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TALLINN UNIVERSITY OF TECHNOLOGY

SCHOOL OF ENGINEERING

Department of Civil Engineering and Architecture

Environmental Engineering and Management (MSc)

SUSTAINABLE PERFORMANCE ASSESSMENT OF URBAN WATER SECTOR. CASE STUDIES IN TALLINN, ESTONIA AND HELSINKI, FINLAND

Linna veesektori jätkusuutliku toimivuse hindamine. Juhtumiuuringud Tallinnas ja Helsingis

MASTER THESIS

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Student code: 211946EAXM

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Tallinn 2023

(*On the reverse side of title page*)

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Hereby I declare, that I have written this thesis independently.
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Water and Environmental Engineering

THESIS TASK

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Thesis topic:

(eesti keeles) **Linna veesektori jätkusuutliku toimivuse hindamine. Juhtumiuuringud Tallinnas ja Helsingis**

(inglise keeles) **Sustainable performance examination of urban water sector. Case studies in Tallinn, Estonia and Helsinki, Finland**

Thesis main objectives:

1. Conduct a detailed literature review, considering the scientific papers associated with urban water sector, importance of sustainability assessment and its application in urban water sector, give theoretical definition of the terms used in this research
2. Based on the similar research topics, develop theoretical framework for evaluating the sustainable performance of the urban water sector in Tallinn and Helsinki
3. By applying the theoretical framework examine the performance of the urban water sector in Tallinn, Estonia and Helsinki, Finland
4. Make a comparison between two cities and highlight future recommendations and strategies for facilitating and strengthening the sustainable performance of the urban water sector in Tallinn, Estonia.

Thesis tasks and time schedule:

Nr	Task description	Deadline
1.	Literature review of the topic	03.2023
2.	Definition of sustainability indicators for water sector and data collection	04.2023
3.	Comparison of the results and compiling the thesis	05.2023

Language: English **Deadline for submission of thesis:** “29” May 2023

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PREFACE

I would like to thank my supervisor, Arvo Iital, for his contributions in helping me with writing this paper. His positive-minded attitude and great experience gave me confidence in several aspects of the work as well as made the process of research more interesting. I would like to also thank Professor Karin Pachel for her constant assistance along this two years Masters journey at Taltech.

Last but not least, I want to express the kindest words to my parents and friends who supported me along this path by sharing their valuable experiences and giving extra pinch of motivation.

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List of abbreviations and symbols

EU – European Union

CO_2 – Carbon Dioxide

HMU – Helsinki Metropolitan Area

UN – United Nations

UWS – Urban Water Sector

SDG – Sustainable Development Goals

SPA – Sustainable Performance Assessment

SPAF – Sustainable Performance Assessment Framework

WTP – Water Treatment Plant

WWTP - Wastewater Treatment Plant

WFD – Water Framework Directive

1. Introduction

Water sector is an essential part of the vital functioning of any country and plays a key role in the government's economy. It encompasses a broad range of activities related to the management and treatment of water resources, involving the design, construction, operation and maintenance of water supply systems, treatment facilities, and other related infrastructure. The water sector is highly responsible for the protection of public health by providing safe drinking water, treating wastewater, and mitigating the impact of possible floods and droughts (Wang, et al., 2022).

Furthermore, the water sector is crucial for sustaining agriculture, manufacturing, energy production, and tourism, among other key economic sectors. In the European Union (EU), the water sector accounts for around 1% of the region's GDP and provides employment to more than two million people (Schellekens, et al., 2018). According to Eurostat, in 2020, the total revenue of water supply, sewerage, and waste management activities in the EU was over €256 billion, while the total value added was €102 billion (Eurostat, 2023).

Despite the vital importance of the water sector, many countries face significant challenges in ensuring sustainable water management in urban areas. Northern European countries such as Scandinavian area and Baltic states are often seen as having a relatively good water management system, however, even this region has challenges in ensuring sustainable water management goals (European Environment Agency, 2009). In the recent years climate change is causing an increasing pressure on the water sector, particularly in countries with cold and temperate climates such as Estonia and Finland (Climate ADAPT, 2023).

These two countries are located in the Baltic Sea region and share similar climatic conditions, with cold winters and mild summers. Tallinn and Helsinki, the capital cities of Estonia and Finland respectively, share many similarities in their water management systems, being both committed to European Union Water Framework Directive and having different collaboration projects in water sector (Tallinn City Council, 2022), but also face specific challenges related to their urban environments. Both cities rely heavily on surface water sources, such as lakes and rivers, for their water supply, which are vulnerable to the impacts of climate change. In addition to that, recent climate trends in this region have led to changes in precipitation patterns, temperature fluctuations, and more frequent extreme weather events, posing significant challenges to their water resources management systems (HELCOM, 2021).

Furthermore, demographic expansion in Tallinn and Helsinki is adding additional stress on water resources, leading to increased risks of water scarcity and drought. For instance, according to Helsinki Region Infoshare population projection, the demographics of Helsinki and its sub areas will grow almost up to 25% by 2050 (Helsinki Region Infoshare, 2022), where Tallinn is projected to experience almost similar population increase of up to 20% by same year (OECD, 2022).

The urban expansion processes in both cities will inevitably bring substantial number of challenges related to water resources management, water supply and wastewater treatment in the future. It must be noted that urbanization also increases the risk of urban flooding, as impermeable surfaces such as concrete and asphalt prevent water from being absorbed into the ground. As mentioned above due to the changes in precipitation patterns and more frequent rainfall, this can lead to severe flooding events in the urban area what will negatively affect the local infrastructure, economic functioning of the cities, public health, and safety of residents (United Nations, 2023).

In 2018 for instance, Tallinn experienced one of the worst flooding events in its history, which caused considerable damage to infrastructure, homes, and businesses. According to the Tallinn Water Department, the 2018 flood was caused by a combination of factors, including heavy rainfall, clogged drainage systems, and inadequate pumping capacity. Apart from flooding, other events such as frequent heat waves and prolonged droughts in Tallinn have an impact on the availability of water resources. Another problem is an outdated water infrastructure like pipes, water pumps and water meters (Tallinna Vesi AS, 2022).

Similarly, Helsinki faces challenges related to water scarcity and the management of wastewater in its urban environment, occasional flooding events in various parts of the city area. The city has a comprehensive water supply system that relies on surface water sources, but the changing climate has led to fluctuations in the availability of water resources, particularly during dry spells (HSY, 2021).

To address these challenges, both cities have implemented various policies and initiatives to promote sustainable water management practices. In Tallinn, the city has introduced measures to improve the efficiency of the water supply system, promote water conservation, and upgrade the wastewater treatment infrastructure (Tallinna Vesi AS, 2022). Similarly, Helsinki has launched a comprehensive water strategy that emphasizes the importance of sustainable water management practices, including the promotion of water conservation, the improvement of wastewater treatment, and the protection of water resources (HSY, 2021).

The aim of this thesis is by developing an assessment framework to investigate, analyse and discuss the key drivers which affect the sustainable performance of the urban water sector, using cases studies in Tallinn, Estonia and its twinned city – Helsinki, Finland.

Based on the research of case studies and comparison of the results with City of Helsinki, this paper will provide comprehensive insights and recommendations for Tallinn policymakers, water utility companies, and other stakeholders on how to improve the transition towards sustainable goals in urban water sector, while ensuring sustainable and equitable access to water resources.

1.1 Research question and objectives

The following research question was formulated in the beginning of the study:

What recommendations for the improvement of sustainable performance of Tallinn urban water sector can be given by examination and comparison with Helsinki urban water sector?

Objectives:

1. Conduct a detailed literature review, with stress on the scientific papers associated with urban water sector, importance of sustainability assessment and its application in urban water sector, give theoretical definition of the terms used in this research
2. Based on the similar research topics, develop theoretical framework for evaluating the sustainable performance of the urban water sector in Tallinn and Helsinki
3. By applying the theoretical framework, analyse scholarly papers, council documents, statistics, water utilities' reports and examine the performance of the urban water sector in Tallinn, Estonia and Helsinki, Finland
4. Make a comparison between two cities and highlight future recommendations and strategies for facilitating and strengthening the sustainable performance of the urban water sector in Tallinn, Estonia.

2. Literature Review

This chapter's objective is to set up a scientifically robust understanding of the theoretical definitions used in the research topic. The literature review focuses on the consideration of the scholarly papers in the realm of the sustainable performance and its assessment in the urban water sector, in addition to that, it will get an insight of the water resources and its management using the World Bank reports, have an overview of the sustainability, and sustainable performance in general.

2.1 Urban Water Sector (UWS)

The water sector or water industry comprises a significant part of a country's economy referring to the various activities, services, and infrastructure that relate to the management, treatment, and distribution of water resources. It encompasses several subdivisions that work together to ensure the availability and quality of water resources for human consumption, agriculture, industrial use, and environmental conservation (OECD, 2016). Figure 1. depicts the typical water cycle in the urban area starting from the precipitation and ending up at the effluents from wastewater treatment plant.

Figure 1. Urban water cycle (Argyle Water Supply Corporation, 2016)

UWS can be subdivided into four main groups – water supply, wastewater management, stormwater management and water conservation (Figure 2.).

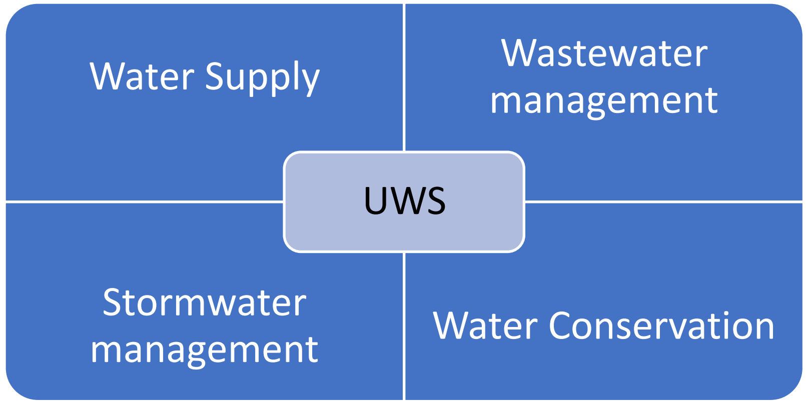

Figure 2. Water sector subdivisions diagram

Water supply

Water supply is a subdivision of the water sector that involves the extraction, treatment, and distribution of freshwater to meet the demands of domestic, industrial, and agricultural users. The primary objective of water supply is to provide clean and safe water to the users while ensuring the sustainability of water resources. The demand for freshwater has been increasing worldwide due to population growth, economic development, and climate change, therefore, the sustainable management of freshwater resources is essential to ensure the availability of water resources for future generations (Otaki , et al., 2022).

Wastewater management

Wastewater management is another crucial subdivision of the water sector that involves the collection, treatment, and disposal of wastewater from domestic, industrial, and commercial sources. Wastewater management plays a significant role in protecting public health, the environment, and water resources. The improper management of wastewater can have severe consequences, such as water pollution, the spread of diseases, and the depletion of water resources. (de Walle, et al., 2023).

Stormwater management

Another part of the water sector is stormwater management that involves the management of rainwater runoff to prevent flooding, erosion, and water pollution in urban areas; it is an essential element in urban areas, where impervious surfaces such as pavements and buildings reduce the infiltration of rainwater into the soil, resulting in high volumes of runoff. The sustainable management of stormwater involves the adoption of green infrastructure, such as rain gardens, green roofs, and permeable pavements, which mimic natural processes to infiltrate, store, and treat stormwater. The use of green infrastructure not only enhances the sustainability of stormwater management but also provides several co-benefits such as urban heat island mitigation, air quality improvement, and biodiversity conservation (Xu, et al., 2023).

Water conservation

Water conservation section involves the adoption of measures to reduce water consumption and its wastage. Water conservation is essential in regions with water scarcity, where the demand for water exceeds the available water resources. As population growth, urbanization, and climate change place increasing pressure on water resources, conserving water becomes crucial to meet the growing demands for domestic, agricultural, and industrial use (Xu, et al., 2023).

2.1.1 Need for sustainability in UWS

Sustainability in broader terms is a complex concept that involves balancing social, economic, and environmental considerations to ensure the continued well-being of present and future generations (Intergovernmental Panel on Climate Change (IPCC), 2018). The United Nations (UN) defines sustainable development as a process of achieving economic, social, and environmental sustainability goals that can meet the needs of the present generation while ensuring that future generations can also meet their own needs. It is a long-term approach that seeks to create an equitable society (United Nations, 1987).

Presently the global urban water sector faces several challenges that must be addressed in order to achieve sustainable development (The World Bank, 2021). The following bullet points are the key issues and challenges related to sustainable development in the water sector according to United Nations and World Bank research:

Water Scarcity and Quality

> Water scarcity and water quality are major challenges in many parts of the world, particularly in developing countries. According to the United Nations, more than two billion people lack access to safe drinking water, and over four billion lack access to adequate sanitation facilities. Climate change is exacerbating these challenges, with droughts and floods becoming more frequent and severe (UNESCO, 2021).

Infrastructure and Investment

> The development of adequate infrastructure and investment is crucial for ensuring sustainable water management. In many countries, particularly in developing

countries, water infrastructure is inadequate, and there is a lack of investment in the sector. This results in inadequate access to water and sanitation facilities, as well as inefficient use of water resources (The World Bank, 2021).

Governance and Institutions

Effective governance and institutions are an essential part for achieving sustainable water management, especially in urban areas where water demands are high and water resources are often limited. Good governance in the urban water sector involves the coordination of various stakeholders, including government agencies, water utilities, civil society organizations, and private sector actors, to ensure that water resources are managed in a sustainable and equitable manner (UNESCO, 2021). However, analogous to the capital investments challenges in water sector, some countries, even developed ones, have governance issues related to poor water management, inappropriate institutional arrangements, corruption and insufficient human capacity (SIWI (Stockholm International Water Institute), 2023).

Addressing these challenges requires an integrated approach that considers the interdependencies between water, energy, and food systems. This approach is reflected in the United Nations Sustainable Development Goal 6 (SDG 6), which aims to ensure access to clean water and sanitation for all, as well as to improve water management and reduce pollution and water-related disasters (UNESCO, 2021).

2.1.1.1 United Nations Sustainable Development Goals

To cope with the uprising challenges United Nations have developed a uniform package of long-term development goals for humanity worldwide. The Sustainable Development Goals (SDGs) which are a set of 17 goals (United Nations, 2015) (Figure 3), were adopted by the United Nations General Assembly in 2015 as part of the 2030 Agenda for Sustainable Development. The SDGs are intended to "end poverty, protect the planet, and ensure that all people enjoy peace and prosperity" by the year 2030 (United Nations, 2023).

Figure 3. UN Sustainable Development Goals infographics (United Nations, 2015)

In terms of water sustainability, SDG 6 focuses on Clean Water and Sanitation, specifically targets the urban water sector, as it aims to ensure the availability and sustainable management of water and sanitation for all.

SDG 6 works as the main target and rigid foundation for the regulation policies and frameworks around the globe and especially in the European Union (EU). EU adopted the European Union Water Framework Directive (WFD) back in the beginning of the 2000s and proposes the protection of Europe’s water resources, including rivers, lakes, groundwater, and coastal waters and the main goal of the directive is to achieve "good water status" in all EU waters by 2027 (European Commission, 2023). The framework requires member states to monitor water quality and quantity, identify and prioritize measures to improve water quality and quantity, and develop river basin management plans to achieve the objectives of the WFD (European Commission, 2023).

One of the key requirements of the WFD is the management of urban wastewater. The Urban Wastewater Treatment Directive, which is a part of the WFD, requires member states to ensure that urban wastewater is collected and treated before it is discharged into the environment. The directive sets out specific requirements: treatment standards for wastewater treatment facilities, monitoring and reporting of the processes, up-to-date treatment techniques, nutrients removal and sludge management (Halleux, 2023).

Moving forwards, another important aspect of the WFD is the management of urban runoff or stormwater management. Urban runoff is the water that flows over urban surfaces, such as streets and rooftops, during rainfall events. It can be a significant source of pollution to water resources, as it can pick up pollutants from the urban environment, such as heavy metals, nutrients, and pathogens (Andersson, et al., 2012).

2.1.1.2 Finland and Estonia

Finland and Estonia being both members of the EU and are therefore subject to the requirements of the WFD and other EU water directives. To meet the water regulation requirements, both countries have developed comprehensive legislation approach for the management of water resources, which include the Water Act in Finland and the Water Act in Estonia. These acts set out the regulatory framework for the use and management of water resources, including the licensing of water use and the monitoring of water quality.

In addition to the requirements of the WFD, both Finland and Estonia have developed national water strategies to guide the management of water resources in their respective countries. These strategies provide a comprehensive framework for sustainability within water industry, considering the needs of all stakeholders, water utilities and end users. The strategies set out specific objectives and measures to achieve these goals, such as improving water efficiency in the urban sector, reducing pollution from agricultural activities, and promoting the use of green infrastructure to manage urban runoff (Riigikogu, 2020; Finnish Ministry of the Environment, 2023).

2.1.2 Importance of sustainable performance assessment in UWS

Sustainable performance assessment (SPA) plays a critical role in evaluating and promoting the long-term viability and environmental, social, and economic impact of various activities, including urban water sectors. It helps to measure and analyse the performance of water management practices and identify areas for improvement, leading to more sustainable and resilient systems.

Firstly, SPA is crucial as it helps to evaluate the water sector's environmental footprint, identify areas of concern, and develop strategies to minimize negative impacts. Moreover, it enables the identification of opportunities for future improving resource efficiency within the industry. This can lead to reduced energy consumption, minimized water losses, and improved overall resource efficiency. SPA also helps to identify vulnerabilities and risks within the urban water sector, including the impacts of climate change, population growth, and urbanization. Strategies can be developed to enhance the sector's resilience and adaptability, ensuring the provision of reliable and sustainable water services even in changing conditions (Opher, et al., 2019).

