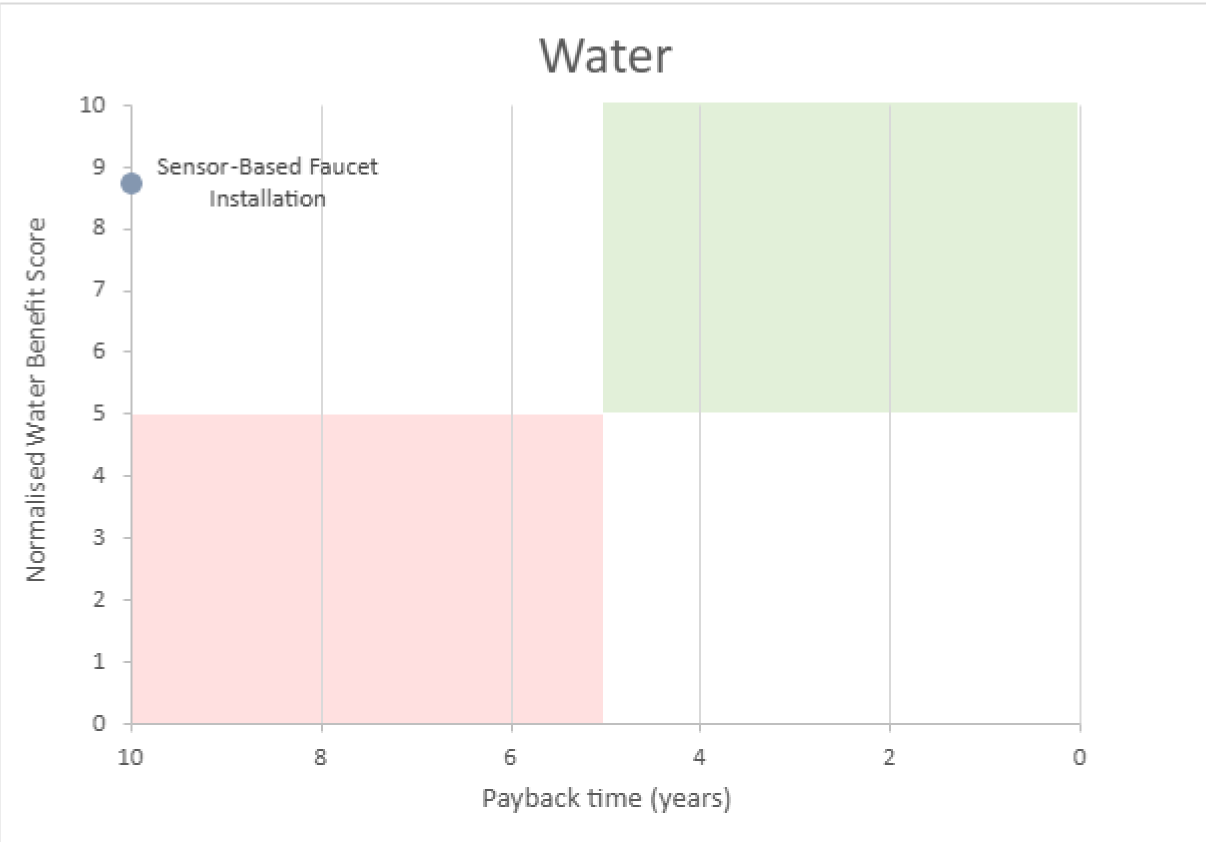
If we exclude the cooling towers from the PV area, since these are process-related and will not be included in the installation of sensor-based faucets, the relative savings from this upgrade become even clearer. The estimated annual saving is 874 cubic meters, and when compared to the total non-process water use in PV, which is 46,066 cubic meters per year, this amounts to about 1.9 percent. This shows that the water-saving potential of sensor-based faucets is greater than one percent when the focus is on office and support facilities. By concentrating on these areas, the positive effect of implementing water-saving measures is more apparent. Although this percentage might appear modest at first glance, such incremental savings become significant when aggregated across multiple water-saving initiatives, collectively contributing to substantial reductions in operational costs and environmental impacts over time.

Given the current trends in municipal water pricing and ongoing infrastructure challenges, accurately forecasting the financial implications of these water savings is critical. Water costs have historically increased by an average of 4–5% annually, with more recent years experiencing heightened increases due to infrastructure investments and resource scarcity pressures. An analysis of historical data and pricing projections by Svenskt Vatten (2024) suggests that the average water cost could reach approximately 29 SEK per cubic meter by 2030. For the SCM analysis conducted over the investment period from 2025 to 2035, this average price was conservatively maintained at 29 SEK per cubic meter to ensure a balanced yet prudent approach. Using the established savings of 874 cubic meters annually at the projected average water cost of 29 SEK per cubic meter, the annual economic savings attributed to reduced water usage are estimated as equation 2.2 follows:

$$874m3/year \times 29SEK/m3 = 25{,}346\ SEK/year \qquad (2.2)$$

Consequently, the revised annual economic benefit associated solely with water savings amounts to approximately 25,346 SEK per year. Table 4 below presents a comparison between the sustainability scores for water and the corresponding payback periods.

Table 4: Payback time versus normalised water benefit score for the sensor-based faucet installation.



4.2.3 Energy Savings Estimation

In addition to direct water savings, the implementation of sensor-based faucets at Volvo Cars is expected to yield significant indirect energy savings. These savings primarily arise from decreased consumption of heated water. Traditional faucets frequently lead to unnecessary hot water use due to human factors, such as leaving taps running or excessive use durations. Sensor-based faucets effectively address these inefficiencies by utilizing automatic shut-off mechanisms, thereby reducing the amount of energy required for water heating.

To quantify the potential energy savings accurately, this analysis builds upon previously established assumptions regarding faucet water use. Based on field data from California State University, Sacramento, sensor-equipped faucets have demonstrated an average water consumption reduction of approximately 32 percent compared to conventional manual faucets (Harmon, 2016). Considering the comparability between the university environment in the cited study and the office or workshop settings at Volvo Cars, this 32 percent reduction was deemed an appropriate and conservative estimate for the analysis.

The subsequent energy savings calculations were conducted in several systematic steps:

Step 1: Estimating Annual Water Consumption (Baseline Scenario)
The calculation considered a scenario involving the installation of 350 faucets across Volvo Cars' facilities. The following assumptions guided this baseline scenario:

- Number of faucets: 350
- Average daily usage per faucet: 20 activations
- Average water volume per activation: 1.5 liters
- Annual operating days: 260 working days

Thus, the total annual water consumption using traditional faucets is calculated as equation 3 follows:

$$350\ faucets \times 20\ activations/day \times 1.5 liters/activation \times 260\ days/year \\ = 2{,}730 m3/year \qquad (3)$$

Step 2: Calculating Potential Water Savings
With the introduction of sensor-based faucets and their estimated 32 percent water-use reduction, the annual water volume savings become as equation 3.1 shows:

$$2{,}730m3 \times 32\% = 873.6m3/year \qquad (3.1)$$

Step 3: Determining Proportion of Hot Water Savings

Standard industry benchmarks indicate that approximately 60 percent of faucet water consumption in commercial and office settings consists of heated water. Applying this figure, the expected annual volume of hot water saved is as equation 3.2 shows:

$$873.6m3 \times 60\% = 524.16m3/year \qquad (3.2)$$

Step 4: Estimating Annual Energy Reduction

Heating water from a baseline temperature (approximately 10°C, typical municipal water supply) to a typical usage temperature (approximately 40°C) requires an average of 0.06 kWh per liter. Using this benchmark, the total annual energy savings resulting from reduced hot water consumption can be computed as equation 3.3 follows:

$$524{,}160liters/year \times 0.06kWh/liter = 31{,}449.6kWh/year$$
$$\approx 31.45MWh/year \qquad (3.3)$$