Secondly, it does consider social aspects such as access to clean and affordable water, its affordability, and social equity in service provision. By addressing these social considerations, the assessment ensures that water services are not only environmentally and economically sustainable but also socially just and inclusive (Juwana, et al., 2012).

Apart from social aspects, assessing the economic viability of the urban water sector helps to estimate the financial sustainability of water management practices. It considers the costs and investments associated with infrastructure development, operation, and maintenance, as well as the economic benefits derived from sustainable water management (Juwana, et al., 2012). This information allows to guide investment decisions, ensuring the long-term financial viability of the sector. Ultimately, sustainability assessment provides a solid foundation for policy development and decision-making processes (Pearsall & Pierce, 2010).

3. Methodology

The following section provides a detailed overview of the steps undertaken to develop the sustainability performance assessment framework which will enable to study the urban water sectors of Tallinn and Helsinki. It should be noted that the main difficulty during the framework development was to establish the boundaries of the researched system, since the amount of data and quantity of factors which affect the sustainable functioning of the urban water sector is exceptionally large and their interconnection is extraordinarily complex.

During data gathering, a content analysis method was utilized to examine various official sources, including but not limited the water and environmental organization's annual environmental and financial reports, governmental sustainability reports, annual statistical statements and City Council's strategical documents, and the OECD (Organization for Economic Co-operation and Development) database. In addition to that, significant amount of examined scientific papers were accessed through https://www.sciencedirect.com/ and https://www.researchgate.net/. The proposed research methodology flow used during this research is shown in Figure 4.

To structure the work during the framework development, a multidisciplinary approach was adopted, involving the expertise of various scientific monographs in the realm of urban water systems. The study of Boldrin & Formiga (2023) proposed an informative table of analyzed publications along with their objectives and main results. Most of the sources mentioned in the table, namely Sambito & Freni (2017), Xue et al. (2019), García-Sánchez & Güereca (2019), Boldrin et al. (2022) were used as an example for the development of the framework utilised within the following research. Table 1 summarizes the examined monographs, with their objectives and brief conclusions, that correlate with the topic of research.

It must be noted that the study of Sahely et al. (2005) served as a solid foundation for the sustainability criteria definition and sustainability indicators design. The study itself lingered more on approaches on how to measure sustainability and what principal challenges rise up during the advent of sustainability paradigm. Although this paper was done back in 2005, it still serves as a notable example of sustainability criteria development; it does provide methodological hints which are relevant to this day.

Table 1. Studied sources for the development of framework (adapted from Boldrin & Formiga 2023)

Source	Name	Objective of the article	Main results
Sahely et al. (2005)	Developing sustainability criteria for urban infrastructure systems. Case Study of Toronto	'Develops a framework for sustainability assessment of urban infrastructure systems.'	A group of sustainability measures and sub-measures are suggested, including environmental indicators such as electricity usage, chemicals, greenhouse gas emissions from wastewater treatment, and discharged treated effluent.
Lane et al. (2015)	The diverse environmental burden of city-scale urban water systems	'Assesses the life cycle of two urban-scale water systems to analyse their potential environmental impacts.'	Indirect environmental effects throughout the life cycle of urban water systems are heavily influenced by electricity consumption. This study indicates that a broader range of water supply options leads to a significant rise in energy usage by the system.
Sambito & Freni (2017)	LCA Methodology for the Quantification of the Carbon Footprint of the Integrated Urban Water System	'To quantify the carbon footprint of an integrated UWS using the LCA methodology'	The impact category evaluated reveals that water collection and treatment stages have the most significant impact, primarily due to high electricity consumption in pumping stations and water treatment facilities. The wastewater treatment plant also has a noteworthy contribution.
Xue et al. (2019)	Holistic analysis of urban water systems in the Greater Cincinnati region: (1) life cycle assessment and cost implications	Presents an environmental and economic life cycle analysis of a UWS in the Greater Cincinnati region (USA).	Compared to the effects of system operation, the infrastructure phase had minimal environmental consequences. The discharge of treated wastewater and power usage from the sewage treatment plant has a substantial impact on the analysed environmental effects.

García-Sánchez & Güereca (2019)	Environmental and social life cycle assessment of urban water systems: The case of Mexico City	‘Evaluates and analyses the environmental and social performance of Mexico City’s water system through an LCA.’	The environmental impact of water distribution was found to be the most significant, primarily due to the high energy consumption during pumping. The study also assessed the positive environmental impact of the sewage treatment plant's nutrient removal operation, which prevented adverse environmental effects.
Landa-Cansigno et al. (2020)	Performance assessment of water reuse strategies using integrated framework of urban water metabolism and water-energy-pollution nexus	‘Explores the impact assessment of water reuse strategies in UWSs (Urban Water Sector) using the integrated urban water metabolism assessment framework and the water–energy–pollution nexus.’	The impact of all stages of the system on GHG emissions is intricately linked to the consumption of fossil fuels and electricity, as well as the consumption of chemicals. The discharge of nutrients from the sewage treatment plant has the most significant impact on the eutrophication category.
Boldrin et al. (2022)	Measuring the environmental performance of urban water systems: a systematic review	‘To evaluate the environmental performance of an integrated water supply and wastewater treatment system that employs a lagooning system for wastewater treatment.'	The water collection and wastewater treatment stages have the most significant impact on the environmental consequences of the analysed system. The primary drivers of these impacts are electricity consumption, chemical usage, and gas emissions from the sewage treatment plant.

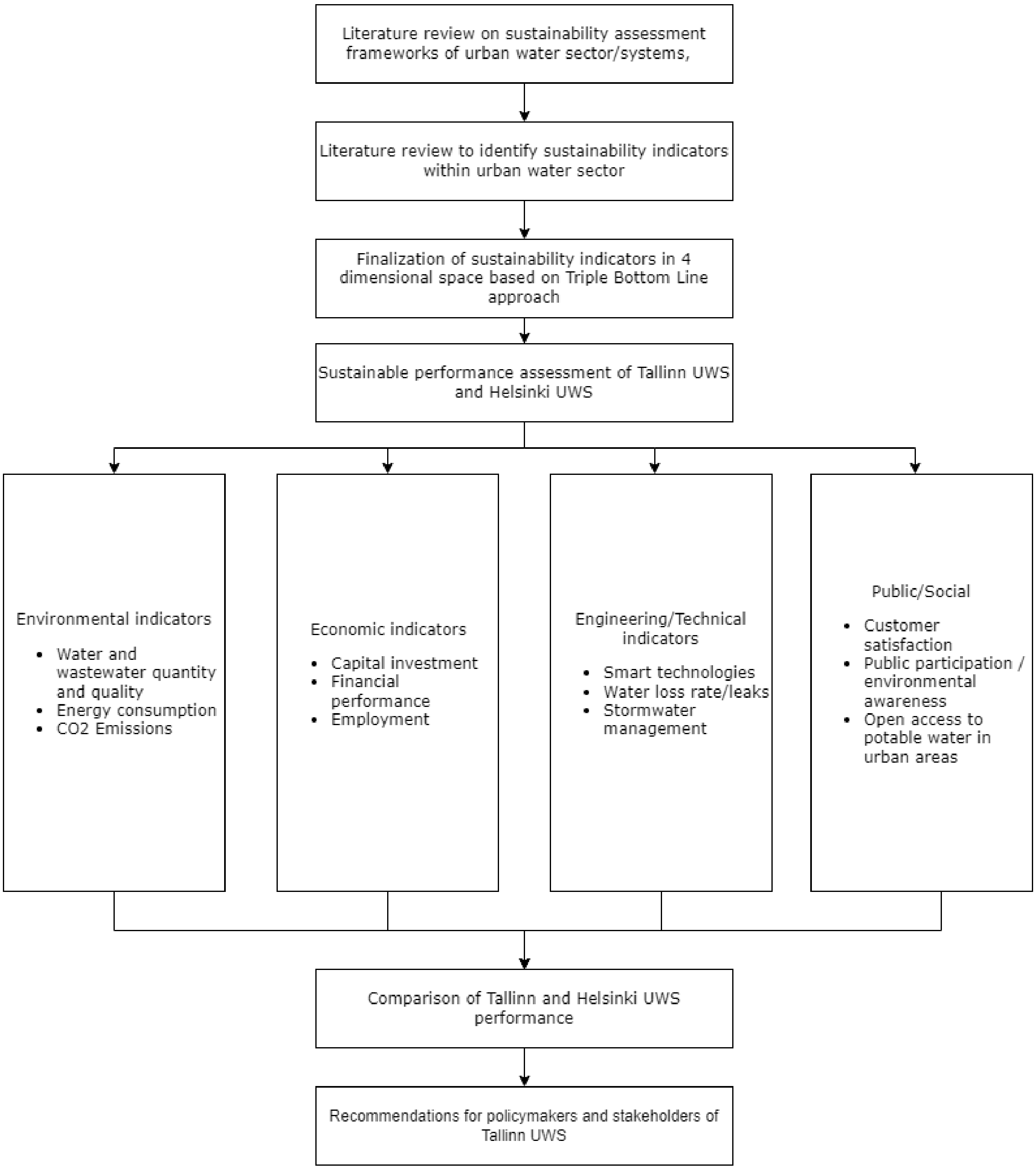

Figure 4. Methodology flow diagram depicting the development process of sustainable performance assessment framework (SPAF)

3.1 Sustainable Performance Assessment Framework (SPAF)

3.1.1 Goal and system boundaries

The primary goal of the case studies was to examine the linear development of the urban water sector in Tallinn and Helsinki for the past 10 years and evaluate the current state of it by using selected sustainability indicators proposed in the methodology part. The first step in developing the framework was to define the assessment objectives and the system's scope to be studied. This involved identifying the relevant stakeholders, such as water providers, regulators, and customers. In the research conditions, the key stakeholders involved in the development, performance and maintenance of urban water sector are local City Council and general water utility company.

As it can be seen from Figure 6, which illustrates the water flow within the urban water sector system, encompassing both the water supply and wastewater systems, and demonstrates the interrelationships between environmental, economic, engineering, and social sustainability objectives, as influenced by factors such as population growth, water demand, and water flow.

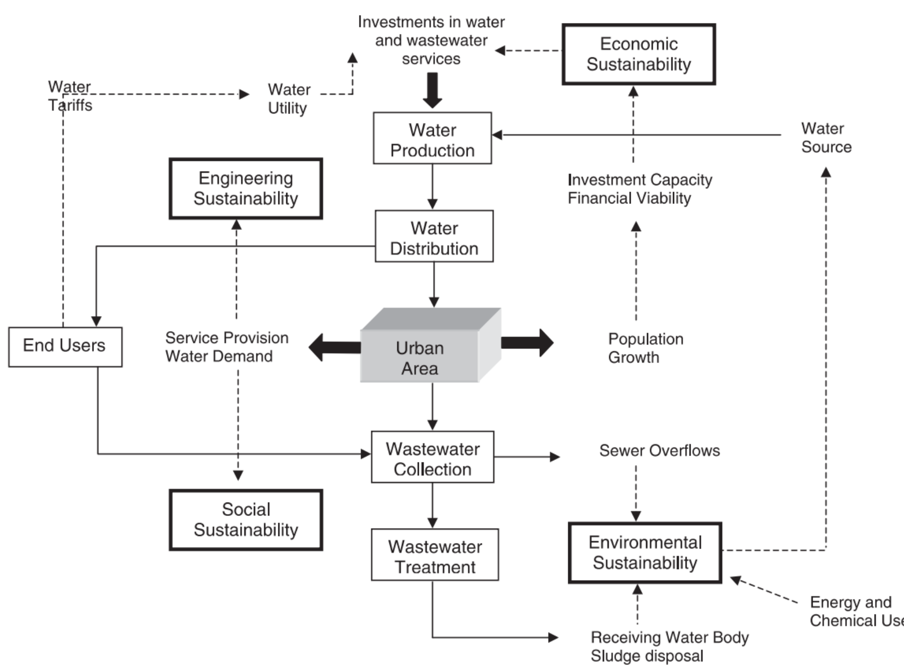

Figure 6. Urban water sector system. Solid lines represent water flows, and broken lines represent relevance to sustainability (adapted from Sahely et. al 2005).

In the economics terms, the financial sustainability of the urban water sector is dependent on the water tariff/price formation system, which is determined by water usage, and thus affected by factors such as population growth and climate related challenges. The ability to invest in the system is also influenced by the macroeconomic conditions in the urban area and the governmental investment policies (Sahely, et al., 2005).

Achieving environmental sustainability goals is intricately linked to water consumption, as facilities for water filtration and wastewater treatment require energy and chemicals which can have a significant environmental impact. The use of chemicals and energy contributes to the depletion of fossil fuel resources and results in the emission of greenhouse gases (GHG). Other environmental factors such as the discharge of biochemical oxygen demand (BOD), nitrogen, and phosphorus can also cause eutrophication[1] in the receiving water bodies (Sahely, et al., 2005).

In addition, the performance of the urban water system is significantly impacted by driving factors such as water demand, what means that the effectiveness of providing water services relies on the condition of the water and wastewater infrastructure, which in turn depends on timely maintenance, renovation planning and design. It is worth mentioning that the assessment framework was developed based on the triple bottom line framework. The triple bottom line (TBL) approach, as seen at Figure 7., recognizes that sustainable development requires the integration of economic, environmental, and social considerations, and seeks to balance these three dimensions of sustainability.

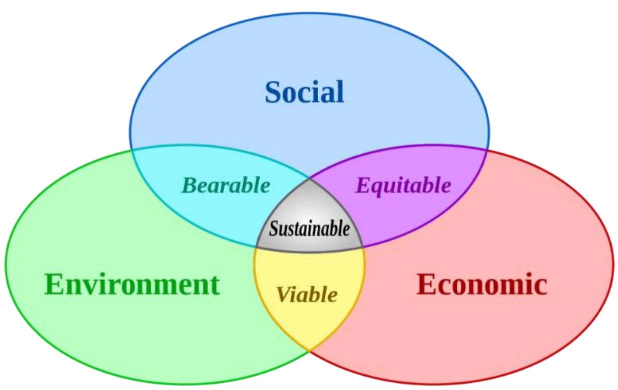

Figure 7. Triple Bottom Line framework diagram

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[1] Eutrophication is the natural or artificial process of nutrient enrichment, particularly nitrogen and phosphorus, in a water body such as a lake, river or coastal zone. This increased nutrient supply can cause excessive growth of algae, which can deplete the oxygen levels in the water as they die and decompose. This can result in the death of aquatic plants and animals, as well as the loss of biodiversity and ecosystem health (Britannica, 2023).

By adopting this framework, the assessment procedure was able to capture a more comprehensive and holistic understanding of the sustainability performance of the urban water sector. The use of the triple bottom line framework allowed for a more balanced and nuanced assessment of the sustainable performance of the urban water sector and provided a robust basis for developing recommendations for improvement.

The next step was to select the dimensions and indicators of sustainability to be included in the framework. This was based on a review of the relevant literature mentioned above, and consultation with the advisor to ensure that the selected dimensions and indicators were relevant, measurable, and reflective of their priorities. The four dimensions with subsequent indicators identified - economic, environmental, engineering, and public/social - were considered the most appropriate for assessing the sustainable performance of the urban water sector. An informative set of sustainability dimensions and indicators are outlined in Table 1 and in section below.

3.1.2 Dimensions and indicators

As mentioned above, the designed SPAF method uses a 4-dimensional matrix which allows to profoundly research the stated objectives. The following part will define all four dimensions with sustainability indicators more broadly and propose potential future use of this information.

3.1.2.1 Economic dimension

3.1.2.1.1 Capital investment and financial performance

The economic dimension concentrates on the analysis and discussion of capital investment and expenditures on fixed assets[2] as well as the overall financial performance of the water utility company in terms of sales revenue[3] and net profit[4]. The capital investment indicator helps to understand in which direction both the water company and the city itself are moving, whether enough funds are invested in updating and adapting existing infrastructures, whether

[2] 'The term fixed asset refers to a long-term tangible piece of property or equipment that a firm owns and uses in its operations to generate income. The general assumption about fixed assets is that they are expected to last, be consumed, or be converted into cash after at least one year (Kenton, 2022)'

[3] Sales revenue, also known as "revenue," is the amount of money a company generates from the sale of its products or services during a specific period of time (Hayes, 2023).

[4] Net profit, also known as "net income" or "earnings," is a financial metric that represents the amount of money a company has earned after deducting all expenses from its total revenue. It is the residual profit that a company earns after deducting all its operating expenses, taxes, interest payments, and other costs from its total revenue (Kenton, 2022).

it is planned to create new material foundations for sustainable development and adaptation to climate challenges or not.

3.1.2.1.2 Employment

The employment indicator was chosen to identify whether urban water sector serves as a contributor to the economic growth of the city and job creations. By monitoring changes in employment in the urban water sector, namely water utilities companies, this data can give insights into the economic impact of water infrastructure projects and make informed decision makers about investment, management, and expansion. This information can also be used to communicate the economic benefits of the water sector to policymakers, investors, and the public, which can help to build support for water infrastructure projects and ensure their long-term sustainability.

3.1.2.2 Environmental dimension

3.1.2.2.1 Water quantity and quality

The following aspect analyses the statistical data of how much water is extracted and treated from the water source of the city, and what amount of water is consumed by the urban customers. The section will also look at the effluent quality mainly the average pollution concentrations of wastewater in terms of Biological oxygen demand (BOD)[5], Chemical oxygen demand (COD)[6], Suspended solids, Total nitrogen (N_{tot}), Total phosphorus (P_{tot}), Oil products. This data might be useful for identifying trends and patterns in water usage and treatment, and for evaluating the effectiveness of water management strategies. It can also be used to monitor compliance with regulatory requirements and to identify areas where improvements are needed.

3.1.2.2.2 Energy Consumption of water utilities

Analyzing the energy consumption of water utilities and biogas production can provide valuable insights into the sustainability and efficiency of these systems. It must be noted that energy consumption is an important factor to consider when evaluating the environmental impact and cost-effectiveness of the processes involved. By evaluating energy consumption data, it is possible to outline areas where energy efficiency improvements can be made, such as through the use of more efficient pumps or the adoption of renewable energy sources in

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[5] Biological oxygen demand (BOD) is a measure of the amount of dissolved oxygen required by microorganisms in water to break down organic matter into carbon dioxide, water, and other inorganic compounds (Britannica, 2023).

[6] Chemical oxygen demand (COD) is a measure of the amount of oxygen required to chemically oxidize the organic and inorganic compounds in water (Hu & Grasso, 2005).

the future. Biogas production analysis aids to identify opportunities to optimize energy production and minimize waste.

3.1.2.2.3 CO_2 emissions of water utilities

Green House Gas (GHG) emissions' control and management is inevitibly one of the most crucial aspects of the sustainble functioning of water utilities' companies within urban water sector. GHG emissions drastically contribute to climate change, therefore by tracking and analysing these levels, it can help mitigate potential negative impacts related to water resources in the future. By analyzing CO_2 emissions data, it is possible to identify opportunities to reduce emissions and improve the sustainability of water management systems. This might include measures such as improving energy efficiency, using renewable energy sources, optimizing chemical and material use, and reducing water loss. This indicator will stress on the Carbon Dioxide (CO_2) emissions from wastewater plants, as being the primary greenhouse gas emitted through human activities (United States Environmental Protection Agency, 2023).

3.1.2.3 Engineering/Technical

3.1.2.3.1 Smart technologies

As the water industry constantly progresses and the regulations get stricker, the need for technological modernisation always come into place. This parameter was chosen to get the insights into how the sector develops in terms of top-end technologies which allow the water industry become more sustainable. These summaries might be useful for future investors, stakeholders and basically consumers for the understanding how the water systems and operations function with the smart-tech equipment.

3.1.2.3.2 Stormwater management

The stormwater management indicator was priotirized and put specifically into the engineening dimension because it serves as the main reactive subject against real time climate change related issues such as increased level of precipitation and flood risks. Effective management can help to reduce the impact of urban and suburban development on natural waterways by controlling the quantity and quality of stormwater runoff. This section will examine the availability of stormwater infrastructure in the urban areas and the need for their development. An emphasis will be made on the City Council strategical documents, reports and development programmes, with the illustrative drawings provided by the institutions.

3.1.2.3.3 Water loss rate/leaks

In the context of water utilities, the water loss rate/leaks indicator was chosen to show the efficiency of water distribution infrastructure of the water companies. High water loss rates can indicate inefficiencies in the distribution system, leading to increased costs and reduced availability of water resources. Furthermore, high water loss rates can also impact the quality of the water being distributed. When there are leaks or other inefficiencies in the distribution system, it can result in the infiltration of contaminants and pollutants into the water supply. The following information can be used by regulators and investors during decision-making processes.

3.1.2.4 Public/Social

3.1.2.4.1 Customer satisfaction

This indicator mostly addresses the customer satisfaction rate in terms of the quality of water utilities' customer service. Satisfied consumers are a big part of the sustainable functioning of the water utilities' companies as it indicates how successfully the water businesses operate. High customer satisfaction rates also indicate that water utility companies are effectively meeting the needs and expectations of their customers. This includes prompt response to customer inquiries and complaints, accurate billing processes, transparent communication, and reliable service provision. When customers feel that their concerns are being addressed and their needs are being met, it fosters a positive relationship between customers and water utility companies.

3.1.2.4.2 Public participation/ environmental awareness

Public participation and environmental awareness are critical components of effective environmental management and sustainable development. Public participation refers to the involvement of the public in decision-making processes related to environmental issues, including the development of policies, plans, and regulations, where environmental awareness refers to the knowledge, attitudes, and values that individuals and communities hold regarding the natural environment and their impact on it. This indicator will examine the city and water utilities companies contribute to providing environmental awareness to their customers and how do they engage the communities for more sustainable attitudes.

3.1.2.4.3 Open access to potable water in urban areas

Access to potable water is a basic human right, and it is essential for the health and well-being of individuals and communities. This indicator provides an insight into how many customers have access to clean water, i.e., connected to the water network. It is a crucial metric for policymakers and city planners to understand as it can inform decisions on where to allocate resources and funding to improve water access in underserved areas. Another aspect which will be included is the availability of public drinking water posts, namely their quantity around the city. Even the presence of public drinking water posts on the streets can have a significant impact on society as it helps to cope with climate related issues like excessive heat waves and drought.

Table 2 Sustainable performance assessment framework (SPAF)

Dimension	Sustainability Indicators	Description	Institutional engagement		Time span	Data Source
			City Council	Water Utility Company		
Economic	Capital investment and financial performance	Sales revenue, generated profit, capital investment	x	x	2011-2021	Water utilities annual reports, City council documents
	Employment	Number of employees in the utility company		x		
Environmental	Water and wastewater treatment	Quantity of consumed drinking water and quality of wastewater		x	2011-2021	Water utilities annual reports and other documents
	Energy Consumption of water utilities companies	How much energy consumed by the utility company and how much energy is produced from renewable sources such as biogas		x		
	CO2 emissions of water utilities	CO2 emissions of wastewater plants		x		
Engineering/Technical	Smart technologies	Smart technologies applied for the control of water resources	x	x	2011-2021	Water utilities company's annual reports, City council documents,
	Stormwater management	Flood management technologies, strategies	x			

	Water loss rate/leaks	Percentage of water leaks in the water supply network		**x**		Governmental modelling maps, other institutional papers
Public/Social	Customer satisfaction	Overall customer satisfaction in terms of drinking tap water		**x**	2011-2021	Water utilities company's annual reports, City council documents, other institutional papers
	Public participation/ environmental awareness	Public awareness and community engagement campaigns and strategies	**x**	**x**		
	Open access to potable water in urban areas	Number of customers that have access to clean water, number of public water taps around the city	**x**	**x**		

3.1.2.4.4 Case studies

Second stage of the research was to apply developed framework to the targeted cities and highlight the most important findings.

Tallinn, Estonia

For Tallinn case study, Tallinna Vesi AS papers from 2011 to 2022 and Public Water Supply and Sewerage Development Plans[7] of 2010-2021 and the most fresh strategic paper for 2023 – 2034 were utilized as the main source of information, however, several other reports such as *Water management infrastructure investment plan* of Estonian Environmental Agency, *Tallinn Sustainable Energy and Climate Action Plan 2030* paper by Tallinn Strategic Management Office, *Analyses and Action Plan Towards Sustainable Water Services in Estonia* document by OECD. Additionally, several AutoCAD drawings of proposed stormwater development systems within Tallinn area were also used as illustrations in the case studies.

Helsinki, Finland

For Helsinki's case study, the analysis of the urban water sector relied on various sources of information. The main sources utilized include *Helsinki Region Environmental Services Authority (HSY) environmental, sustainability and human resources reports* that offer detailed information on water supply and distribution, water treatment processes, customer service, infrastructure maintenance in Helsinki and overall functioning of the institution. Also, the analysis used different *Helsinki City Development Plans and statistics* which provide insights into priorities related to water management, infrastructure investments, and sustainability goals.

In addition to these reports, *copies of online maps* of proposed stormwater development systems within the Helsinki area and the locations of public water taps were utilized as illustrations in the case study. These drawings visually represent infrastructure plans and projects. It must be once again mentioned that the research area of the city of Helsinki was concentrated only on capital region.

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[7] In Estonian 'Tallinna ühisveevärgi ja -kanalisatsiooni arendamise kava 2010-2021'

4. Case Study: Tallinn, Estonia

4.1.1 Background of Tallinn and its urban water sector

Tallinn is the capital and largest city of Estonia, with a population of 458,373 people (ELVL, 2023), located on the northern coast of the country, by the Gulf of Finland. City belongs to the West Estonian watershed system. The main sources of drinking water for the city are Lake Ülemiste, whose natural catchment area is only 9.8 km^2 (Pedusaar, 2010). For this reason, additional water resources from the Pirita, Jägala, Soodla and Pärnu rivers are directed to Lake Ülemiste to maintain an optimal water level as it can be seen from the Figure 6 (Tallinn City Council, 2015).

City's water supply system in the service area covers more than 1,200 km of water pipes, which are supported by 22 water pumping stations and 46 ground water pumping stations equipped with 93 boreholes. The catchment area of the water supply system spans over Harju and Järva Counties and covers around 1,800 km2. The public sewerage system in the service area comprises over 1,187 km of wastewater network and 520 km of stormwater network, which are supported by 176 wastewater and stormwater pumping stations (Tallinna Vesi AS, 2022).

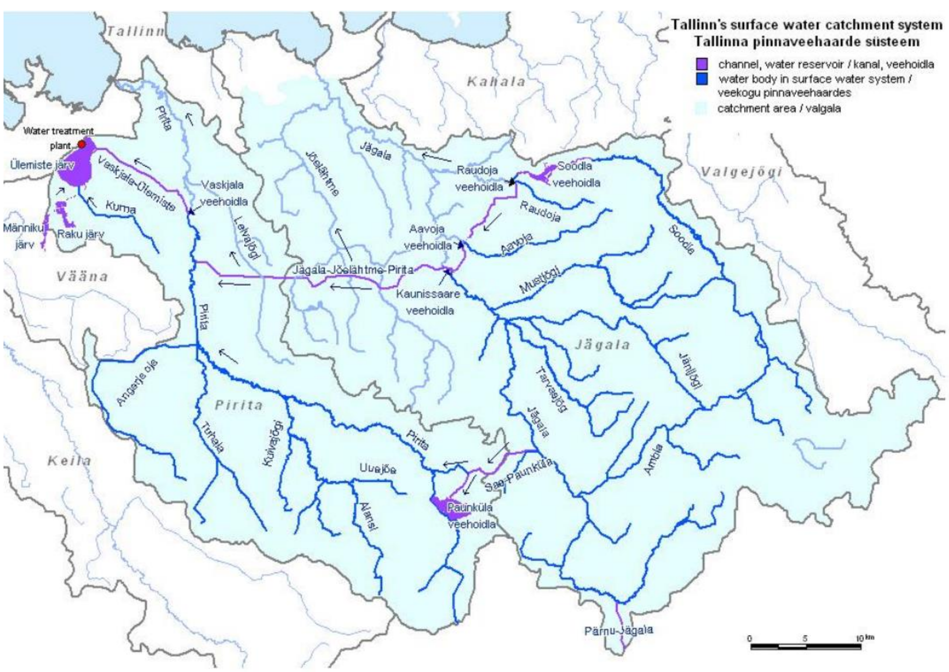

Figure 5. Surface water intake system of Tallinn (Tallinn City Council, 2015)

The main water utility company is Tallinna Vesi AS which is a public company based in Tallinn, Estonia, which provides drinking water supply and wastewater treatment services to the city of Tallinn and its surrounding areas. The company was founded in 1992 and was listed on the Tallinn Stock Exchange in 2005 (Tallinna Vesi AS, 2022).

Tallinna Vesi

Figure 6. Tallinna Vesi AS logo

Tallinna Vesi AS operates and maintains a network of water supply and sewerage pipelines, as well as a water treatment plant and several wastewater treatment plants. In 2022, company served over 24000 private customers and businesses and approximately 470,000 end consumers in Tallinn and its surrounding areas: City of Maardu, City of Saue, Harku Small Town and Saku Municipality. Tallinna Vesi AS has two water treatment plants - the Ülemiste water treatment plant and the Paljassaare wastewater treatment plant. The city has one surface water treatment facility and one wastewater treatment plant both located in the area of Tallinn (Figure 7).

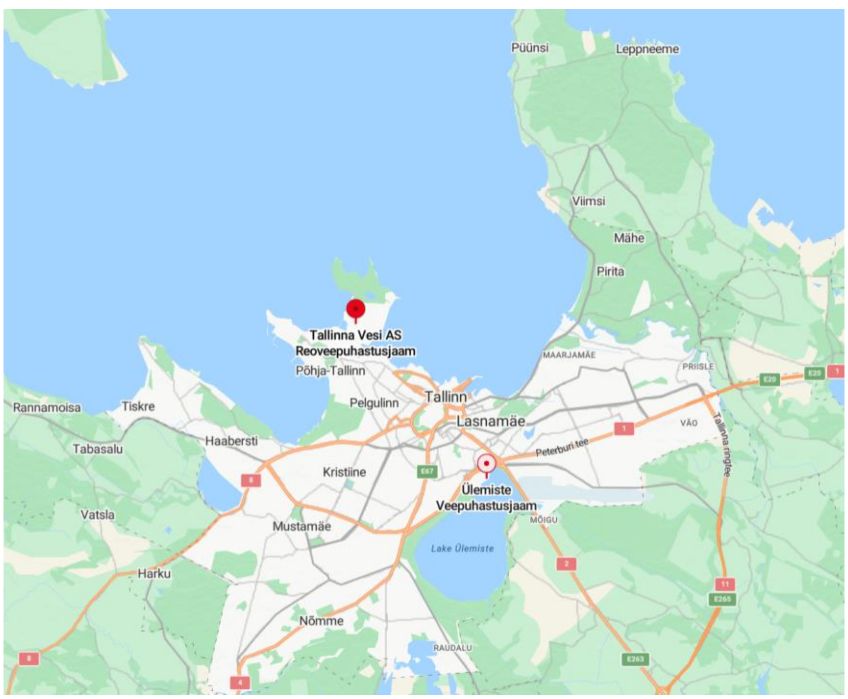

Figure 7. Illustrative locations of Tallinn water and wastewater treatment plants (source: Bing Maps)

4.1.1.1 Water Treatment Process

The water from Lake Ülemiste (Figure 9.) and the groundwater sources are treated at Ülemiste water treatment plant, which treats an average of 70,200m^3 per day (Tallinna Vesi AS, 2022).

Figure 9. Tallinna Vesi Water Treatment Plant at lake Ülemiste

The treatment process includes several stages, such as pre-treatment, coagulation, flocculation, sedimentation, filtration, and disinfection (Figure 9). During the pre-treatment stage, the raw water is screened to remove large particles such as leaves, twigs, and other debris. The coagulation and flocculation stages involve the addition of chemicals to the water to form flocs, which are then removed by sedimentation. The filtered water is then disinfected using chlorine, which kills any remaining bacteria and viruses (Tallinna Vesi AS, 2022).

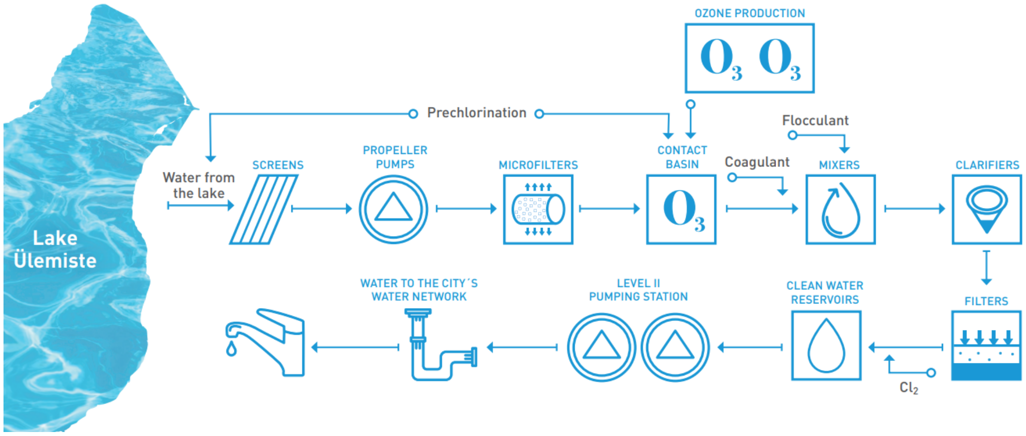

Figure 8. Water treatment process at Ülemiste Water treatment plant (Tallinna Vesi AS, 2022)

4.1.1.2 Wastewater Treatment Process

Figure 9. Paljassaare Wastewater treatment plant (Tallinna Vesi, 2023)

The city's wastewater treatment plant (WWTP) is located in Paljassaare and is one of the largest and most advanced wastewater treatment facilities in the Baltic region. The Paljassaare WWTP has a treatment capacity of up to 180,000 cubic meters per day and serves a population of over 400,000 people. The plant uses a combination of mechanical, biological, and chemical treatment processes to remove pollutants from the wastewater (Tallinna Vesi AS, 2022).

The treatment process begins with preliminary treatment, which involves screening and grit removal to remove large objects and debris from the wastewater. The wastewater then undergoes primary treatment, where suspended solids and organic matter are removed through sedimentation. Next, the wastewater undergoes secondary treatment, where biological processes are used to remove dissolved organic matter and nutrients. This process involves the use of activated sludge, which is a mixture of microorganisms that consume and break down the organic matter and nutrients in the wastewater. After secondary treatment, the wastewater undergoes tertiary treatment, where advanced treatment processes such as membrane filtration, UV disinfection, and chemical treatment are used to remove remaining pollutants from the water. The treated wastewater is then discharged into the Gulf of Finland (Tallinna Vesi AS, 2022).