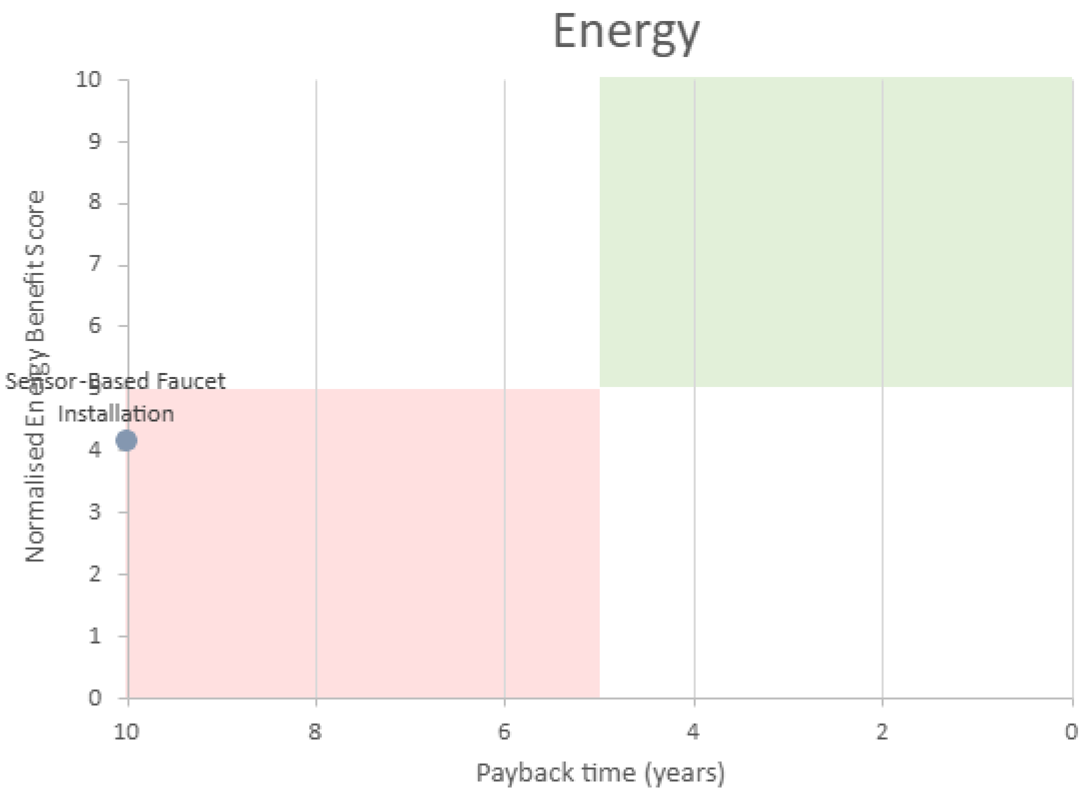
Step 5: Economic Valuation of Annual Energy Savings

Volvo Cars' average energy price for the year was 0,33SEK per kWh, the annual financial benefits derived from energy savings are estimated as equation 3.4 shows:

$$31{,}449.6kWh/year \times 0{,}33SEK/kWh = 10{,}378SEK/year \qquad (3.4)$$

Thus, the projected indirect economic benefit from reduced energy demand related to water heating amounts to approximately 10,378 SEK annually. *Table 5* represents the SCM models energy payback time and benefit scores.

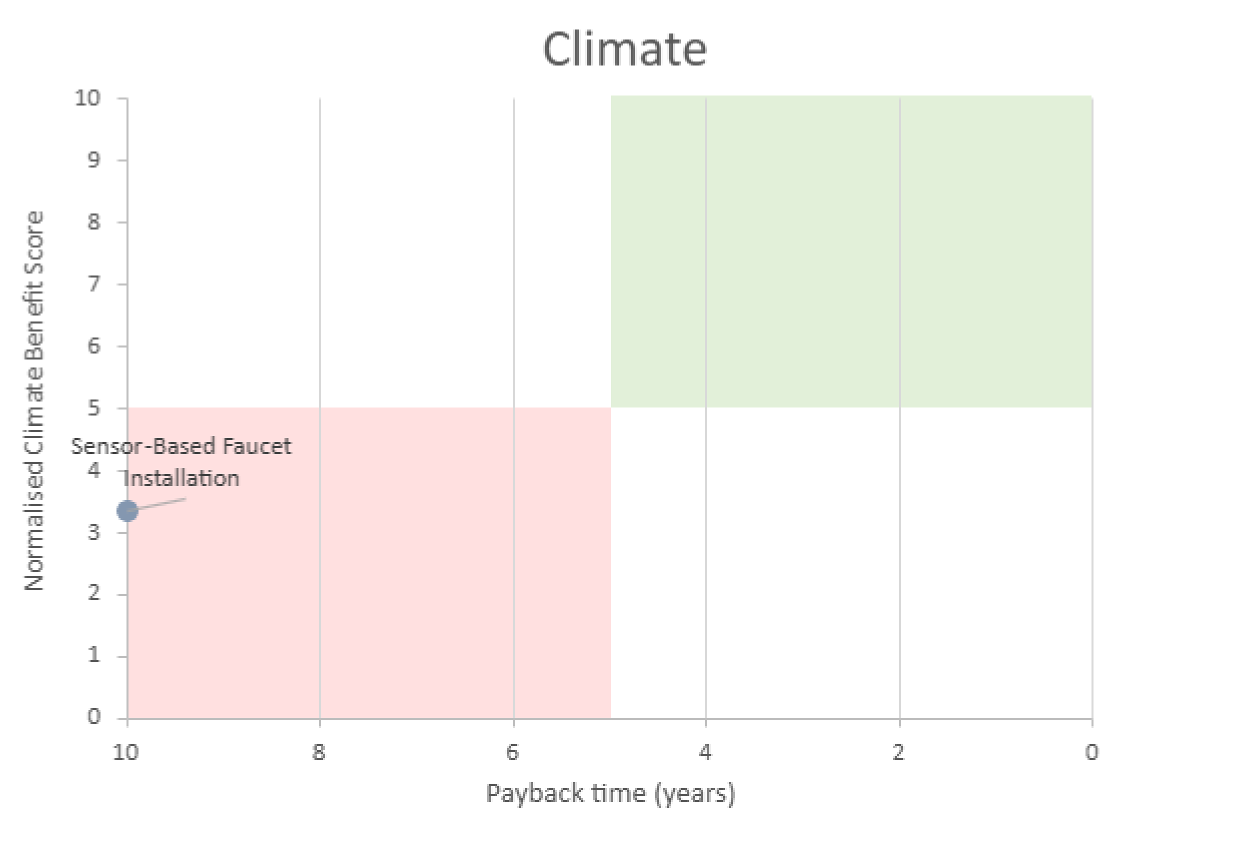
Table 5: Payback time versus normalised energy benefit score for the sensor-based faucet installation.