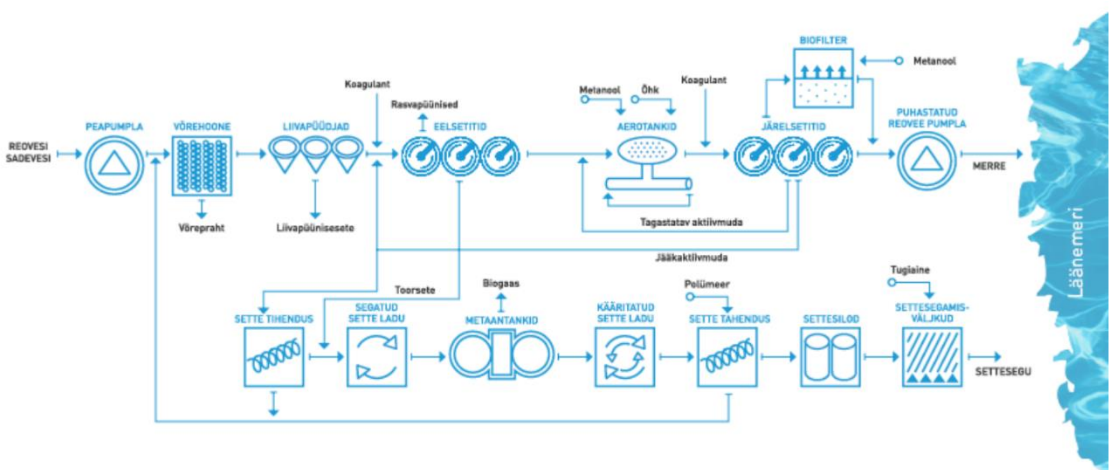

Figure 10. Wastewater treatment process at Paljassaare wastewater treatment plant (Tallinna Vesi AS, 2021)

4.2 Sustainability performance assessment

4.2.1 Economic Dimension

4.2.1.1 Capital investment and financial performance

The detection of financial efficiency of UWS as a whole is a very complicated task as it requires analysis of large amount of different data with different background. It was decided to narrow down the examination process only to general indicators of Tallinna Vesi AS, such as its sales revenue and net profit, in order to outline its economic sustainability. However, the investing activity of both, Tallinna Vesi AS and City Council were identified.

4.2.1.1.1 Financial performance

According to the financial statements of Tallinna Vesi AS for the past 10 years (Figure 11), the company's sales revenue has been consistently increasing until 2019, where it hit the point of €63.42 million which was the highest during the decade. This growth in revenue can be attributed to the increase in the number of customers and the increase in the tariffs charged by the company. However, because of the COVID-19 pandemic in 2020, the company’s revenue remarkably fell by approximately 18.5% just in one year. The decline in revenue was due to the decrease in water consumption by commercial and industrial customers, as many businesses were forced to close temporarily or reduce their operations (Tallinna Vesi AS, 2022).

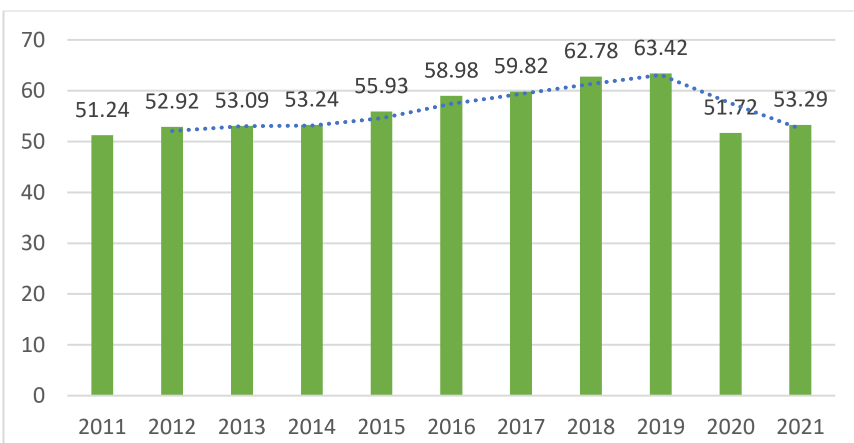

Figure 11. Total sales of Tallinna Vesi AS, € million (Tallinna Vesi AS, 2022)

On the contrary, the net profit trendline during the past decade was significantly fluctuating, with the lowest of €7.22 million in 2017 and highest of €27.76 million in 2019 respectively (Figure 12). Such a negative trend in 2017 can be attributed ‘to lower financial expenses mainly in relation to the positive change of the fair value of swap contracts[8] by EUR 0.89 million'.

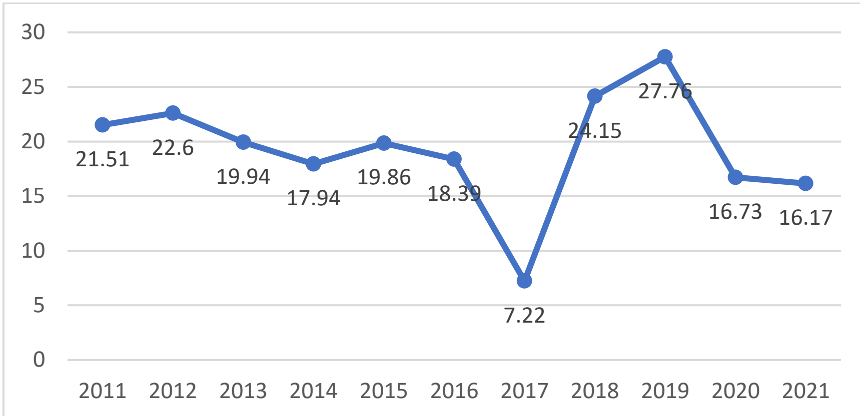

Figure 12. Net profit of Tallinna Vesi AS, € million (Tallinna Vesi AS, 2022)

Several other factors have affected Tallinna Vesi AS's financial performance over the past five years. One of the significant factors that affected the company was the tariff dispute with the Estonian Competition Authority. The dispute arose over the methodology used by the company to calculate tariffs for its services. This dispute had an impact on the company's financial performance, as it resulted in a decrease in revenue and a delay in tariff increases (Käi, 2017).

Another factor that has affected Tallinna Vesi AS's financial performance is its ongoing investments in upgrading its water and wastewater infrastructure. These investments are necessary to ensure that the company can continue to provide reliable and high-quality services to its customers. However, they also result in increased capital expenditure, which can put pressure on the company's financial performance in the short term (Tallinna Vesi AS, 2022).

4.2.1.1.2 Investments

The capital investment in water infrastructure is a part of its broader capital expenditure program of City of Tallinn. The specific amount allocated for water infrastructure development may vary from year to year. According to the City Council, the most important factors which affected investment planning are:

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[8] A swap is a derivative contract where one party exchanges or "swaps" the cash flows or value of one asset for another. For example, a company paying a variable rate of interest may swap its interest payments with another company that will then pay the first company a fixed rate (Chen, 2023).

1. Water and sewerage contracts between the City of Tallinn and Tallinna Vesi AS (so-called project contracts).
1. Between the City of Tallinn and various municipalities and Tallinna Vesi AS and other municipalities signed water and sewage contracts.
2. Directives of the European Union and laws of the Republic of Estonia, the deadlines set by them for water and to improve the quality of sewage services and meet environmental requirements.
5. Technical condition and working efficiency of water and sewage facilities.
6. Socio-economic aspects (consumer welfare and tariff policy).
7. Budget possibilities of Tallinn City Council (Tallinn City Council, 2010).

Investing activity within the water sector is predominantly managed by Tallinna Vesi AS and City Council, who have invested heavily in infrastructure over the years, including upgrades to its water treatment plants and distribution networks around the city (Tallinn City Council, 2010). Tallinna Vesi AS's investments were typically funded through a combination of government subsidies, private financing, and revenue from tariffs. Figure 13 depicts the investment activities of City Council and Tallinna Vesi AS. The graph shows that the considerable number of expenditures by City Council were done in the first part of the decade, while the water company increased the investing pace by the end of 2021.

It is worth noting that sustainable water infrastructure development requires long-term planning and investment to ensure reliable and efficient water supply and wastewater treatment. Therefore, both Tallinn City Council and Tallinna Vesi AS are expected to continue to invest in the development of water facilities in the future according to their annual reports and development plans (Tallinna Vesi AS, 2022).

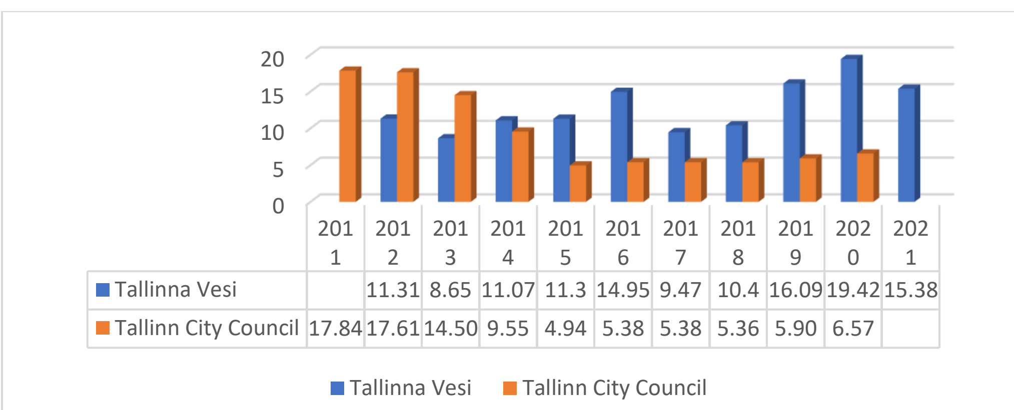


Figure 13. Investments in fixed assets in water sector by Tallinna Vesi AS and Tallinn City Council, € million (Tallinna Vesi AS, 2022;) (Tallinn City Council, 2022)

4.2.1.2 Employment

City of Tallinn’s strategic planning and its development policy of water supply and sewerage infrastructure gave the momentum to the construction of new projects, which accordingly created job opportunities for local residents during the 2011-2021 period (Tallinn City Council, 2010). These projects required a range of skills, from engineering and design to manual labour and machinery operation. Due to specificity and the high amount of construction work, it is hard to quantify the exact number of job places created during this period. However, it must be noted that this process had a positive impact on the market.

In addition to job creation in the construction sector, the water sector also provides employment opportunities in operations, maintenance, and management of WTP and WWTP. For example, Tallinna Vesi AS, for the past 8 years employed in a range of 300+ people in different roles, including engineers, technicians, customer service representatives, and administrative staff. These jobs provide stable employment opportunities for residents and contribute to the economic vitality of the city (Tallinna Vesi AS, 2020).

According to the Figure 14, a significant growth of employees' number over the past 4 years (2018-2021) can be witnessed. Such pattern can be explained by simultaneous increase of the investments in fixed assets by the company, including but not limited the upgrade of WTP and WWTP facilities, construction and modernization of the water and sewerage pipelines, leakage elimination procedures, etc (Tallinna Vesi AS, 2020).

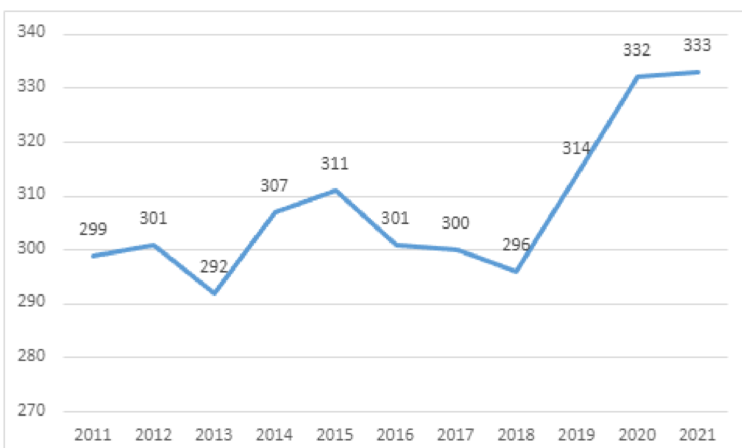


Figure 14 Number of Tallinna Vesi AS employees during 2011-2021

It must also be mentioned that beyond direct job creation, the water sector also has a multiplier effect on the economy. Access to clean water and improved sanitation can lead to a healthier workforce and increased productivity, which can have positive effects on other sectors of the economy. In this way, investments in the water sector can help to support broader economic growth and development.

4.2.2 Environmental dimension

4.2.2.1 Water quantity and quality

4.2.2.1.1 Water consumption

According to the statistics of Tallinn, daily per capita water consumption has increased since 2015, from 89 l/d to 94.9 l/d in 2021, with a peak level of 98.2 l/d in 2020. Peak levels of water consumption in 2020 can be explained by the COVID-19 pandemic lockdown and curfew regulations due to which people were intended to stay at home most of the time, what therefore contributed to the increased water consumption.

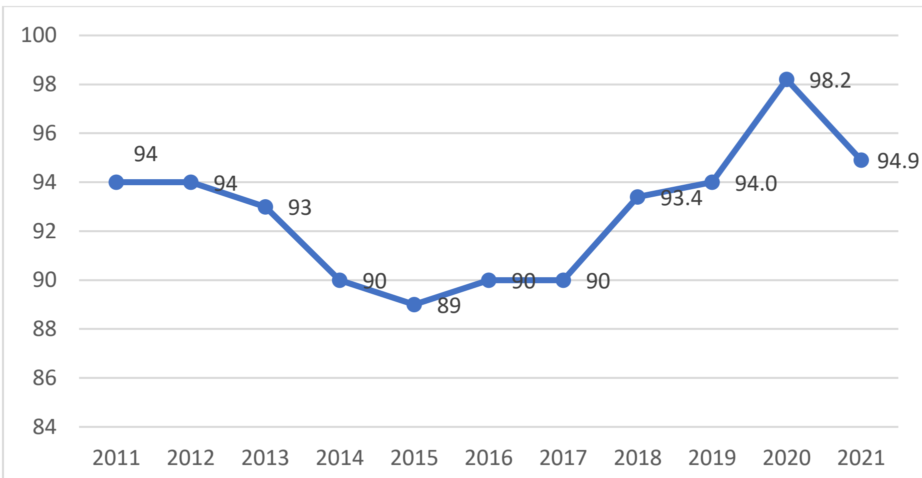


Figure 15 Average water consumption per capita in 2011-2021, l/d

4.2.2.1.2 Quality of wastewater

The quality of wastewater in Tallinn is considered to be good. Tallinna Vesi AS monitors the quality of the water supply and reports on it in their annual environmental reports. According to the most recent report, which covers the year 2021, the water quality in Tallinn met all national and European Union standards for drinking water. The report states that the water supply was free from any microbiological, chemical, or physical parameters that could pose a risk to human health.

Set of tables provided by Tallinna Vesi AS in the Error! Reference source not found. shows t he wastewater treatment plant's treatment efficiency in comparison with Helsinki. The charts depict data from 2011–2021-time frame. The overall efficiency of wastewater treatment of Tallinn is high, indicators such as BOD, COD and Nitrogen remain in the same range along the decade. On the contrary the treatment efficiency of oil products has notably increased what was caused by the upgrade of wastewater treatment plant at Paljassaare (Tallinna Vesi AS, 2021).

4.2.2.2 Energy Consumption of Tallinna Vesi AS

4.2.2.2.1 Electricity consumption

Tallinna Vesi's primary electricity consumption is dedicated to sustaining the functionality of its water and wastewater treatment plants and network pumping stations, which are crucial aspects of its core business activities. Despite considerable investments and efforts to minimize energy consumption over the years, electricity usage is still a crucial necessity to maintain business continuity. Consumption can be affected by fluctuations, changes in the scope of activities, and external natural factors. Starting from the latter half of 2021, Tallinna Vesi AS has committed to using only electricity generated from renewable sources for its facilities and production processes (Tallinna Vesi AS, 2021). Figure 16 shows the total electricity consumption of the Tallinna Vesi AS during the period of 2011-2021. Consumption has remained relatively stable for the past 6 years since 2016, which is a great indicator of the efficient using of the electricity power.

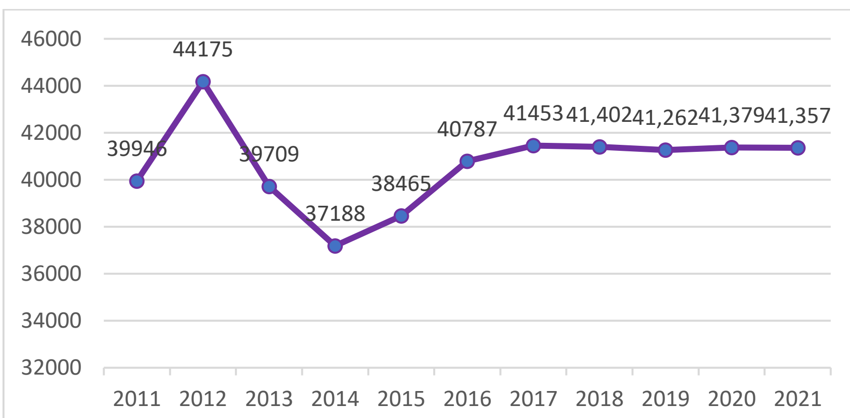


Figure 16. Total Electricity consumption of Tallinna Vesi AS in 2011-2021, MWh

4.2.2.2.2 Biogas production

Another additional aspect which was worth mentioning in Tallinn water sector is the biogas production. As the Tallinna Vesi AS is on the strong direction of becoming fully renewable, biogas use is a great marker of the sustainable functioning and can be a top priority index for future investments from aside. From Figure 17 a clear pattern of increasing biogas gas production can be witnessed. This data shows that Tallinn has made a significant contribution into becoming eco-friendly company which is adaptable for climate neutral conditions.