4.2.4 Carbon Footprint and Environmental Benefits

A vital component of the SCM model involves calculating reductions in carbon emissions resulting from decreased energy consumption and lower operational waste. The reduction of 31.45 MWh/year in district heating usage corresponds to an annual reduction of approximately 10.3 tons of CO_2-equivalents, based on the local energy supplier's emission factor. Additionally, reduced operational waste, including fewer maintenance interventions and reduced faucet replacements, accounted for an annual decrease of approximately 0.3 tons of CO_2-equivalents. These figures underscore the project's substantial positive environmental impacts beyond financial savings, significantly contributing to Volvo Cars overall sustainability ambitions and regulatory commitments. *Table 6* below represents the climate benefit score compared to the payback time.

Table 6: Climate benefit score vs. payback time for sensor-based faucet installation.



The implementation of sensor-based faucets at Volvo Cars offers clear benefits beyond immediate water savings. These devices contribute to energy efficiency by reducing the amount of heated water used, which in turn lowers overall energy consumption. This not only leads to economic gains but also supports Volvo Cars broader environmental strategy, including efforts to reduce greenhouse gas emissions and meet regulatory expectations under frameworks like the Corporate Sustainability Reporting Directive (CSRD). From both a financial and sustainability perspective, the investment in smart faucet technology aligns well with the company's long-term goals.

According to A2, a data analyst responsible for tracking water consumption trends across the Torslanda site, one of the growing challenges is the need to make progress visible and measurable. This is especially important given the increasing pressure from the CSRD to report environmental performance in a structured and transparent way. A3, a graduate working with water risk assessments, noted: "We're one of the early adopters. That means we must get this right. Water might seem like a small issue compared to carbon or energy, but we're being asked to show measurable progress."

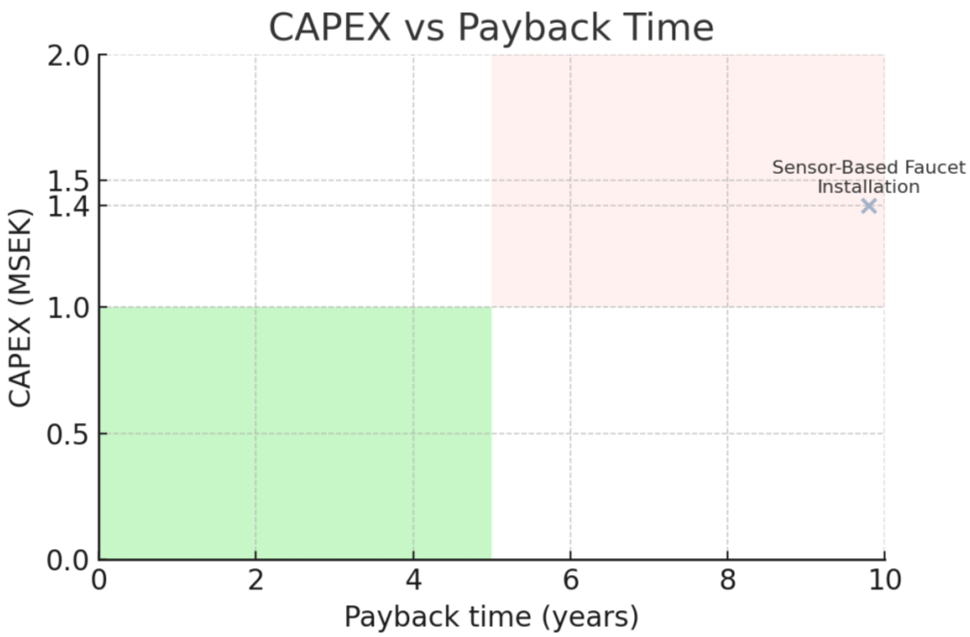
Both interviewees pointed out that water, unlike emissions or energy use, is distributed across a complex and fragmented infrastructure. This makes it more difficult to monitor and manage effectively. “We’re trying to move toward more segmented data,” A2 explained. “So we can identify leaks, inefficiencies, or unexpected spikes in individual buildings.”

4.2.5 Payback Time Analysis and Interpretation

The final stage of the SCM analysis involved integrating all financial data, both costs and savings, to calculate the investment’s overall payback period, an essential metric for investment decision-making. The analysis accounted for all previously mentioned parameters: initial CAPEX of 1,400,000 SEK, annual OPEX of 20,000 SEK, annual water savings of 25,346 SEK and energy savings of 10,378 SEK. Additional minor revenues or avoided costs, such as reduced personnel hours due to decreased maintenance needs, contributed approximately 12,000 SEK annually.

Considering all factors, the calculated payback period from the SCM model was found to be approximately 10 years. While this payback time is somewhat higher compared to Volvo Cars' typical threshold of 5 years for similar investments, it remains within an acceptable range for projects significantly enhancing sustainability. This relatively lengthy payback period can primarily be attributed to the considerable initial investment costs and the conservative estimation of ongoing operational expenditure. However, it is essential to emphasize that the analysis used conservative cost estimations to minimize risk, and actual payback could be shorter with optimal operational management and reduced maintenance costs. *Table 7* below represents the SCM models indicator on Capex vs payback time.

Table 7: Figure X. CAPEX vs Payback Time for Sensor-Based Faucet Installation.



The results indicate that although the direct economic payback is extended, substantial non-financial benefits, such as environmental impact reduction and compliance with future sustainability targets, further justify the investment. Additionally, future increases in water tariffs or potential tax incentives related to environmental improvements were not fully incorporated into the initial calculation, suggesting that real-world economic returns could indeed be higher.

4.2.6 Exploring Water-Saving Technologies and Behavioral Strategies at Volvo Cars Torslanda

The discussion surrounding water-saving opportunities at Volvo Cars Torslanda inevitably begins with an analysis of the potential and limitations of sensor-based faucet systems. These systems, while widely used in public and commercial facilities across Sweden, represent both a symbolic and practical step toward enhanced water stewardship within the industrial context. The facility's evaluation of this technology shows that while the measurable savings in water consumption amount to just under 1 percent of total use, the technology nonetheless holds considerable value in broader sustainability terms. The calculated sustainability score of 8.8 reflects a strong alignment with environmental objectives, despite the relatively long payback period of approximately ten years. This division between environmental benefit and financial return illustrates a recurring theme in industrial water conservation particularly in regions such as Sweden where low water tariffs diminish the financial incentive for change.

As highlighted in Svenskt Vatten (2024), the average cost of water in Sweden today stands at approximately 22,7 SEK per cubic meter, a figure that is substantially lower than in many other industrialized nations. Therefore, cost-efficiency should not be the sole driver of sustainability decisions. In fact, the implementation of sensor-based faucets could serve as a highly visible, low-threshold intervention that signals Volvo Cars commitment to sustainable water use, particularly within its office and administrative buildings. The ubiquity of sensor-operated fixtures in municipal and commercial buildings across Sweden suggests that the technology is already well understood, reliable, and socially accepted. Introducing these systems at Volvo Cars would not only demonstrate environmental leadership but also create an opportunity to foster a culture of awareness and behavioral change among employees.

Indeed, the human dimension of water conservation cannot be overstated. The behavior of employees plays a fundamental role in shaping the outcomes of water-saving initiatives. As emphasized by Hage et al. (2009), the willingness of individuals to engage in environmentally responsible behavior is strongly influenced by perceived behavioral control, personal norms, and contextual factors. This underscores the importance of pairing technical upgrades with organizational strategies that promote awareness, responsibility, and collective engagement. A2 emphasized the importance of cross-departmental collaboration to reach sustainability goals. “Sometimes, sustainability gets lost in management layers,” they noted. “Some departments drive it strongly; others forget it unless reminded.” This inconsistency makes it difficult to gain momentum across the organization.

Although technology alone cannot instil long-term behavioural change. Therefore, any investment in water-saving infrastructure should be accompanied by targeted communication and engagement strategies. Internal communication channels such as email newsletters, Teams announcements, and visual reminders in restrooms could be employed to raise awareness about water conservation and the role of sensor technologies. Equally important are interactive formats such as workshops, informal discussions, and sustainability-themed events, which can encourage employees to take an active role in shaping the company’s environmental practices.

While the water-saving impact of sensor faucets in isolation may be limited, their real value lies in their role as part of a broader portfolio of incremental improvements. As articulated in studies like Zang et al. (2021), the combination of decentralized water technologies and behavioural efficiency tools has proven effective in creating long-term reductions in water demand.

Moreover, the environmental benefits of sensor-based systems extend beyond water savings. These technologies also contribute to reduced energy consumption associated with hot water use. As highlighted by Stefanakis (2019), even marginal reductions in hot water use can translate into meaningful decreases in energy demand, especially in large facilities with significant sanitary infrastructure. Thus, the energy savings associated with shorter or more efficient tap usage further bolster the case for implementation, particularly when coupled with Volvo Cars' broader decarbonization goals.

In examining the barriers to broader implementation, economic constraints related to Sweden's low water tariffs continue to challenge the viability of many water-saving investments. Nevertheless, it is important to recognize that environmental return on investment does not always align with traditional financial metrics. As noted by Aleksic et al. (2019), automotive manufacturing is a water-intensive industry, and the sector faces increasing pressure to adopt innovative solutions that reduce freshwater withdrawal. Although rainwater harvesting and process water recycling are likely to yield greater absolute savings, sensor-based systems offer a more accessible and politically visible means to demonstrate environmental leadership.

Looking beyond the immediate facility context, it is also worth considering how the lessons learned from implementing sensor-based systems could inform future investments in more advanced digital monitoring and leakage detection tools. As explored in the wider literature (e.g., Koo et al., 2015; Braun & LU, 2024), the integration of smart technologies into industrial water systems has the potential to unlock significant efficiency gains, particularly when supported by real-time data analytics and predictive maintenance algorithms. While these systems require higher initial investments and more complex implementation strategies, their long-term potential for reducing non-revenue water and optimizing operations makes them a compelling target for future exploration.

4.3 Potential of Alternative Water Sources: Rainwater Harvesting and Stormwater Recycling

This chapter explores the potential for integrating alternative water management practices, specifically rainwater harvesting into Volvo Cars Torslanda's facility operations. The insights presented stem from an interview study with key stakeholders, including sustainability professionals, technical consultants, and project managers. Although practical implementation of these systems at Torslanda has not yet taken place, the qualitative data gathered provide an essential foundation for understanding both opportunities and challenges in adopting these water management solutions. The discussion revolves around technical feasibility, economic implications, and strategic alignment with broader sustainability objectives.

4.3.1 Rainwater Harvesting: Implementation Opportunities and Challenges

Rainwater harvesting has emerged as a compelling measure for reducing dependency on municipal freshwater sources and improving sustainability metrics within industrial operations. According to stakeholder interviews, rainwater harvesting systems offer considerable potential in industrial and commercial contexts, especially where non-potable water demands are high. Project leader B2, involved extensively in water management evaluations for Volvo Cars, underscored the practicality of rainwater harvesting, suggesting it could be effectively utilized in facility operations such as cleaning, irrigation, or sanitary functions. However, B2 also emphasized the critical role of aligning water treatment methods with intended end-use purposes. Successful implementation, therefore, hinges upon carefully matching water quality standards with operational demands, an observation echoed consistently by all interviewees.

Sustainability manager B3 provided further perspective on the strategic importance of rainwater harvesting, particularly in relation to achieving green building certifications like LEED or BREEAM. These certifications increasingly mandate rigorous water management practices, making alternative water sources a logical consideration for facilities striving for higher sustainability credentials. B3 shared practical experiences from recent projects, notably a bus depot developed by Skanska, where rainwater retention ponds effectively collect and filter rainwater, subsequently reusing it for operational purposes such as vehicle washing. This real-world application demonstrates the viability of closed-loop water management systems, achieving substantial reuse levels and simultaneously alleviating strain on municipal stormwater infrastructure. However, such implementations are context-dependent, requiring thorough upfront planning, appropriate technology, and clearly defined operational protocols.

Technical consultant B4 contributed insights into the regulatory and maintenance challenges associated with rainwater harvesting. One significant barrier highlighted was regulatory ambiguity concerning harvested rainwater, especially in industrial applications. Existing frameworks often lack clarity or comprehensive guidelines on water quality standards, permissible uses, and health-related requirements. Furthermore, seasonal variations, particularly pronounced in northern European climates, introduce additional complexity.

Economically, the stakeholders recognized an increasingly favorable outlook for rainwater harvesting. Rising municipal water prices, consistently increasing by approximately 4–5% annually in Sweden, enhance the economic justification for considering alternative water sources. B2 noted that if integrated during initial construction phases, rainwater harvesting systems can demonstrate reasonable payback periods when factoring in savings on municipal water consumption and reduced stormwater management fees. Consequently, early-stage planning was unanimously highlighted as critical for effectively integrating these systems into facility design. Retrofitting such systems post-construction was described as considerably more expensive and operationally complicated, underscoring the importance of foresight and early inclusion in project specifications.

4.3.2 Stormwater Recycling: Strategic Integration in Sustainable Facility Design

The interviews further explored the integration of sustainable stormwater management practices within facility design and operational frameworks. Unlike traditional engineering approaches that view stormwater management primarily as a logistical concern, contemporary perspectives emphasize holistic integration within overall sustainability objectives. Respondents C2 and C3 provided valuable insights from their involvement in major urban development projects, highlighting how stormwater recycling aligns closely with broader environmental and sustainability ambitions.

Respondent C2, representing the client side of a high-profile development, emphasized stormwater management as inseparable from the facility's sustainability strategy. Early planning phases prioritized preserving natural landscapes and facilitating natural water flows, significantly aligning the project with stringent sustainability criteria such as LEED certification. This strategic integration was driven not only by environmental concerns but also by long-term financial and regulatory incentives increasingly linked to sustainable practices in the real estate sector. Thus, stormwater management became integral to the project's value proposition, impacting both immediate design decisions and longer-term operational strategies.

A primary approach described by respondents involved the creation of onsite stormwater retention and infiltration systems, including biofilters, rain gardens, and permeable surfaces designed to manage stormwater entirely within the property boundaries. This method effectively reduced reliance on municipal stormwater infrastructure, lowered environmental impact, and supported biodiversity goals. C2 highlighted that the sustainability objectives for the project explicitly mandated onsite stormwater handling, promoting water as a resource rather than a waste product. This philosophy underpinned a broader collaborative sustainability program, developed in partnership with tenants and stakeholders, emphasizing biodiversity, resource efficiency, and long-term environmental resilience.