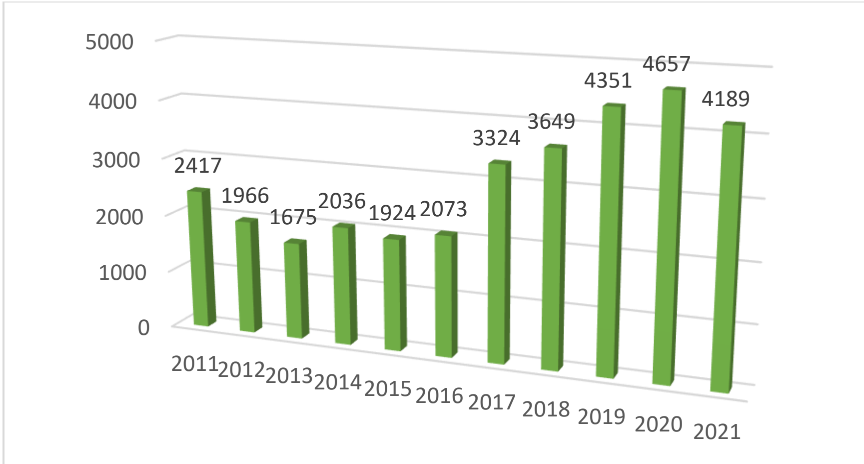


Figure 17 Biogas production by Tallinna Vesi AS 2011-2021, th m3

4.2.2.3 CO_2 Emissions

The carbon dioxide emissions from the wastewater plant in Tallinn have been notably increasing over the years. It can be seen from the Figure 18 how the levels of CO_2 emissions have exponentially grown from 2011 till 2021, with the highest number of 5715 tons in 2020, which value was almost beyond the limit. This trend raises concerns as it indicates a potential environmental impact and highlights the need for mitigation measures within the wastewater management system. It should be noted that several factors contribute to the notable increase in CO_2 emissions from the wastewater plant; one of the factors is surely the growing population and urbanization in Tallinn, which leads to an increase in wastewater generation. As the volume of wastewater increases, the treatment process requires more energy, resulting in higher carbon emissions (Tallina Vesi AS, 2016).

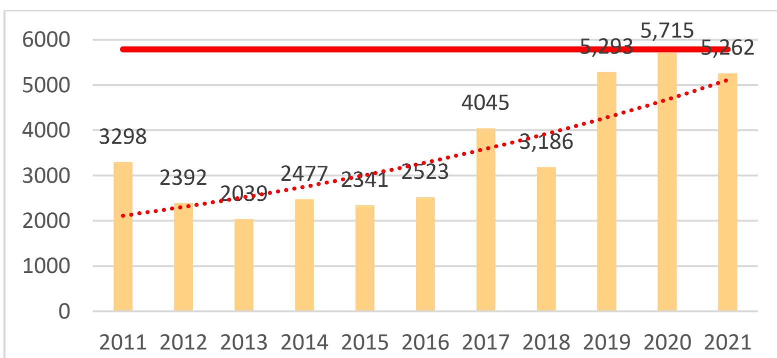


Figure 18 Carbon dioxide (CO_2) emissions at Tallinna Vesi WWTP (at the limit of 5789.49 t/yr)

4.2.3 Engineering Dimension

4.2.3.1 Smart technologies

One of the notable innovations that were taken into force by Tallinna Vesi is the installation of smart water meters. Telia Eesti AS, a technology company, was awarded a contract for the supply of smart water meters and the transmission of data through Telia's network in the city. The initial batch of smart meters was delivered in the beginning of 2022, and installation commenced by the end of the year. These smart water meters are being installed for both private individuals and businesses who have entered into a direct contract with Tallinna Vesi, the water utility company. Each year, new meters will be installed for customers whose water meters were last verified five years ago. By the end of 2026, the entire service area will be equipped with smart water meters, ensuring comprehensive coverage and accurate measurement of water consumption (Tallinna Vesi AS, 2022).

The implementation of smart water meters brings several benefits to both customers and Tallinna Vesi. These advanced meters provide real-time data on water consumption, enabling customers to monitor and manage their usage more effectively. By utilizing Telia's network and partnering with a technology company, Tallinna Vesi is leveraging innovation to enhance customer experience, promote water conservation, and ensure accurate billing based on actual water consumption (Tallinna Vesi AS, 2022).

Figure 19 Smart water meter adopted by Tallinna Vesi AS

4.2.3.2 Stormwater management

In Tallinn, stormwater sewage is managed through a system of pipes and infrastructure that collects and treats stormwater runoff before it is discharged into the sea. The city's stormwater sewage system is connected with its wastewater system, which handles sewage from toilets and other sources what puts extra pressure on the pipelines during the extreme weather events (Tallinn City Council, 2010). Although decent amount of work has been done in this direction, stormwater management in Tallinn still requires development and investment according to the City Council strategic plan. Figure 40 from the Appendices part depicts areas which require the construction or upgrade of the stormwater systems, which is a fair amount of area still to develop. The upgrade and development need to be extended to the districts of Mustamäe, Southwest regions of city and Pirita area (Tallinn City Council, 2023).

4.2.3.3 Water loss rate/leaks

According to the annual reports of Tallinna Vesi AS, the company has been actively working to reduce water leaks over the past decade. The company has implemented various measures and investments to improve the water distribution network and reduce water losses. In particular, Tallinna Vesi AS has invested in upgrading the aging water infrastructure and replacing old pipes, valves, and other equipment with more modern and efficient systems.

The results of these efforts are reflected in the data on water losses reported by Tallinna Vesi AS. According to the company's annual environmental reports, the level of water losses in the distribution system has steadily decreased over the past decade, from around 22% in 2011 to around 14% in 2020 (Figure 21). While there is still room for improvement, the reduction in water losses is seen as a positive trend for the city of Tallinn. It not only helps to conserve water resources but also ensures that the water distribution system is functioning effectively and efficiently, reducing the likelihood of service interruptions or disruptions due to leaks or other issues.

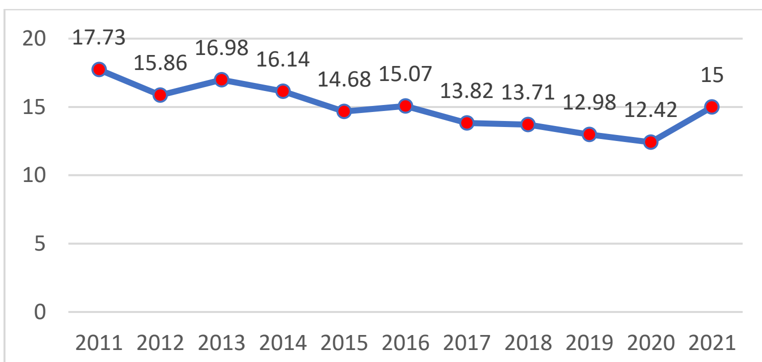


Figure 20 Leakage level in 2011-2021, %

4.2.4 Public/social dimension

4.2.4.1 Customer satisfaction

Tallinna Vesi AS primarily deals with the water customer satisfaction surveying every year and reveals these statistics in their annual reports. The objective of customer satisfaction research is to understand whether people tend to drink water from tap instead of other sources. By tracking the data from 2011 up to 2021 from annual environmental reports of Tallinna Vesi AS, it can be said that number of customers who prefer to drink tap water provided by the company has significantly risen since 48% in 2011 to the average values of

90% in the last 3 years (Figure 22). These results might be explained by the activities conducted by Tallinna Vesi AS regarding social and environmental awareness campaigns, public advertising about the stable superior quality of water and its availability in general. Overall, this is great evidence of sutstainable public attitude towards using tap water.

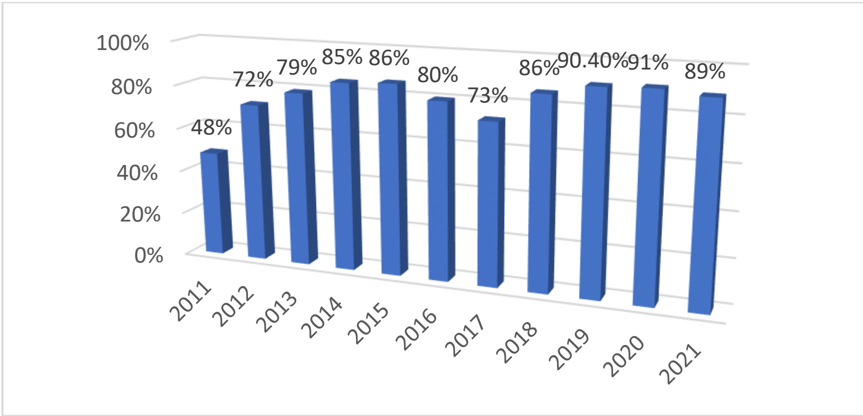


Figure 21 Customer satisfaction rate in drinking tap water, %

4.2.4.2 Public participation/environmental awareness

As mentioned above, over the past decade Tallinna Vesi AS has been committed to promoting environmental awareness and encouraging public participation in environmental protection initiatives. The company recognizes the importance of engaging with its customers and stakeholders to build trust and transparency, and to ensure that its activities align with the needs and values of the community.

One of the ways in which Tallinna Vesi AS has promoted environmental awareness is through its educational programs and initiatives. The company has collaborated with schools and other educational institutions to raise awareness about the importance of water conservation and protection and has provided educational materials and resources to help students and teachers learn about these issues. In addition, the company has organized events and campaigns aimed at promoting

Figure 22. Educational campaign in one of the Tallinn kindergartens provided by Tallinna Vesi AS , (Tallinna Vesi AS, 2017)

sustainable water use and raising awareness about the impact of human activities on the environment (Tallinna Vesi AS, 2017).

Tallinna Vesi AS and City Council have also worked to encourage public participation in environmental protection initiatives, through various channels such as public consultations and stakeholder engagement. The company recognizes that input and feedback from customers and stakeholders is important for identifying and addressing environmental concerns and ensuring that its activities are aligned with community values.

4.2.4.3 Access to potable water in urban areas

Access to potable water in urban areas of Tallinn is good, as the city has a well-developed water supply and distribution system managed by Tallinna Vesi AS. The company provides drinking water to over 460,000 customers in Tallinn and surrounding areas (Tallinna Vesi AS, 2022). Almost all parts of the city are connected to the central water grid what makes water resource accessible.

4.2.4.3.1 Public drinking water taps

City of Tallinn, in collaboration with Tallinna Vesi AS, has implemented the strategy of providing public drinking water taps across the city (Figure 24). This plan helps to make the city areas more environmentally friendly and adaptable for the extreme hot weather events during the summer months (Tallinna Vesi AS, 2021).

Figure 23. Public drinking water tap in Tallinn

Currently, Tallinn has thirty-eight taps (Figure 25) which are properly maintained and quality-checked every summer. However, it must be noted that with the increasing urbanization density and the uncertainty around extreme hot weather during summer months in place, the necessity for more water taps is crucial, therefore a development planning must be on track. From the map below it can be seen that the water taps are sparsely located in the residential areas of Mustamäe, Lasnamäe and Õismäe being densely populated regions where people tend to spend significant amount of time outside too, aside from city centre and beach areas.

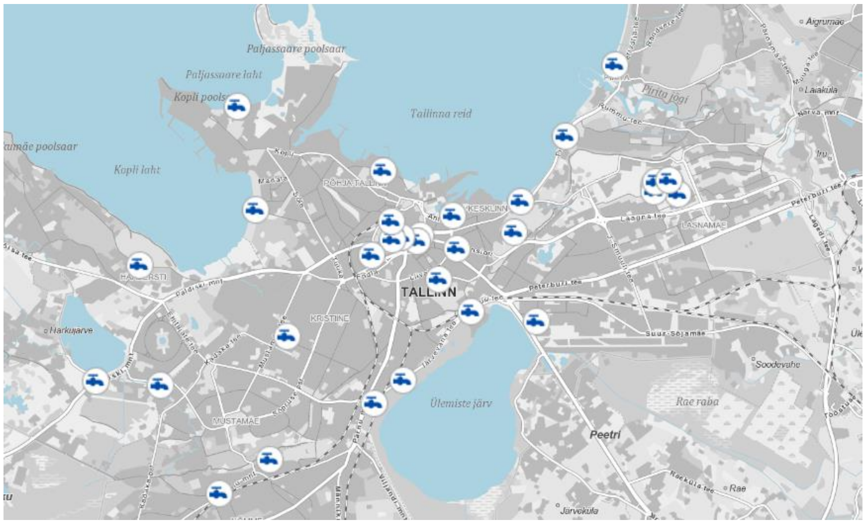


Figure 24. Location map of drinking water taps (source https://gis.tallinn.ee/portal/apps/webappviewer/index.html?id=6a4b405bc7b04c499e3673df5cf528f4)

5. Case Study: Helsinki, Finland

5.1.1 Background of Helsinki and its urban water sector

Helsinki is the capital and largest city of Finland, located on the southern coast of the country, by the Gulf of Finland. With a population of around 664 028 as of 2022, Helsinki is the most populous city in Finland and the center of the country's political, cultural, and economic activities. The average water consumption per capita in the city of Helsinki is around 113 liters per capita per day. This includes water used for household purposes such as drinking, cooking, washing, and cleaning, as well as for industrial and commercial purposes (HSY, 2022).

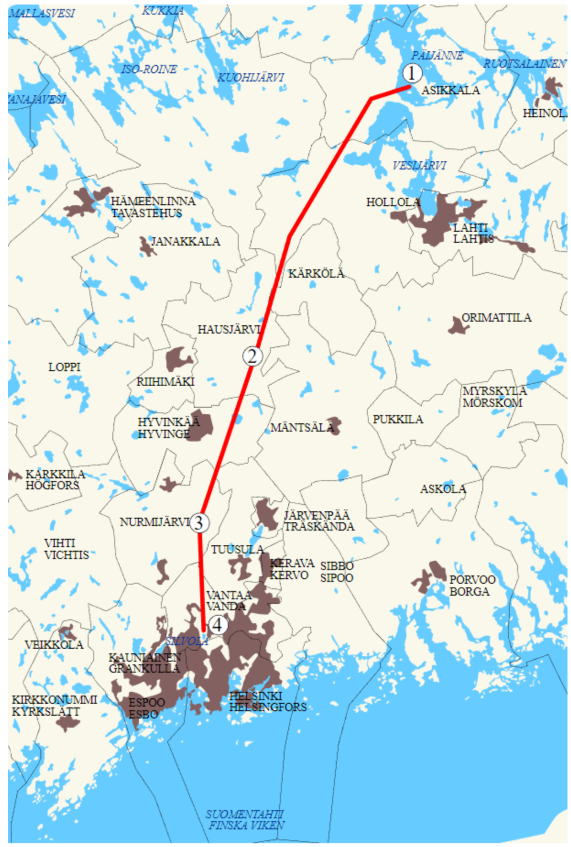


Figure 25. 'Map of the Päijänne Water Tunnel. 1. Asikkalanselkä 2. Kalliomäki water distribution station 3. Korpimäki water pump station 4. Artificial lake of Silvola' (Riv, 2020)

Helsinki Region Environmental Services (HSY) company manages Helsinki water resources. The Helsinki metropolitan area is served by two surface water treatment facilities, namely Pitkäkoski and Vanhakaupunki, both located in Helsinki. Additionally, a small number of residents in Vantaa receive their water supply from the Kuninkaanlähde groundwater intake plant. The raw water for both Pitkäkoski and Vanhakaupunki treatment plants is sourced from Lake Päijänne through a water tunnel located in Central Finland (as shown in Figure 26). The raw water travels along a 120-kilometer-long rock tunnel to reach the treatment plants (HSY, 2023).

5.1.1.1 Wastewater treatment

The wastewater treatment in the city is handled by four main plants, namely Viikinmäki, Suomenoja, Käppäselkä, and Blominmäki which is still under construction. The Viikinmäki plant is the largest and manages the majority of the city's wastewater, while the other three plants handle wastewater from specific areas of the city. The water supply and wastewater networks in Helsinki consist of thousands of kilometres of pipes and other infrastructure. The water supply network is primarily made up of steel and ductile iron pipes, while the wastewater network is made up of concrete pipes (HSY, 2023).

Figure 26. Viikinmäki wastewater treatment plant (credit: Risto Tuomarla)

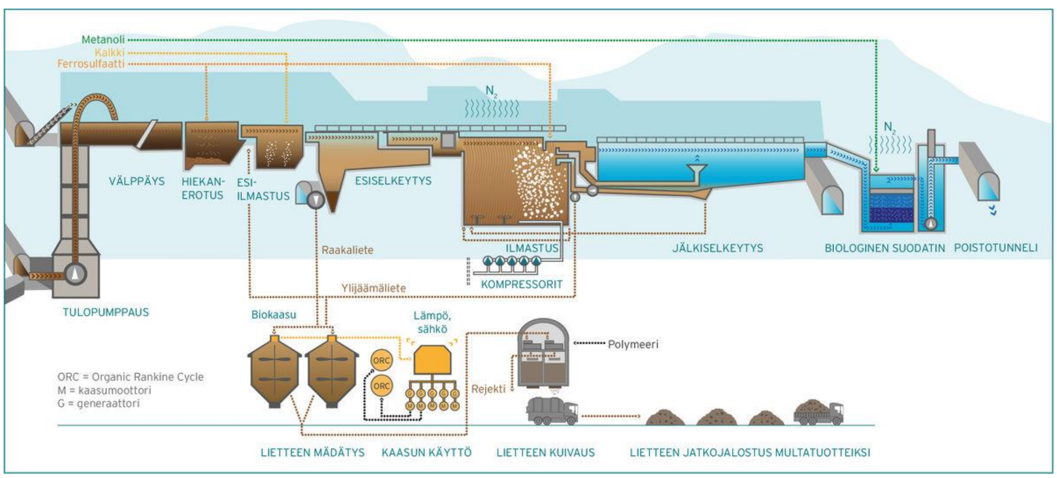


Figure 27 Wastewater treatment process at the Viikinmäki station (HSY, 2022)

5.2 Sustainability performance assessment

5.2.1 Economic Dimension

Unfortunately, data on the financial performance of the Helsinki water sector, including sales revenue, profit, and other financial indicators, for the past 10 years is not readily available. It is important to note that financial data of such nature may be subject to numerous factors, including data availability, reporting practices, and confidentiality considerations.

While it is unfortunate that specific financial performance data for the past decade is not accessible, it is worth highlighting that the Helsinki water sector is known for its strong financial management practices and commitment to ensuring the long-term sustainability of water services. The sector's financial stability is reflected in its ability to invest in infrastructure development, maintain high service standards, and attract investments from public and private sources. It is common for organizations and public entities to have specific guidelines and regulations regarding the release of financial data, particularly when it comes to sensitive information or commercial considerations. The lack of publicly available financial data may be due to these factors. However, in terms of investment activities HSY publicly holds records on their official website.