Technical consultant C3 elaborated on practical challenges faced during the early design and construction stages, including managing natural runoff patterns, construction logistics, and unpredictable site conditions. Such complexities required adaptive planning and continuous collaboration among diverse stakeholders, including architects, engineers, contractors, and sustainability consultants. Misalignment or poor coordination among these parties was identified as a significant risk factor that could compromise system effectiveness and lead to operational inefficiencies.

4.3.3 Exploring the Viability and Strategic Integration of Rainwater Harvesting and Water Recycling at Volvo Cars Torslanda

The implementation of alternative water management strategies, specifically rainwater harvesting and water recycling, presents both compelling opportunities and distinct challenges in the context of Volvo Cars Torslanda. Although these measures have not yet been practically adopted at the site, insights from expert interviews combined with relevant literature offer a robust basis for evaluating their feasibility and strategic value for future operations.

Rainwater harvesting emerged from the interviews as a potentially impactful practice for reducing dependence on municipal freshwater resources, especially in contexts with significant nonpotable water demand. According to stakeholder B2, who has extensive experience with water management assessments at Volvo, the adoption of rainwater harvesting would primarily depend on matching water quality standards to suitable uses. This aligns closely with findings in the literature, where Aleksic et al. (2019) emphasize the importance of integrating harvested rainwater with appropriate treatment systems. Specifically, harvested rainwater could effectively meet nonpotable water needs such as cleaning, cooling, and irrigation, provided that adequate filtration systems are established. The technological feasibility of these systems is well-documented in studies by Braun and LU (2024), who demonstrate that advanced filtration methods like ceramic membrane technology can significantly enhance the quality and usability of rainwater in industrial contexts.

Despite this technological feasibility, economic considerations surfaced as a notable barrier throughout the interviews. Particularly in relation to advanced solutions such as water recycling and rainwater harvesting. While effective, these systems are expensive and may not be justified in non-manufacturing facilities. “It might make sense in a factory, but not necessarily in an office building,” A3 admitted. Instead, Volvo is leaning toward more cost-effective methods like leak detection and preventative maintenance. “The goal is to fix problems before they grow,” A3 explained, “but we need better data to do that”. This perspective mirrors insights from Sabia et al. (2023), who point out that regions with low water tariffs often face challenges in economically justifying investments in advanced water management infrastructure. Moreover, stakeholders such as B4 raised regulatory ambiguity as an additional barrier, stressing the lack of clear guidelines for harvested rainwater use in industrial contexts. This concern resonates with Engvall (2021), who underscores that without supportive regulatory frameworks, businesses are less inclined to adopt alternative water management solutions.

However, increasing water prices, documented by Svenskt Vatten (2024) as rising annually by approximately four to five percent in Sweden, could gradually shift the economic landscape. Interviewee B2 noted that if rainwater harvesting systems are integrated into new construction projects rather than retrofitted into existing structures, they could offer more attractive payback periods. This strategic viewpoint is supported by Wennberg (2018), who suggests that early integration of decentralized water solutions into facility design enhances economic viability by reducing subsequent retrofitting costs.

Regarding water recycling, the interviews clearly articulated the strategic importance of sustainable water management within broader sustainability frameworks. Respondents C2 and C3 particularly emphasized the integration water recycling systems into facility design as a key sustainability strategy. This strategic perspective aligns closely with the green infrastructure models described by Liu and Jensen (2018), who argue for a holistic approach to water recycling management that supports environmental, social, and economic sustainability simultaneously.

Thus, while Volvo Cars Torslanda currently perceives rainwater harvesting and water recycling primarily as challenging from an economic and practical standpoint, these approaches offer substantial strategic value in terms of regulatory compliance, market positioning, and long-term operational resilience. The literature and interviews collectively indicate that future developments in water pricing, regulatory expectations, and digital innovation could significantly enhance the attractiveness and feasibility of these alternative water management strategies. For Volvo Cars, maintaining strategic awareness and openness to integrating such solutions in future facility expansions or renovations could prove essential for achieving sustained environmental and economic performance.

5

Conclusion

This thesis aimed to investigate strategies for optimizing water management practices at Volvo Cars Torslanda, focusing on identifying current inefficiencies, evaluating potential technological solutions, and assessing the feasibility of sustainable water practices such as rainwater harvesting and water recycling. To achieve this aim, three research questions were defined and explored through quantitative data analysis and qualitative insights from stakeholder interviews.

RQ1: What are the existing water usage and consumption patterns, and where are the inefficiencies at Volvo Cars Torslanda?

The study revealed substantial discrepancies between measured water consumption and the volumes purchased from the water supplier, indicating significant amounts of unmeasured water. On average, about 15,000 cubic meters per month of water remained unaccounted for, particularly prominent during periods of high cooling demand and identified water leaks. A primary cause of this inefficiency was the inadequate segmentation of the internal water network, which hindered accurate and timely leak detection. The existing monitoring system, eSight, despite being capable of detailed data tracking and real-time alerts, was found to be underutilized, limiting the effectiveness of anomaly detection and rapid intervention. Additionally, smaller yet notable gaps were identified in certain facilities due to malfunctioning or disconnected meters, further complicating accurate consumption tracking. Improved collaboration and clearer communication channels with the external water supplier were also highlighted as necessary for promptly identifying and mitigating water losses.

RQ2: What technologies or practices can improve water efficiency at Volvo Cars Torslanda?

Sensor-based fixtures, particularly automated faucets, emerged as viable technological solutions capable of reducing unnecessary water usage substantially. Although the initial investment is modest, the extended payback period results from limited water savings and the relatively low cost of water. However, they align strategically with Volvo's broader sustainability objectives, offering meaningful long-term environmental benefits. Complementing these technical solutions, the research highlighted behavioral change initiatives as essential. Moreover, alongside these technical solutions, the importance of behavioral change was underscored. Employee engagement initiatives such as targeted education, training programs, and regular internal communication campaigns were emphasized as essential to complement and maximize the effectiveness of technological upgrades.

RQ3: How can Volvo Cars integrate sustainable practices such as rainwater harvesting or stormwater recycling into their water management system?

The feasibility analysis demonstrated that rainwater harvesting, and stormwater recycling systems possess substantial potential to improve water sustainability at the Torslanda facility, particularly when integrated at the early planning and design phases of new constructions. These systems can significantly reduce dependency on municipal water supplies and mitigate future risks associated with rising water tariffs and potential regulatory changes. However, implementing these solutions in existing facilities was determined to be economically challenging, given the high initial investment and considerable retrofitting complexities. Despite these short-term economic constraints, strategically incorporating rainwater harvesting and recycling solutions into future building projects can deliver long-term environmental advantages and align Volvo Cars Torslanda with emerging sustainability standards and industry best practices.

To conclude, while Volvo Cars Torslanda currently faces specific challenges related to metering, data utilization, and economic barriers for sustainable water technologies, the findings emphasize clear opportunities to improve water management practices. Addressing these identified inefficiencies, leveraging appropriate technologies, and strategically considering sustainable practices from an early planning stage will position Volvo Cars as a leader in sustainable industrial water use, achieving both environmental and operational benefits.

6

Recommendations for Future Water Management at Volvo Cars Torslanda

Based on the findings and analysis presented in this thesis, several targeted recommendations are proposed to help Volvo Cars Torslanda strengthen its water management, reduce inefficiencies, and further advance its sustainability profile. The suggested actions address technological, organizational, and strategic opportunities identified through both data analysis and stakeholder interviews. The following steps will be systematically presented in Table 8 below.

Table 8: Overview of recommendation to Volvo Cars.

Priority	Recommendation	Concrete Steps	Timeline
High	Maximize use of eSight monitoring system	Activate real-time alerts and notifications. Ensure regular follow-up of anomalies and assign clear responsibilities for immediate actions.	Short-term (within 6 months)
High	Improve segmentation of water network	Install additional external meters strategically to create measurable sub-zones. Prioritize key facilities with	Medium-term (6-12 months)

		historically high consumption or leaks.	
High	Strengthen coordination with water supplier	Establish regular coordination meetings focused specifically on leak detection, joint data review, and improvement plans.	Short-term (within 3 months)
Medium	Gradual implementation of sensor-based fixtures	Incorporate sensor-based water fixtures during planned renovations. Initially target high-use areas such as bathrooms and kitchens.	Medium to Long-term (within 1-3 years)
Medium	Promote behavioral change initiatives	Launch regular educational workshops and internal campaigns to raise awareness of water conservation among employees. Integrate water-saving behaviours into ongoing training programs.	Short-term (starting immediately and ongoing)
Medium	Enhance internal and international collaboration	Create internal working groups focused on sustainability and water management.	Medium-term (within 6-12 months and ongoing)

		Regularly exchange best practices with international Volvo facilities to identify effective solutions.	
Long-term	Integrate rainwater harvesting and recycling in new projects	Set clear sustainability targets for new facility construction. Include water recycling and rainwater harvesting as standard criteria in planning and design phases.	Long-term (5 years and ongoing)

Enhance Use of Existing Digital Monitoring Systems

It is recommended that Volvo Cars continues to utilize the eSight monitoring platform but focuses on leveraging its full capabilities. In particular, the implementation and active use of the platform's alarm and notification functions should be prioritized. By setting up real-time alerts for abnormal consumption patterns or sudden changes in flow, facility management can respond more rapidly to water anomalies, significantly reducing water losses and minimizing the risk of undetected leaks.

Additionally, Volvo Cars should invest in network segmentation by installing additional metering points at key locations outside the buildings. Segmenting the water distribution system will improve the ability to localize and isolate potential leaks, provide better visibility over the internal water network, and support more data-driven decision-making. Maintaining ongoing dialogue and collaborative problem-solving with the water supplier is also essential for addressing complex leakage issues that span organizational boundaries. Regular coordination meetings and joint investigations into unexplained water losses will help ensure that both internal and external responsibilities are clearly defined and acted upon.

Invest in Sensor-Based Water-Saving Technologies and Promote Behavioral Change

Volvo Cars is encouraged to invest in sensor-based fixtures, such as automated faucets, as part of its long-term water-saving strategy. Although the payback period for these systems may be relatively long due to the currently low price of municipal water, the investment required is modest approximately 1.4 million SEK for full-scale implementation. By introducing these upgrades gradually, for instance in conjunction with planned bathroom renovations, Volvo can manage costs effectively and limit operational disruption. In the long run, these investments will contribute to lower water consumption, improved sustainability metrics, and compliance with future regulatory requirements.

Beyond technology, organizational change is vital for maximizing water-saving potential. Volvo Cars should initiate workshops and targeted information campaigns to increase awareness among employees about the importance of reducing water consumption. By fostering a culture of responsible water use and providing practical tips for everyday behavior, these initiatives can help ensure that the benefits of technological upgrades are fully realized. Improved collaboration between different departments, as well as sharing best practices internationally within the Volvo Group, will further reinforce a holistic approach to water management and drive continuous improvement.

Integrate Stormwater Recycling and Rainwater Harvesting in Future Developments

For new construction projects, Volvo Cars should actively consider the integration of stormwater recycling and rainwater harvesting systems as a strategic priority. By establishing these goals from the initial planning stage, the company can design buildings and infrastructure that are both resilient and resource efficient. While the payback time for such systems may remain high under current economic conditions, their long-term value will likely increase as water prices rise and regulatory expectations around sustainability intensify. These forward-looking investments will not only reduce dependency on municipal water but also position Volvo Cars as an industry leader in sustainable industrial practices.

Strategic Impact

By adopting these recommendations, Volvo Cars can significantly strengthen its sustainability profile and demonstrate leadership in industrial water management. Implementing advanced monitoring, sensor-based savings solutions, and sustainable water systems in new developments will help future-proof the facility, improve compliance with frameworks such as CSRD, and enhance the company’s brand value as a proactive and responsible manufacturer.

7

Future Research and Development

This thesis has contributed to a better understanding of water management challenges and opportunities at Volvo Cars Torslanda, but several important questions remain for future exploration. Drawing from the findings and limitations of this study, as well as observed trends in the industry, the following areas are proposed as fruitful directions for continued research and development.

Beyond Payback Time: Rethinking the Motivation for Water Efficiency

One central theme that emerged in this thesis is the dominance of payback time calculations when evaluating water-saving investments. While economic return is naturally important in industrial decision-making, there is growing recognition that sustainability, regulatory compliance, and long-term resilience must also be prioritized. Future research should examine how companies can be motivated to value water efficiency for more than just short-term financial returns. This could involve studying business models that integrate non-financial benefits such as improved brand reputation, better compliance with regulations like the Corporate Sustainability Reporting Directive, and alignment with environmental targets. Comparative studies across different industries could reveal how broader value perspectives can encourage companies to invest in water-saving measures even when payback periods are long or uncertain.

Implementing Rainwater Harvesting and Recycling in Existing Facilities

Another key area for future study concerns the practical challenges and opportunities involved in retrofitting rainwater harvesting and stormwater recycling systems into operational industrial facilities. As highlighted in this thesis, the economic and technical barriers to implementing these systems in existing buildings are often significant. However, with increasing water prices and tightening regulations, interest in such solutions is likely to grow. Research could focus on real-world pilot projects that attempt to integrate rainwater or recycling technologies into older facilities, exploring what technical solutions are most effective, what financing models can make retrofits viable, and how maintenance and quality assurance can be managed over time. Documenting and analyzing these efforts would provide valuable guidance for other companies facing similar decisions.

Business Models and Incentives for Industrial Water Sustainability

A further research need lies in developing and evaluating new business models and incentive structures that can accelerate the adoption of sustainable water practices. Case studies could investigate how different types of contracts, partnerships, or financial incentives influence investment in water-saving technologies. Special attention could be paid to mechanisms that share risks and rewards between companies, suppliers, and other stakeholders. Understanding which models are most effective in different organizational and market contexts would help both practitioners and policymakers design frameworks that support more ambitious water management goals.

References

Bryman, A., & Bell, E. (2017). Företagsekonomiska forskningsmetoder (3 uppl.). Stockholm: Liber.