5.2.1.1 Capital investment and financial performance

Helsinki has made significant investments in its water sector to ensure the sustainable and efficient management of water resources and infrastructure. These investments have aimed to improve water quality, enhance wastewater treatment, strengthen stormwater management, and promote overall environmental sustainability (HSY, 2022). Some notable projects and statistics regarding investments in the Helsinki water sector include:

1. Water Supply Network Investments:
    - Helsinki has invested in the renovation and expansion of its water supply network to ensure reliable and high-quality water supply to its residents.
    - Over the past decade, Helsinki has invested an average of 50 million euros annually in water supply network improvements (HSY, 2022).
2. Wastewater Treatment Plant Upgrades:
    - Helsinki has allocated significant funds for the modernization and expansion of its wastewater treatment plants.
    - The Blominmäki plant expansion project cost around 70 million euros and included upgrades to enhance treatment capacity and improve environmental performance (HSY, 2023).
3. Stormwater Management Investments:
    - Helsinki has prioritized investments in stormwater management to mitigate the impacts of heavy rainfall and prevent urban flooding.

- The Marttila-Pitäjänmäki water network renovation project aimed to improve stormwater management infrastructure in the Pitäjänmäki district.
- The project involved the construction of new stormwater sewers and the renovation of existing systems to enhance their capacity and efficiency

As part of this commitment, HSY invested around EUR 200 million annually in the improvement, expansion, and repair of water services in the region. These investments play a crucial role in ensuring the availability of high-quality water supply, efficient wastewater treatment, and effective stormwater management (HSY, 2023).

5.2.1.2 Employment

The employment within the water industry in Helsinki has demonstrated relative stability over the past 10 years. However, it is worth noting that there has been a decrease in the number of employees from 510 in 2011 to 423 in 2021 respectively (Figure 29). While this decline in employment may raise concerns, it is essential to consider numerous factors that could contribute to this change. One explanation for the decrease in employment could be advancements in technology and automation within the water sector. As modern technologies and systems are implemented, they may streamline processes, increase efficiency, and reduce the need for a large workforce. Automation and digitalization in tasks such as data monitoring, analysis, and maintenance may have contributed to a more streamlined workforce. Another factor to consider is the potential impact of external factors such as economic conditions or organizational restructuring. Changes in funding, budget constraints, or strategic decisions within the water sector could result in adjustments to the workforce size (HSY, 2022).

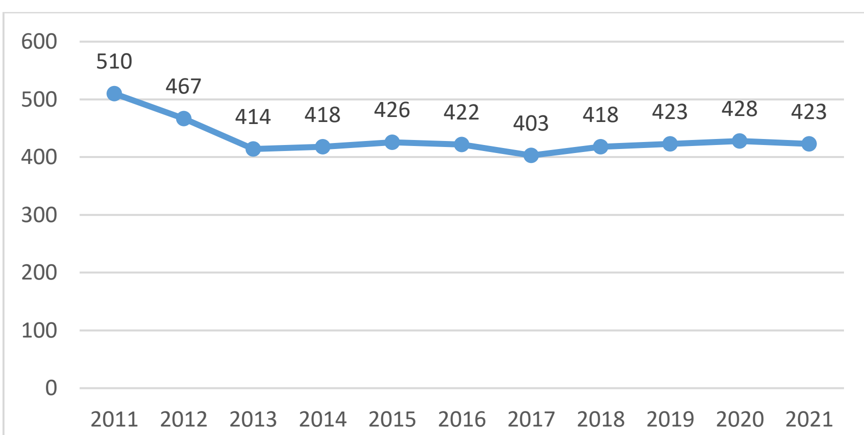


Figure 28 HSY Water sector employees' number during 2011-2021 (HSY Statitsics Department, 2023)

5.2.2 Environmental Dimension

5.2.2.1 Water quality and quantity

Daily per capita water consumption in Helsinki has significantly decreased since 2013, from peak levels of 122 l/d to an average of 108 l/d in 2021. Comparing with Tallinn, Helsinki has significantly higher water consumption rate, however, the pattern tends to lower down during the decade.

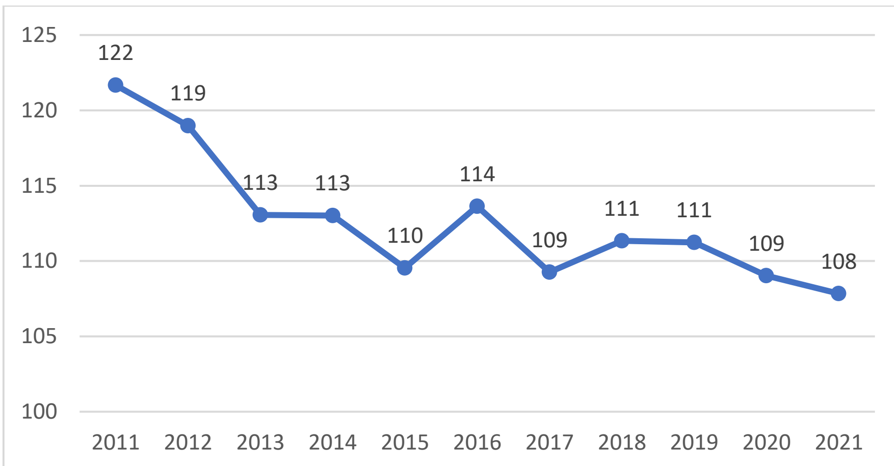


Figure 29. Average water consumption per capita in 2011-2021, l/d (HSY Statitsics Department, 2023)

5.2.2.1.1 Quality of wastewater

The quality of wastewater in Helsinki is identically considered to be good, even outperforming Tallinna Vesi AS. By using the set of tables provided by Tallinna Vesi AS in the Error! Reference s ource not found. it is possible to navigate the wastewater quality data from 2011–2021-time frame. The overall efficiency of wastewater treatment of Helsinki is higher than Tallinn ones, indicators such as BOD, COD and Nitrogen remain in the same range along the decade.

5.2.2.2 CO2 Emissions

The data obtained from HSY Statistical Department reveals a stable trend in CO_2 emissions, with a noticeable decrease observed from 2011 to 2021 (Figure 31). This reduction can be attributed to various factors, including the implementation of energy-efficient technologies, improved operational practices, and a growing emphasis on sustainability. However, it is important to note that there was a spike in CO_2 emissions in 2019, deviating from the overall decreasing trend. This sudden increase may have been influenced by various factors such as changes in operational conditions, maintenance activities, or fluctuations in energy sources. It highlights the need for continuous monitoring and assessment to identify and address such anomalies promptly.

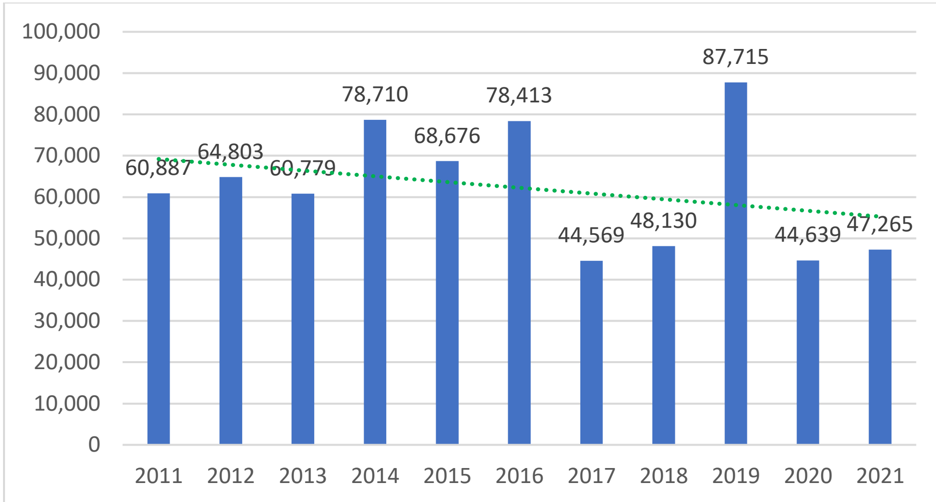


Figure 30. Combined CO_2 emissions from WWTPs in Helsinki, tons (HSY Statitsics Department, 2023)

5.2.2.3 Energy Consumption of HSY

HSY continuously strives to improve energy efficiency and implement innovative solutions to reduce energy consumption across its operations. The company employs various strategies and technologies to optimize energy usage and enhance overall sustainability. In terms of energy consumption, the water sector encompasses several key areas where energy is utilized. These include water treatment plants, wastewater treatment facilities, pumping stations, and distribution networks. Each of these components contributes to the overall energy consumption of HSY (HSY, 2022).

From statistical data obtained, Figure 32 shows decreasing trend of the energy consumption by HSY. The overall treatment processes become more ergonomic due to the investments into renovation and upgrade of the systems (HSY, 2022).

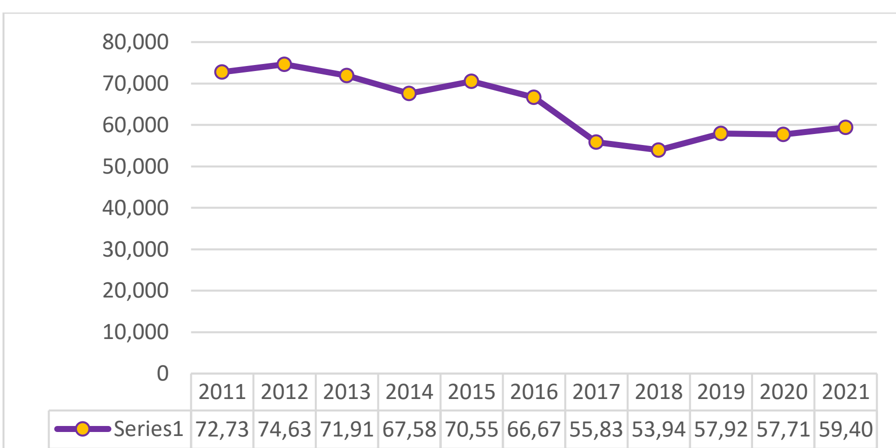


Figure 31. Total Electricity consumption of HSY in 2011-2021, MWh (HSY Statitsics Department, 2023)

5.2.2.3.1 Biogas production

In 2019, biogas production was 39073 thousand cubic meters which is the highest across the decade. From Figure 33 it is seen that Helsinki's biogas generation is increasing since 2011 as the company is seeking to become energy independent from the main grid (HSY, 2022).

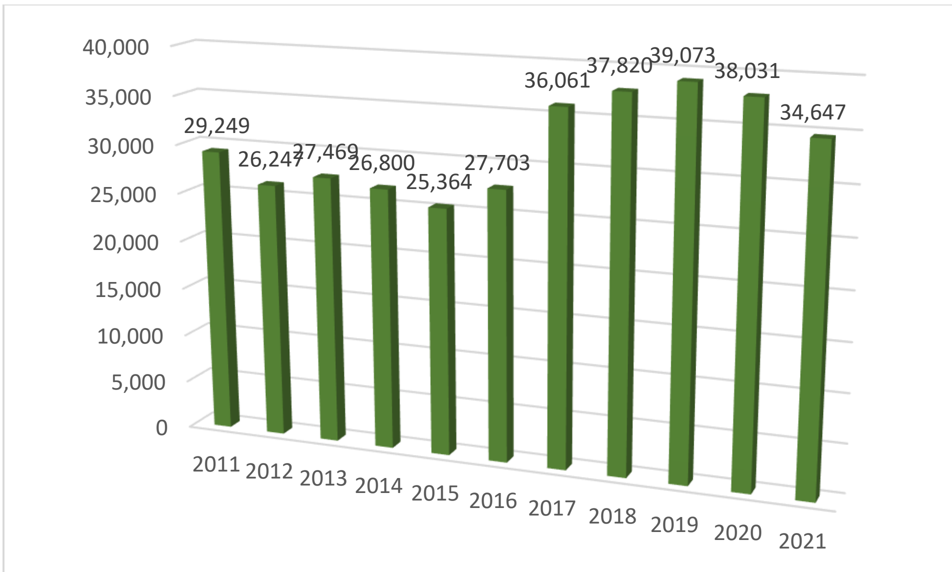


Figure 32. Biogas production by HSY, th m3 (HSY Statitsics Department, 2023)

5.2.3 Engineering dimension

5.2.3.1 Smart technologies

The Helsinki urban water sector has been actively incorporating smart technologies to enhance efficiency, sustainability, and the overall management of water resources. The city uses smart water meters, real-time monitoring, and control systems such as SCADA. Helsinki makes an emphasis on overall sustainable strategies by integrating the innovative technologies by monitoring the market. It is important to note that the specific smart technologies implemented in the Helsinki urban water sector may evolve over time, and modern technologies are continually being explored and adopted to enhance the efficiency and sustainability of water management practices in the city (HSY, 2022).

5.2.3.2 Water loss rate/leaks

Helsinki has implemented measures to address water loss and minimize leaks within its urban water systems. HSY continuously monitor and manage water loss to ensure the efficient use of water resources. Although, there was no statistics found concerning the water leaks within the city area of Helsinki, the general approach for managing the water leaks is highlighted. No major water leaks problems were addressed by the company in the annual reports.

It is known that HSY focuses on early detection and swift repair of leaks within the water distribution network. Regular inspections, monitoring systems, and advanced leak detection technologies are employed to identify and locate leaks promptly.

5.2.3.3 Stormwater management

The stormwater management strategy was conducted as part of the RAINMAN project, aimed at enhancing the adaptive capacity of cities in managing climate change impacts on stormwater volumes in urbanized areas (Kautto, 2021).

Figure 33. Fannynkallio residential area of Helsinki where the topography was designed so that surface waters are directed to the rain gardens

Nature-based stormwater management has gained traction in the Helsinki Metropolitan Area (HMA) due to national-level legislation and city-level programs. The stormwater working groups in the HMA cities play a crucial role in promoting and advancing nature-based solutions. Table 3 provides an overview of the stormwater management solutions proposed by HSY. It is worth noting that stormwater management solutions in the HMA cities often combine both "green" and "grey" infrastructure, resulting in hybrid approaches. Nature-based solutions offer various additional benefits beyond managing stormwater, including supporting biodiversity, enhancing aesthetics and recreation, and mitigating the urban heat island effect (Kautto, 2021). Figure 35 provides an illustration of Helsinki urban area in terms of stormwater management areas, where blue regions indicate sstormwater sewerage area, grey ones combined sewerage zone and brown areas to which stormwater sewerage needs to be extended.

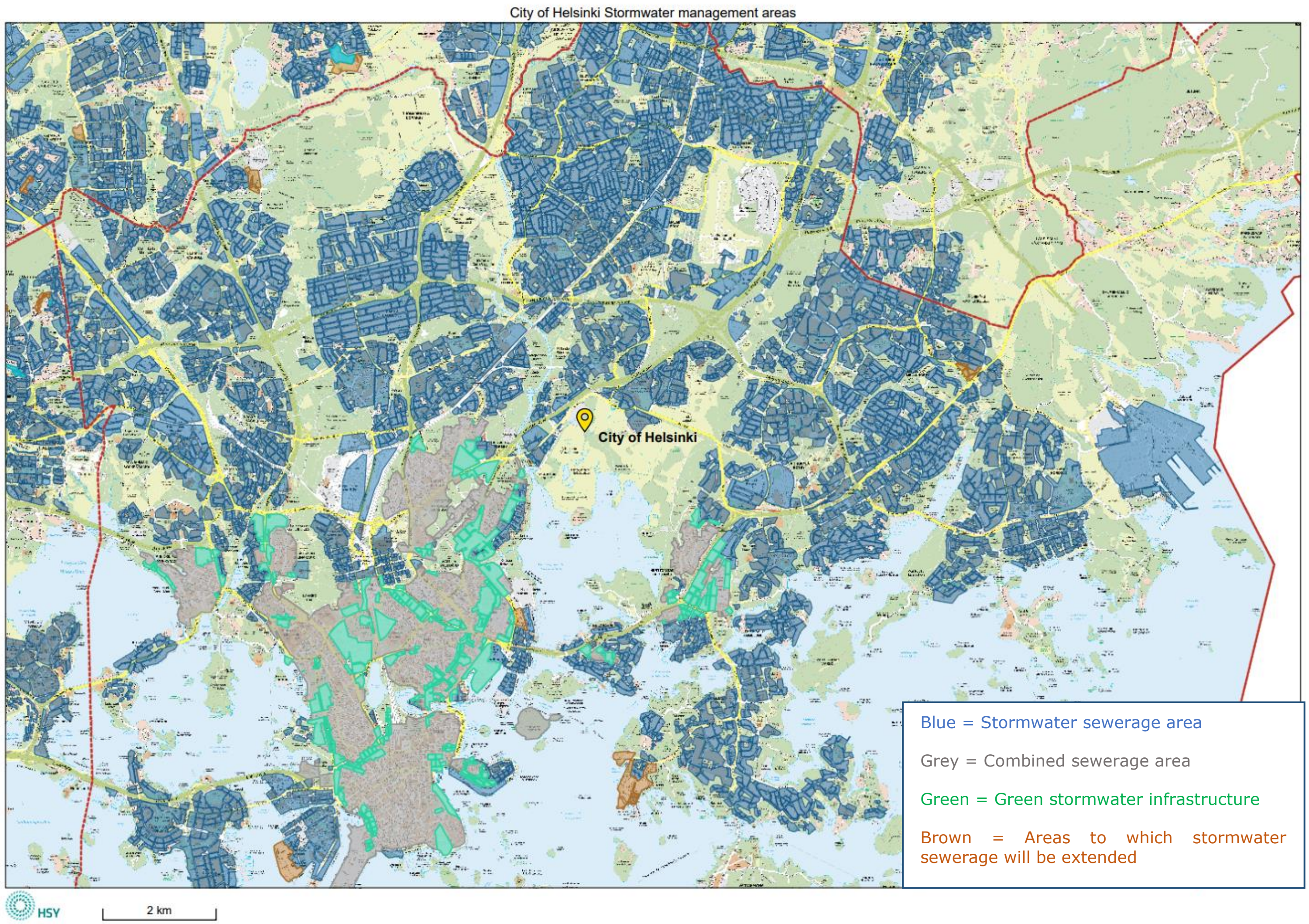


Figure 34. Illustrative map of Helsinki stormwater management areas (source: https://kartta.hsy.fi/?zoomLevel=4&coord=25495739.65300286_6675638.027632485&mapLayers=27+100+rasteri%2c435+100+vh_sekaviemarointialue%2c434+100+vh_hulevesiviemaroity_alue%2c436+100+vh_hva_laajennusalueet&uuid=508752a1-2d1e-4011-a0f7-a96e857fff64&showIntro=false)

Table 3. Challenges and solutions for stormwater management in changing climate in developing, densely built-up and historic built-up areas proposed by HSY (HSY, 2021).