Aleksic, N., Šušteršič, V., Gordić, D., Nikolić, D., & Rakić, N. (2019). Reduction of water consumption in waste water treatment systems in the automotive industry. Retrieved from https://scidar.kg.ac.rs/handle/123456789/15488

Bauer, S., Linke, H. J., & Wagner, M. (2020). Optimizing water-reuse and increasing water-saving potentials by linking treated industrial and municipal wastewater for a sustainable urban development. *Water Science and Technology*, 81(9), 1927–1940. Retrieved from https://doi.org/10.2166/wst.2020.257

Boysen, B., Cristóbal, J., Hilbig, J., Güldemund, A., Schebek, L., & Rudolph, K. U. (2020). Economic and environmental assessment of water reuse in industrial parks: case study based on a Model Industrial Park. *Journal of Water Reuse and Desalination*, 10(4), 475–489. Retrieved from https://doi.org/10.2166/wrd.2020.034

Braun, M., & LU, O. (2024). *Rainwater Harvesting: A Study on Gravity-Driven Ceramic Membranes for Non-Potable Water Use*. Retrieved from https://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=9151871&fileOId=9152123

Castro, C. V., Carney, C., & de Brito, M. M. (2023). The role of network structure in integrated water management: a case study of collaboration and influence for adopting nature-based solutions. *Frontiers in Water*, 5, 1011952. Retrieved from https://doi.org/10.3389/frwa.2023.1011952

Cirkulation. (2018, 6 mars). Kampanj mot vattensvinnet. Retrieved from https://cirkulation.se/artiklar-och-notiser/kampanj-mot-vattensvinnet/

Covello, V. T., Minamyer, S., & Clayton, K. (2007). *Effective risk and crisis communication during water security emergencies: Summary report of EPA sponsored message mapping workshops* (EPA/600/R-07/027). U.S. Environmental Protection Agency. Retrieved from https://www.epa.gov/sites/default/files/2015-08/documents/effective_risk_and_crisis_communication_during_water_security_emergencies.pdf

Engvall, T. (2021). *Possibilities for Rainwater Harvesting in Industry – A Case Study of Sandvik AB's Industrial Area in Sandviken*. Uppsala University. Retrieved from https://www.diva-portal.org/smash/get/diva2:1567742/FULLTEXT01.pdf

European Commission. (2015). *Best Environmental Management Practice in the Car Manufacturing Sector: Background Report*. Joint Research Centre. Retrieved from https://susproc.jrc.ec.europa.eu/product-bureau/sites/default/files/inline-files/BackgroundReport_BEMP_CarManufacturing.pdf

European Environment Agency. (n.d.). *Urban Waste Water Treatment in Sweden*. Water Information System for Europe (WISE). Retrieved April 14, 2025, from https://water.europa.eu/freshwater/countries/uwwt/sweden

Food and Agriculture Organization of the United Nations. (2016). *AQUASTAT regional overviews*. Retrieved from https://www.fao.org/aquastat/en/countries-and-basins/regional-overviews

Gryaab. (2022). *Hållbarhetsredovisning 2022*. Retrieved from https://www.gryaab.se/wp-content/uploads/2023/04/220222_Gryaab_hallbarhetsredovisning2022_tillg.pdf

gry, A. (2016, April). *Do automatic water faucets actually save water? A comparative test of manual and automatic water faucets at California State University, Sacramento*. Retrieved from https://www.csus.edu/experience/innovation-creativity/sustainability/_internal/_documents/ir-faucet.pdf

Göteborg Energi. (2022). *Framtidens batterifabrik kyls med avloppsvatten*. Retrieved from https://www.goteborgenergi.se/i-var-stad/artikelbank/framtidens-batterifabrik-kyls-med-avloppsvatten

Hage, O., Söderholm, P., & Berglund, C. (2009). Norms and economic motivation in household recycling: Empirical evidence from Sweden. *Resources, Conservation and Recycling*, 53(3), 155–165. Retrieved from https://doi.org/10.1016/j.resconrec.2008.11.003

IVL. (2020). *The LoV-IoT project: Air and water monitoring with Internet of Things – Water* (Report No. R2020:19). IVL Swedish Environmental Research Institute. Retrieved from https://goteborg.se/wps/wcm/connect/3f476c27-611c-4498-a8f5-bffccb6cd5b3/N800_R_2020_20_The-LoV-IoT+project.pdf?MOD=AJPERES

IVL Svenska Miljöinstitutet. (2023). *Smart vattenövervakning med hjälp av ny uppfinning*. Retrieved from https://www.ivl.se/press/pressmeddelanden/2023-03-15-smart-vattenovervakning-med-hjalp-av-ny-uppfinning.html

Koo, D., Piratla, K., & Matthews, J. (2015). Towards sustainable water supply: Schematic development of big data collection using Internet of Things (IoT). *Sustainable Cities and Society*, 15, 84–94. Retrieved from https://doi.org/10.1016/j.scs.2014.10.005

Kristianstads kommun. (2024). *SmartVA – Realtidsövervakning av avloppssystem i Kristianstad*. Retrieved from https://www.kristianstad.se/byggaboochmiljo/byggprojekt/smartva.5558.html

KTH. (2024). *Sensorteknik hittar läckor och spårar föroreningar i dricksvattnet*. Retrieved from https://www.kth.se/en/om/nyheter/centrala-nyheter/sensorteknik-hittar-lackor-och-sparar-fororeningar-i-dricksvattnet-1.1313658

Lee, M., & Tansel, B. (2013). Water conservation quantities vs customer opinion and satisfaction with water efficient appliances in Miami, Florida. *Journal of Environmental Management*, 128, 683–689. Retrieved from https://doi.org/10.1016/j.jenvman.2013.05.044

Liu, L., & Jensen, M. B. (2018). Green infrastructure for sustainable urban water management: Practices of five forerunner cities. *Cities*, 74, 126–133. Retrieved from https://doi.org/10.1016/j.cities.2017.11.013

Malm, A., Svensson, G., Røstum, J., & Axell, L. (2020). Sustainable economic level of leakage in Norway and Sweden – manual of practice. *Water Practice & Technology*, 15(2), 343–349. Retrieved from https://doi.org/10.2166/wpt.2020.018

Mårtensson, H., Malm, A., Sederholm, B., Sällström, J.-H., & Trägårdh, J. (2018). *Framtidens hållbara VA-ledningssystem* (SVU-rapport Nr 2018-10). Svenskt Vatten Utveckling. Retrieved from https://www.svensktvatten.se/forskning--utveckling/rapporter/2018/svu-rapport-2018-10/

Najar, N., & Persson, K. M. (2023). Status improvement in water and wastewater fixed facilities: Success and challenges of 11 Swedish water utilities as case studies. *Water Policy*, 25(7), 656–679. Retrieved from https://doi.org/10.2166/wp.2023.263

Ocal, Z. B., Karagunduz, A., Keskinler, B., Dizge, N., & Ashqar, H. I. (2023). Investigation of reusability of effluents from an organized industrial zone wastewater treatment plant using a pressure-driven membrane process. *Water Reuse*, 13(4), 559–570. Retrieved from https://doi.org/10.2166/wrd.2023.066

Rothman, M., Abrahamson, S., Karlsson, N., Huss, L. G., Johansson, T., Ousbäck, J. O., Rahm, J., Samuelsson, C., Örbom, A., & Axelsson, D. (2013). *Ny metod för läcksökning* (SVU-rapport 2013-02). Svenskt Vatten Utveckling. Retrieved from https://vattenbokhandeln.svensktvatten.se/produkt/ny-metod-for-lacksokning/

Sabia, G., Mattioli, D., Langone, M., & Petta, L. (2023). Methodology for a preliminary assessment of water use sustainability in industries at sub-basin level. *Journal of Environmental Management*, 343, 118163. Retrieved from https://doi.org/10.1016/j.jenvman.2023.118163

Santos, P. G., Scherer, C. M., Fisch, A. G., & Rodrigues, M. A. S. (2020). Petrochemical wastewater treatment: Water recovery using membrane distillation. *Journal of Cleaner Production*, 267, 121985. Retrieved from https://doi.org/10.1016/j.jclepro.2020.121985