	Developing (or rural) areas	Densely built-up areas	Historic built-up areas
Challenges	• Lack of data for adequate design of systems (e.g. expected increase in rainfall and runoff) • Green areas/ vegetation are not accounted for during the development of urban areas • Conflicting interests	• Amount of impervious cover is high • Lack of space for nature-based solutions • Inadequate sewer systems	• Amount of impervious cover is high • Area development regulations • High costs of retrofitting existing sewer systems • Inadequate sewer systems • Combined sewer • Lack of developed flood routes for increased rainfall and extreme events
Solutions	• Nature-based solutions designed hand in hand with other planning • Using the green factor tool • Construction of drainage channels in nearest suburbs • Taking into account urban flooding in the planning phase • Development of standards regarding dimensioning of systems	• Adding green roofs in buildings when applicable • Guiding water to areas where is does the least harm, away from critical infrastructure • Retention tanks construction/ system flow control and redirecting with valves • Mandates for stormwater retention in individual plots • Modernisation of water disposal systems taking into account updated climate parameters • Surface permeability ratio decrease	• Parking lots turned to micro parks with plants • Development of adaptive storm water management • Use streets as water routes in the case of extreme rain events (Copenhagen example) • New solutions that can work alongside existing stormwater infrastructure

5.2.4 Public/Social dimension

5.2.4.1 Customer satisfaction

Despite extensive research and analysis, the specific customer satisfaction data, and statistics in Helsinki's water sector, in the similar format to Tallinn, was not found in the public sources. It is important to note that the absence of available data does not imply that customer satisfaction is non-existent or not valued in Helsinki's water sector. The city likely recognizes the importance of delivering high-quality, reliable, and accessible water services to its residents.

5.2.4.2 Public participation/environmental awareness

Figure 35. Environmental guide for local businesses developed by HSY (source: https://ekokompassi.fi/)

Public participation and environmental awareness play significant roles in the Helsinki urban water sector. The city of Helsinki recognizes the importance of engaging the public and raising awareness about environmental issues related to water management. HSY has been actively involved in organizing educational events for Finnish organizations in taking control of environmental issues and in continuous improvement such as Ekokompassi. Apart from that HSY also propagates environmental education for school students and children in the kindergartens. By prioritizing public participation and environmental awareness, Helsinki aims to create a sense of shared responsibility and empower individuals to contribute to sustainable water practices.

5.2.4.3 Access to potable water in urban areas

In urban areas of Helsinki, access to potable water is well-established and readily available through various means. For instance, Helsinki offer public water taps in parks, recreational areas, and public spaces. These taps provide residents and visitors with easy access to free drinking water. They are typically designed with multiple outlets, allowing multiple individuals to use them simultaneously (HSY, 2022).

Figure 36. Public water post in Helsinki

Source: https://www.hsy.fi/en/water-and-sewers/water-posts/

Household water supply which is the primary method of accessing potable water in urban areas of Helsinki is through household connections to the municipal water supply system. Each residence is connected to the water supply network, ensuring a reliable and continuous flow of clean drinking water to households. The water supplied meets the highest quality standards and undergoes regular testing and treatment. The water supply undergoes regular monitoring and treatment processes to ensure its cleanliness and safety for consumption (HSY, 2022).

Figure 37. Positioning of public water taps in the city area of Helsinki (red line is the border of Helsinki City) (source: https://kartta.hsy.fi/?zoomLevel=5&coord=25497040.137644865_6672912.258888039&mapLayers=27+100+rasteri,468+100+VH_vesipostit_kuvalla&uuid=508752a1-2d1e-4011-a0f7-a96e857fff64&showMarker=true&showIntro=false)

6. Comparative analysis of Tallinn and Helsinki UWSs

The following part will provide an overview of the significant findings from the previous part.

6.1.1.1 Tallinn, Estonia

Tallinn showed robust performance in various dimensions, including water and wastewater treatment quality, financial attitudes, and public work. However, there are also challenges that need to be addressed to enhance the sustainability and effectiveness of the water sector. In terms of water quality, city generally demonstrates a high standard, outperforming the governmental requirements set for treated wastewater, ensuring the provision of clean and safe water to its residents. The city's water treatment facilities are efficient in removing impurities and maintaining compliance with national and international standards.

Wastewater quality has been also outstanding for the past decade, similarly, surpassing the standards put by the Estonian authorities. Energy consumption has been relatively stable for the past 5 years with no significant fluctuations; Tallinna Vesi AS from the second half of 2021, only uses electricity produced from renewable sources at the facilities and in the treatment process. This data is correspondent to the increase in biogas production in the company which is mostly used as the energy source.

For the economic part, Tallinn, while having a satisfactory financial performance from 2011-2021, with shrinks in net profit of 2017 and 2020, may have opportunities for improvement in revenue generation and cost recovery post COVID-19 pandemics. It must be noted that the investment activities of the City Council have been notably decreasing by the end of the research timeline, while Tallinna Vesi AS have in turn increased it. City should also focus on strategic investments to address challenges such as rising CO_2 emissions coming from wastewater treatment and keep developing the stormwater systems.

6.1.1.2 Helsinki, Finland

Helsinki demonstrated solid financial performance in their water sectors over the last decade. The HSY efficient management practices and revenue generation strategies contribute to its strong financial position, enabling continued investments in infrastructure upgrades, maintenance, and development, such as the construction of new Blominmäki WWTP, Pitäjänmäki-Marttila water network renovation and other water supply systems upgrade. It must be noted that apart from HSY, City of Helsinki itself continuously invests in the renovation of the water infrastructure, making it more adaptable and resilient for the climate change and increased population growth.

Helsinki has implemented effective strategies to manage stormwater, mitigating potential risks and minimizing flood occurrences. The city has developed comprehensive stormwater management systems that account for the increase in impermeable surfaces and changing precipitation patterns. In addition to stormwater management, Helsinki excels in wastewater treatment, ensuring high efficiency which outperform the treatment regulations set by the government. In addition, Helsinki has also achieved low greenhouse gas (GHG) emissions from its wastewater treatment plants, contributing to the city's commitment to environmental sustainability.

Furthermore, city places great emphasis on public awareness campaigns and community engagement. Recognizing the significance of involving citizens in water management, the city actively promotes public awareness about the value of water resources, efficient water use, and conservation practices. Through educational programs, community events, and communication campaigns, Helsinki fosters a sense of responsibility and ownership among its residents, encouraging them to actively participate in sustainable water practices.

6.1.1.3 Bottom line

The detailed development process of SPAF enabled to outline the important indicators which in the opinion of the author could notably contribute to the progress of this monograph. SPAF as a tool helped to highlight the differences between the cities and shed light on narrowly significant aspects of the urban water sectors.

After the analysis and comparison of both water sectors it can be stated that Tallinn and Helsinki have many common practices in water and wastewater management, and overall have collective aim for the environmentally sustainable future.

6.2 Recommendations for sustainable urban water management in Tallinn

After a thorough analysis and comparison of both urban water sectors, the following list of recommendations was created to assist in making the strategies for facilitating and strengthening the future sustainable performance of the urban water sector in Tallinn, Estonia:

- **Continuous investment in water infrastructure:** Tallinn should continue to invest in upgrading its water infrastructure to improve the energy efficiency and decrease greenhouse gases emissions from wastewater plant as well as reduce water loss through leaks. The City Council itself should be more actively engaged in capital allocation on the development of the city's water sector in order to make the urban areas, water and wastewater networks more adaptable towards population growth and climate change.
- **Sustainable Water Management**: Tallinn should prioritize sustainable water management practices, such as rainwater harvesting, stormwater management, and wastewater reuse. The City Council should bring more innovative solutions and make a thorough strategic planning for the water resources to overcome the challenges associated with climate change and growing urbanization.
- **Public awareness and environmental education**: Tallinn should continue to educate the public about the importance of water conservation and efficient water use. Apart from Tallinna Vesi AS, City Council could also enhance using more communication channels to reach different target audiences, including social media, educational programs in schools, and different community events in order to spread more resilient attitude in using the water resources.
- **Stormwater Management**: City of Tallinn should keep up with enhancing its stormwater management systems to mitigate the risks of flooding and minimize the impact of urban runoff on water quality. Implementing green infrastructure solutions such as permeable pavements, rain gardens, and retention ponds can help to absorb and filter stormwater effectively. Also, the continuous development of stormwater sewage in the different districts of the city is crucial as it will help to reduce the risk of flooding in the residential areas.
- **Monitoring and Data Analysis**: Establishing comprehensive monitoring systems and utilizing data analysis tools for future modelling can help Tallinn track water quality,

water usage patterns, and system performance. City should keep monitoring the market for new and more advanced IT-software such Artificial Intelligence driven programs that would enable to more qualitatively control the real-time situation and besides that be able to model the different scenarios way ahead. This data-driven approach will enable informed decision-making and allows for timely interventions to address any issues or optimize water management strategies.

- **Increase the amount of public water taps around the city:** in order to adapt for the uncertain whether events associated with climate change, it is recommended to add more public water taps around the city, especially in residential areas such as Mustamäe, Õismäe, Lasnamäe and Kopli.

SUMMARY

The sustainable performance assessment of the urban water sectors in Tallinn and Helsinki has provided valuable insights into the performance, challenges, and sustainability of water management practices in both cities. By developing an analysis framework and utilizing a range of sources including reports, development plans, and scientific papers, a comprehensive understanding of the urban water sectors was achieved. The overall analysis has highlighted the strengths and areas for improvement in both cities, providing a basis for future actions and decision-making with an emphasis on the city of Tallinn.

Tallinn overall has demonstrated an outstanding performance in terms of water quality and wastewater treatment efficiency. In addition to that, the city's focus on upgrading water infrastructure such as water and sewage networks, and treatment facilities has contributed to the stable provision of clean and safe water to its residents. Tallinna Vesi AS, the city’s main water utility company, has implemented the use of new smart water meters which make the control of water resources even more precise and studied engineering dimension more attractive. The company has also showed strong results in capital management and financial performance, namely in growing sales revenue and employment rate increase over the studied decade. However, Tallinn City Council’s investing activity has notably declined over the years compared to the utility company. Other downsides of the city’s water sector were the rising CO_2 emissions from wastewater treatment plants and problems with the management of stormwater, namely lack of infrastructure in different areas.

Helsinki on the contrary, highlighted robust performance across multiple dimensions. The city excels in water quality, reliability, wastewater treatment efficiency, and environmental sustainability over the past years. Its decreasing greenhouse gas emissions from wastewater treatment plants and resource-efficient practices set a positive example for Tallinn. Additionally, the city has showed robust investment performance and effective stakeholder engagement, which contribute to the overall success of its urban water sector and served as a stable employee over the years. Helsinki’s water utility company HSY keeps heavy investments in the water sector, constructing new wastewater treatment facilities such as Blominmäki, similarly upgrading and developing the water and sewage pipelines, and implementing several stormwater management technologies. It must be mentioned that over the years, Helsinki has also provided effective and high-quality environmental awareness campaigns which remarkably contributed to the sustainability of the urban water sector from the public perspective.

After the analysis of two case studies and the comparison between both cities, the list of specific recommendations for future sustainable functioning of the water sector of Tallinn was set. The following guidance were proposed:

- to continuously invest in water sector to adapt for the climate change issues;
- keep developing the sustainable water management strategies for the city as well as keep organizing and developing public education campaigns about water resources and its management;
- improve the stormwater management within the city;
- enhance the data analytics and systems monitoring with a future focus on Artificial Intelligence driven technologies;
- add extra public water taps for the convenience of local residents.

For future studies, it is recommended to further comprehensively explore the financial dimension of urban water sector, including issues of public affordability, equity in service provision, and assets management overall. Understanding the financial aspects will contribute to a more methodical assessment and enable the development of targeted interventions that address the specific needs and concerns of the communities and future investors. Furthermore, continued monitoring and evaluation of the technological/engineering aspects of treatment facilities are crucial to track progress, identify emerging challenges, and assess the effectiveness of implemented measures. Longer term data collection and analysis as well as specific interviews will provide valuable insights into trends, allowing for timely adjustments and improvements in water management strategies.

In conclusion, the assessment of the urban water sectors in Tallinn and Helsinki has provided a solid foundation for understanding the current state of urban water sectors. Both cities are remarkably similar in terms of management and sustainability attitudes, however, several aspects such as stormwater management and CO_2 emissions as well as the investment activities differ significantly. Overall, cities have done a great contribution in the transition to sustainable performance. The proposed assessment framework worked as a great tool for structuring the analysis of the water sectors and at the end highlighting the differences, what means it can be used for the future research.

KOKKUVÕTE

Tallinna ja Helsingi linnaveesektorite jätkusuutliku tulemuslikkuse hindamine on andnud väärtuslikku teavet mõlema linna veemajandustavade tulemuslikkusest, väljakutsetest ja jätkusuutlikkusest. Analüüsiraamistiku väljatöötamisega ja mitmesuguste allikate, sealhulgas aruannete, arengukavade ja teadustööde kasutamisega saavutati terviklik arusaam linnade veesektoritest. Üldanalüüsis on välja toodud mõlema linna tugevused ja täiustamist vajavad valdkonnad, mis on aluseks tulevastele tegevustele ja otsuste tegemisele rõhuasetusega Tallinna linnal.

Tallinn on veekvaliteedi ja reoveepuhastuse tõhususe osas näidanud silmapaistvaid tulemusi. Lisaks sellele on linna keskendumine veeinfrastruktuuri, nagu vee- ja kanalisatsioonivõrkude ning puhastusrajatiste uuendamisele aidanud kaasa elanike stabiilsele puhta ja ohutu veega varustamisele. Linna peamine vee-ettevõte Tallinna Vesi AS on võtnud kasutusele uued nutikad veearvestid, mis muudavad veevarude kontrolli veelgi täpsemaks ning uuritud insenertehnilist mõõdet atraktiivsemaks. Ettevõte on näidanud tugevaid tulemusi ka kapitali juhtimises ja finantstulemustes, nimelt kasvavas müügitulu ja tööhõive määra kasvus uuritud kümnendil. Tallinna Linnavolikogu investeerimisaktiivsus on aga aastatega võrreldes kommunaalettevõttega märgatavalt langenud. Linna veesektori muud miinused olid reoveepuhastite kasvav CO_2 emissioonid ja probleemid sademevee käitlemisega, nimelt infrastruktuuri puudumine erinevates piirkondades.

Vastupidi, Helsingi tõi esile tugeva jõudluse mitmes mõõtmes. Linn on viimastel aastatel silma paistnud vee kvaliteedi, töökindluse, reoveepuhastuse tõhususe ja keskkonnasäästlikkuse poolest. Selle vähenevad kasvuhoonegaaside heitkogused reoveepuhastitest ja ressursitõhusad tavad on Tallinnale positiivseks eeskujuks. Lisaks on linn näidanud tugevat investeerimistulemust ja tõhusat sidusrühmade kaasamist, mis aitab kaasa linna veesektori üldisele edule ja on aastate jooksul olnud stabiilne tööandja. Helsingi veeettevõte HSY jätkab suuri investeeringuid veesektorisse, ehitades uusi reoveepuhastiid nagu Blominmäki, uuendades ja arendades samamoodi vee- ja kanalisatsioonitorustikke ning rakendades mitmeid sademeveekäitlustehnoloogiaid. Peab mainima, et Helsingi on aastate jooksul korraldanud ka tõhusaid ja kvaliteetseid keskkonnateadlikkuse tõstmise kampaaniaid, mis on aidanud märkimisväärselt kaasa linnaveesektori jätkusuutlikkusele avalikust vaatenurgast.

Pärast kahe juhtumiuuringu analüüsi ja linnade võrlemist koostati konkreetsete soovituste loetelu Tallinna veesektori tulevaseks jätkusuutlikuks toimimiseks. Pakuti välja järgmiseid aspekte:

- jätkuda investeerimistega pidevalt veesektorisse, et kohaneda kliimamuutustega;
- jätkata linna säästva veemajanduse strateegiate väljatöötamist, samuti korraldada ja arendada veevarusid ja selle majandamist käsitlevaid üldsuse harivaid kampaaniaid, parandada linna sademevee juhtimine;
- täiustada andmeanalüütikat ja süsteemide seiret, keskendudes tulevikus tehisintellektipõhistele tehnoloogiatele;
- ning lisada kohalike elanike mugavuse huvides täiendavaid avalikke veekraane.

Tulevaste uuringute jaoks on soovitatav täiendavalt põhjalikult uurida linna veesektori finantsmõõdet, sealhulgas avaliku taskukohasuse, teenuste osutamise võrdsuse ja varade haldamise küsimusi üldiselt. Finantsaspektide mõistmine aitab kaasa metoodilisemale hindamisele ja võimaldab välja töötada sihipäraseid sekkumisi, mis vastavad kogukondade ja tulevaste investorite konkreetsetele vajadustele ja muredele. Lisaks on väga oluline jälgida ja hinnata puhastusrajatiste tehnoloogilisi/tehnilisi aspekte, et jälgida edusamme, teha kindlaks tekkivad probleemid ja hinnata rakendatud meetmete tõhusust. Pikemaajaline andmete kogumine ja analüüs kuigi ka intervjuud annavad väärtuslikku ülevaadet suundumuste kohta, võimaldades veemajandusstrateegiaid õigeaegselt kohandada ja täiustada.