Semmens, J., Bras, B., & Guldberg, T. (2014). Vehicle manufacturing water use and consumption: An analysis based on data in automotive manufacturers' sustainability reports. *The International Journal of Life Cycle Assessment*, 19(1), 246–256. Retrieved from https://doi.org/10.1007/s11367-013-0612-2

Stefanakis, A. I. (2019). The Role of Constructed Wetlands as Green Infrastructure for Sustainable Urban Water Management. *Sustainability*, 11(6981). Retrieved from https://doi.org/10.3390/su11246981

Strand, M. (2023, September 11). Kemiföretaget Perstorp återanvänder Stenungsunds avloppsvatten | *VA-guiden*. Vaguiden.se. https://vaguiden.se/2023/09/kemiforetaget-perstorp-ateranvander-stenungsunds-avloppsvatten/

Svenskt Vatten. (2024). *Taxestatistik 2024: Statistik över brukningsavgifter för vatten och avlopp i Sverige*. Retrieved from https://www.svensktvatten.se/globalassets/dokument/organisation--styrning/va-statistik/sv-rapport_2024_taxestatistik.pdf

Svenskt Vatten. (2024). *Taxestatistik 2024: Vad kostar vatten- och avloppstjänsterna i Sverige? Statistik, utveckling och exempel från alla 290 kommuner*. Retrieved from https://www.svensktvatten.se/vattentjanster/organisation-och-juridik/va-statistik/taxeundersokning/

Svenskt Vatten, Maskinentreprenörerna, & VVS-Fabrikanternas Råd. (2023, 9 oktober). Flera hundra läckor i kommunala VA-system i fjol. *Dagens Samhälle*. Retrieved from https://www.dagenssamhalle.se/opinion/debatt/flera-hundra-lackor-i-kommunala-va-system-i-fjol/

Svenskt Vatten Utveckling. (2019). *Vattenförluster från ledningsnätet – beräkningsverktyg för en hållbar vattenförlustnivå* (SVU-rapport 2019-17). Retrieved from https://vav.griffel.net/filer/svu-rapport-2019-17.pdf

Tahric, D. (2023). *Designing the Next-Generation Water Faucet with focus on Sustainability and Efficiency*. Retrieved from https://odr.chalmers.se/items/16990195-7382-45b4-bf7b-320c34074437

UNESCO/UN-Water. (2020). *The United Nations World Water Development Report 2020: Water and climate change*. United Nations Educational, Scientific and Cultural Organization. Retrieved from https://www.unesco.org/en/wwap/wwdr/2020

United Nations. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development*. Retrieved from https://sdgs.un.org/2030agenda

VA-guiden. (2023). *Kemiföretaget Perstorp återanvänder Stenungsunds avloppsvatten*. Retrieved from https://vaguiden.se/2023/09/kemiforetaget-perstorp-ateranvander-stenungsunds-avloppsvatten/

Volvo Cars. (2023). *Volvo Cars doubles down on climate action, aims to cut CO_2 emissions per car by 75 per cent by 2030 and become a circular business by 2040*. Retrieved from https://www.media.volvocars.com/global/en-gb/media/pressreleases/321665/volvo-cars-doubles-down-on-climate-action-aims-to-cut-co2-emissions-per-car-by-75-per-cent-by-2030-a

Weerasooriya, R. R., Liyanage, L. P. K., Rathnappriya, R. H. K., Bandara, W. B. M. A. C., Perera, T. A. N. T., Gunarathna, M. H. J. P., & Jayasinghe, G. Y. (2021). Industrial water conservation by water footprint and sustainable development goals: a review. *Environment, Development and Sustainability*, 23, 12661–12709. Retrieved from https://doi.org/10.1007/s10668-020-01184-0

Wennberg, A. J. (2018). *Rainwater Harvesting: An Assessment of the Future Potential in Sweden* (Master's thesis, KTH Royal Institute of Technology). Retrieved from https://www.diva-portal.org/smash/get/diva2:1256384/FULLTEXT01.pdf

World Economic Forum. (2024). *The Global Risks Report 2024*. Retrieved from https://www.weforum.org/publications/global-risks-report-2024/

Zang, W., Li, X., Huang, Y., & Yang, Y. (2021). Real-world sustainability analysis of an innovative decentralized water system with rainwater harvesting and wastewater reclamation. *Environmental Research Letters*, 16(7), 077003. Retrieved from https://doi.org/10.1088/1748-9326/ac0a4e

Interview Guideline

The following interview guideline was developed to systematically collect qualitative insights on water management and sustainability practices at Volvo Cars Torslanda. The guideline was designed to facilitate semi-structured interviews, ensuring flexibility to explore specific topics in greater depth depending on the respondent's area of expertise and professional role.

Opening Questions

- Can we record and transcribe this interview?
- Is it acceptable to mention your professional role and department within Volvo Cars in the final thesis?
- Could you briefly introduce yourself, your background, and your current responsibilities related to water management and sustainability?

Water Consumption and Monitoring Practices

- Could you describe the current state of water consumption at your facility or within your area of responsibility?
    - Are there specific areas or processes where water usage is particularly high?
- How do you currently measure and monitor water consumption?
    - Are there established routines or systems (such as eSight or other digital tools) for identifying and addressing anomalies or leaks?
- What challenges have you faced in accurately tracking and managing water usage?

Technical Solutions and Innovations

- Have you considered or implemented any technical solutions aimed at reducing water consumption, such as sensor-based fixtures, leak detection systems, or digital twins?
    - Could you share your experiences or challenges related to implementing these technologies?
- From your perspective, what are the main barriers (technical, economic, organizational) to adopting more advanced water-saving technologies?

Data Management and Analysis

- How do you typically collect and structure consumption data for different buildings or zones?
    - Which data visualization or business intelligence tools do you use, if any, to analyze and present water consumption data?
- When analyzing data, what specific patterns or anomalies do you look for as indicators for potential water-saving improvements?
- Do you face particular challenges with data quality, consistency, or the granularity of data at the building level?

Rainwater Harvesting and Alternative Water Sources

- Have you explored or implemented rainwater harvesting solutions at your facilities?
    - Could you describe how these systems are designed, including storage capacity and water treatment processes?
    - What proportion of your water demand is currently covered by harvested rainwater, if applicable?
- What technical, regulatory, or economic challenges have you encountered regarding rainwater harvesting?
- Do you see rainwater harvesting as strategically valuable for future projects and facility developments?

Behavioral and Organizational Engagement

- How important do you consider behavioral and organizational measures for achieving water efficiency at Volvo Cars?
    - Have you implemented any specific initiatives to increase employee awareness or promote sustainable water use behaviors?
- Could improved internal collaboration or communication strategies enhance water management efforts? If so, how?

Strategic Considerations and Sustainability Goals

- How does effective water management fit into Volvo Cars' broader sustainability and corporate social responsibility (CSR) strategies?

- In your opinion, what future trends or external pressures (e.g., regulatory changes, rising water tariffs) might influence water management practices at Volvo Cars?
- What would you recommend as priority areas for future investments or actions regarding water sustainability at Volvo Cars?

Closing Questions

- Is there any critical aspect related to water management and sustainability that we have not discussed but you believe is important?
- Could you suggest additional individuals or roles within the organization who would be beneficial to interview for further insights?
- Would you like to review a draft of the final thesis before submission?

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
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