Kokkuvõtteks võib öelda, et Tallinna ja Helsingi linnade veesektorite hindamine on andnud tugeva aluse veemajanduse hetkeolukorra mõistmiseks, parandamist vajavate valdkondade väljaselgitamiseks ja soovituste andmiseks edasisteks meetmeteks. Mõlemad linnade veesektorid on majandamise ja jätkusuutlikkuse hoiakute poolest märkimisväärselt sarnased, kuid mitmed aspektid, nagu sademevee käitlemine ja CO_2 emissioon ning investeerimistegevus, erinevad märkimisväärselt. Üldiselt on linnad näidati suure panuse jätkusuutlikule toimimisele üleminekul. Kavandatud hindamisraamistik toimis suurepärase vahendina veesektorite analüüsi struktureerimiseks ja lõpuks erinevuste esiletoomiseks, mis tähendab, et seda saab tulevastes uuringutes kasutada.

LIST OF REFERENCES

Andersson, I., Petersson, M. & Jarsjö, J., 2012. Impact of the European Water Framework Directive on local-level water management: Case study Oxunda Catchment, Sweden. *Land Use Policy,* 29(1), pp. 73-82.

Argyle Water Supply Corporation, 2016. *URBAN WATER CYCLE.* Argyle: s.n.

Boldrin, M. T. N. & Formiga, K. . T. M., 2023. Measuring the environmental performance of urban water systems: a systematic review. *Water Supply,* 00(7-9).

Britannica, 2023. *Eutrophication.* [Online]
Available at: https://www.britannica.com/science/boundary-ecosystem
[Accessed April 2023].

Britannica, 2023. *https://www.britannica.com.* [Online]
Available at: https://www.britannica.com/science/biochemical-oxygen-demand
[Accessed May 2023].

Chen, J., 2023. *https://www.investopedia.com/.* [Online]
Available at:
https://www.investopedia.com/terms/s/swap.asp#:~:text=A%20swap%20is%20a%20derivative%20contract%20where%20one%20party%20exchanges,first%20company%20a%20fixed%20rate.
[Accessed May 2023].

Climate ADAPT, 2023. *https://climate-adapt.eea.europa.eu/.* [Online]
Available at: https://climate-adapt.eea.europa.eu/en/countries-regions/countries/estonia#:~:text=Sea%2Dlevel%20rise%20due%20to,extensive%20low%2Dlying%20coastal%20areas.
[Accessed April 2023].

de Walle, A. V. et al., 2023. Greywater reuse as a key enabler for improving urban wastewater management. *Environmental Science and Ecotechnology,* Volume 16.

ELVL, 2023. *www.elvl.ee.* [Online]
Available at: https://www.elvl.ee/elanike-arv
[Accessed May 2023].

Estonian Ministry of the Environemnt, 2021. *Strategy and development.* [Online] Available at: https://envir.ee/en/ministry-news-and-contact/strategy-and-development [Accessed May 2023].

European Commission, 2021. *www.research-and-innovation.ec.europa.eu.* [Online] Available at: https://research-and-innovation.ec.europa.eu/document/9224c3b4-f529-4b48-b21b-879c442002a2_en
[Accessed 9 April 2023].

European Commission, 2023. *https://environment.ec.europa.eu/.* [Online] Available at: https://environment.ec.europa.eu/topics/water/water-framework-directive_en [Accessed May 2023].

European Environment Agency, 2009. *Water resources across Europe — confronting water scarcity and drought,* Copenhagen: EEA.

European Parliament, 2023. *www.europarl.europa.eu.* [Online]
Available at:
https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits?&at_campaign=20234-Economy&at_medium=Google_Ads&at_platform=Search&at_creation=RSA&at_goal=TR_G&at_audience=eu%20circular%20econo
[Accessed 09 April 2023].

Eurostat, 2023 . *https://ec.europa.eu/.* [Online]
Available at:
https://ec.europa.eu/eurostat/databrowser/view/sbs_na_ind_r2/default/table?lang=en
[Accessed May 2023].

Finnish Ministry of the Environment, 2023. *Management of water resources and marine environments in Finland.* [Online]
Available at: https://ym.fi/en/management-of-water-resources-and-marine-environments-in-finland
[Accessed April 2023].

Halleux, V., 2023. *https://www.europarl.europa.eu/.* [Online]
Available at:
https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/739370/EPRS_BRI(2023)7393

70_EN.pdf
[Accessed May 2023].

Hayes, A., 2023. *https://www.investopedia.com/.* [Online]
Available at: https://www.investopedia.com/terms/r/revenue.asp
[Accessed May 2023].

HELCOM, 2021. *Climate Change in the Baltic Sea 2021 Fact Sheet ,* Helsinki: Helsinki Commission – HELCOM.

Helsinki Region Infoshare, 2022. *https://hri.fi/.* [Online]
Available at: https://hri.fi/data/en_GB/dataset/helsingin-vaesto-ja-asuntotuotantoennuste-alueittain
[Accessed May 2023].

HSY Statitsics Department, 2023. *https://www.hsy.fi/.* [Online]
Available at: https://www.hsy.fi/en/environmental-information/open-data/avoin-data---sivut/helsinki-region-environmental-services-authoritys-hsy-energy-and-material-balances-and-greenhouse-gas-emissions/
[Accessed May 2023].

HSY, 2021. *Nature-based solutions for stormwater management in the Helsinki Metropolitan Area, Finland – Prerequisites and good practices,* Helsinki: Helsinki Region Environmental Services Authority.

HSY, 2022. *https://www.hsy.fi/.* [Online]
Available at: https://www.hsy.fi/globalassets/ymparistotieto/projektisivustot-ja-hanke-esittelyt/tiedostot/blominmaki/blominmaki_7-2019_en.pdf
[Accessed May 2023].

HSY, 2022. *www.hsy.fi.* [Online]
Available at: https://www.hsy.fi/en/water-and-sewers/tips-for-water-use/#:~:text=A%20resident%20in%20the%20Helsinki,litres%20of%20water%20per%20day.
[Accessed April 2023].

HSY, 2023. *https://www.hsy.fi/.* [Online]
Available at: https://www.hsy.fi/en/water-and-sewers/how-the-water-supply-works/
[Accessed April 2023].

HSY, 2023. *https://www.hsy.fi/.* [Online]
Available at: https://www.hsy.fi/en/water-and-sewers/water-services-investment-projects/
[Accessed April 2023].

Hu, Z. & Grasso, D., 2005. *Encyclopedia of Analytical Science.* II ed. s.l.:Elsevier.

Intergovernmental Panel on Climate Change (IPCC), 2018. *An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development,,* Cambridge: IPCC.

Juwana, I., Muttil, N. & Perera, B., 2012. Indicator-based water sustainability assessment — A review. *Science of The Total Environment,* Volume 438, pp. 357-371.

Käi, R., 2017. *https://tallinnavesi.ee/.* [Online]
Available at: https://tallinnavesi.ee/en/tallinn-circuit-court-dismissed-as-tallinna-vesis-appeal-in-the-tariff-dispute-between-as-tallinna-vesi-and-competition-authority/
[Accessed May 2023].

Kautto, N., 2021. *Nature-based solutions for stormwater management in the Helsinki Metropolitan Area, Finland – Prerequisites and good practices,* Helsinki : Helsinki Region Environmental Services Authority.

Kenton, W., 2022. *https://www.investopedia.com/.* [Online]
Available at: https://www.investopedia.com/terms/f/fixedasset.asp
[Accessed May 2023].

Kenton, W., 2022. *https://www.investopedia.com/.* [Online]
Available at: https://www.investopedia.com/terms/n/netincome.asp
[Accessed May 2023].

OECD, 2016. *Water, growth and finance policy perspectives,* s.l.: The Organisation for Economic Co-operation and Development (OECD).

OECD, 2022. *Shrinking Smartly in Estonia: Preparing Regions for Demographic Change,* Paris: OECD Rural Studies, OECD.

Opher, T., Friedler, E. & Shapira, A., 2019. Comparative life cycle sustainability assessment of urban water reuse at various centralization scales. *The International Journal of Life Cycle Assessment,* Issue 24, p. 1319–1332.

Otaki , Y. et al., 2022. Demand-side water management using alternative water sources based on residential end-use. *Water Practice & Technology,* 17(4), pp. 950-957.

Pearsall, H. & Pierce, J., 2010. Urban sustainability and environmental justice: evaluating the linkages in public planning/policy discourse. *The International Journal of Justice and Sustainability,* 15(6), pp. 569-580.

Riigikogu, 2020. *Water Act.* Tallinn: Riigikogu.

Riv, G., 2020. *https://en.wikipedia.org/.* [Online]
Available at:
https://en.wikipedia.org/wiki/P%C3%A4ij%C3%A4nne_Water_Tunnel#/media/File:P%C3%A4ij%C3%A4nnetunneli.svg
[Accessed April 2023].

Sachs, J. et al., 2022. *Sustainable Development Report,* Cambridge: United Nations.

Sahely, H. R., Kennedy, C. A. & Adams, B. J., 2005. Developing sustainability criteria for urban infrastructure systems. *Canadian Journa of Civil Engineering,* Volume 32, p. 72–85.

Schellekens, J., Heidecke, L., Nguyen, N. & Spit, W., 2018. *The Economic Value of Water - Water as a Key Resource for Economic Growth in the EU,* Rotterdam: ECORYS.

SIWI (Stockholm International Water Institute), 2023. *https://siwi.org/why-water/water-governance/#:~:text=Poor%20resource%20management%2C%20corruption%2C%20inappropriate,the%20effective%20governance%20of%20water..* [Online]
Available at: https://siwi.org/why-water/water-governance/#:~:text=Poor%20resource%20management%2C%20corruption%2C%20inappropriate,the%20effective%20governance%20of%20water.
[Accessed May 2023].

Tallina Vesi AS, 2016. *Annual Report,* Tallinn: Tallina Vesi AS.

Tallinn City Council, 2010. *https://www.riigiteataja.ee/.* [Online]
Available at:
https://www.riigiteataja.ee/aktilisa/4210/5201/3035/1110118953.attachment.pdf#
[Accessed May 2023].

Tallinn City Council, 2015. *https://www.tallinn.ee/.* [Online]
Available at: https://www.tallinn.ee/et/media/294706
[Accessed April 2023].

Tallinn City Council, 2022. *https://www.tallinn.ee.* [Online]
Available at: https://www.tallinn.ee/en/news/tallinn-and-helsinki-mayors-renew-twin-city-cooperation-agreement
[Accessed April 2023].

Tallinn City Council, 2022. *https://www.tallinn.ee/.* [Online]
Available at: https://www.tallinn.ee/en/statistics-and-yearbooks
[Accessed May 2023].

Tallinn City Council, 2023. *https://www.tallinn.ee/.* [Online]
Available at: https://veeb.tallinnlv.ee/pilv/index.php/s/vwSdIUCgBhA38RK
[Accessed May 2023].

Tallinna Vesi AS, 2015. *Environmental report,* Tallinn: Tallinna Vesi AS.

Tallinna Vesi AS, 2017. *Environmental Report,* Tallinn: Tallinna Vesi AS.

Tallinna Vesi AS, 2020. *Financial Report,* Tallinn: Tallinna Vesi AS.

Tallinna Vesi AS, 2021. *Environmental report,* Tallinn: Tallinna Vesi AS.

Tallinna Vesi AS, 2021. *https://tallinnavesi.ee/.* [Online]
Available at: https://tallinnavesi.ee/interaktiivne-kaart-vaata-kus-avati-tallinnas-tasuta-joogiveekraanid/
[Accessed May 2023].

Tallinna Vesi AS, 2022. *Financial Report,* Tallinna: Tallinna Vesi AS.

Tallinna Vesi AS, 2022. *Report,* Tallinn: Tallinna Vesi AS.

Tallinna Vesi, 2023. *https://tallinnavesi.ee/.* [Online]
Available at: https://tallinnavesi.ee/sotsiaalne-vastutus/ekskursioonid/paljassaare-reoveepuhastusjaam/
[Accessed April 2023].

The World Bank, 2021. *Global Water Security & Sanitation Partnership Annual Report,* Washington, DC: International Bank for Reconstruction and Development/The World Bank.

UNESCO, 2021. *The United Nations World Water Development Report,* Colombella: Global Water Assessment Division of Water Sciences, UNESCO.

United Nations, 1987. *Report of the World Commission on Environment and Development: Our Common Future,* s.l.: United Nations.

United Nations, 2015. *Goal 6: Ensure access to water and sanitation for all.* s.l.:United Nations.

United Nations, 2015. *www.un.org.* [Online]
Available at: https://www.un.org/sustainabledevelopment/blog/2015/12/sustainable-development-goals-kick-off-with-start-of-new-year/
[Accessed April 2023].

United Nations, 2023. *Sustainable Development Goals.* [Online]
Available at: https://sdgs.un.org/goals
[Accessed April 2023].

United States Environmental Protection Agency, 2023. *Overview of Greenhouse Gases.* [Online]
Available at: https://www.epa.gov/ghgemissions/overview-greenhouse-gases#:~:text=Carbon%20dioxide%20(CO2)%20is,gas%20emissions%20from%20human%20activities.
[Accessed April 2023].

Wang, D. et al., 2022. Cross-sectoral urban energy–water–land nexus framework within a multiscale economy: The case of Chinese megacities. *Journal of Cleaner Production,* Volume 376.

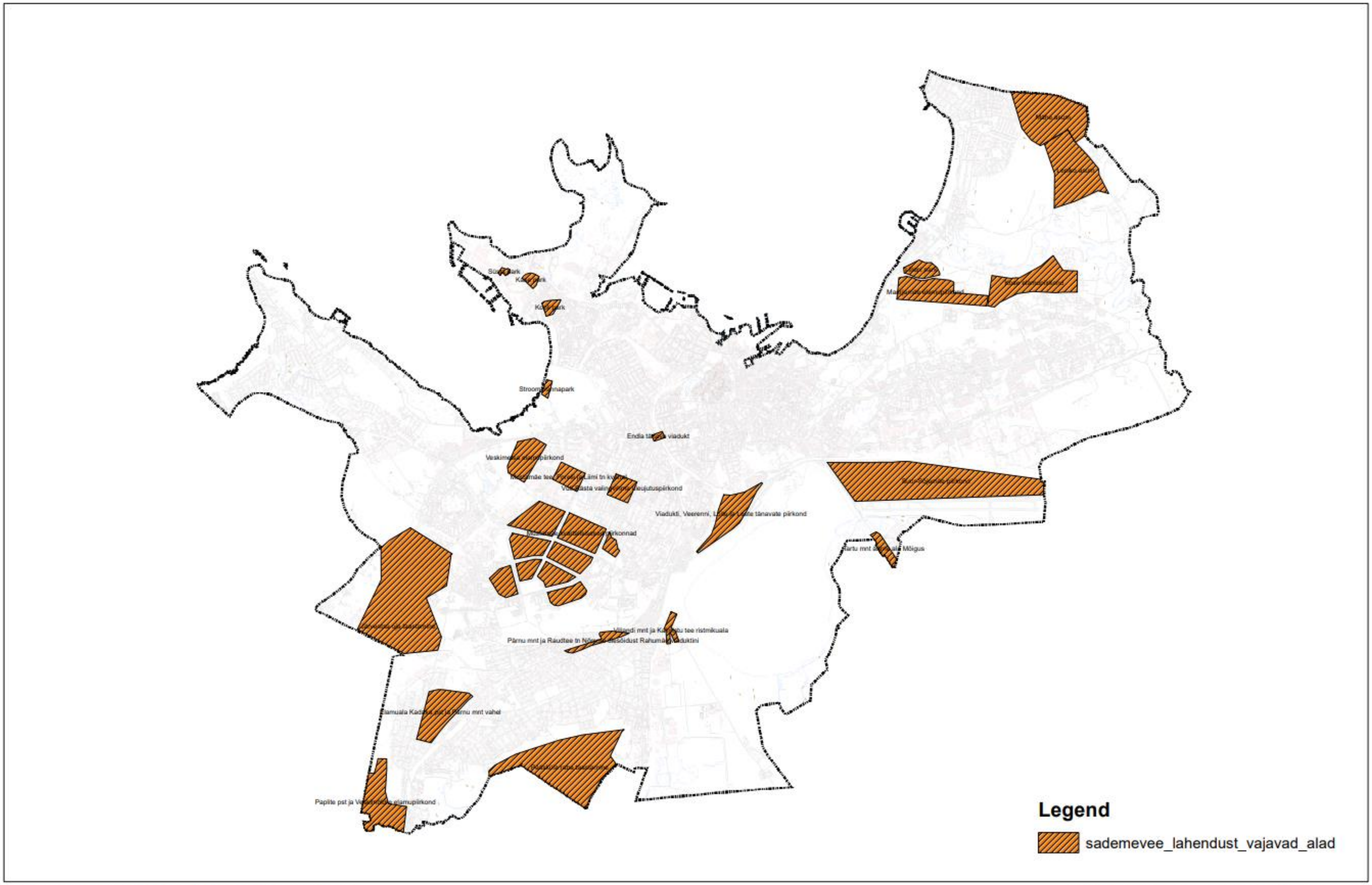
Xu, H., Fryd, O. & Randall, M., 2023. Urban stormwater management at the meso-level: A review of trends, challenges and approaches. *Journal of Environmental Management,* Volume 331.

APPENDICES

Table 4. Wastewater treatment plant's treatment efficiency in 2017-2021, compared to minimum regulatory requirements and results of Helsinki HSY, % (Tallinna Vesi AS, 2021)

Table 5. Wastewater treatment plant's treatment efficiency in 2013-2017, compared to minimum regulatory requirements and results of Helsinki HSY, % (Tallinna Vesi AS, 2021)

Table 6. Wastewater treatment plant's treatment efficiency in 2011-2015, compared to minimum regulatory requirements and results of Helsinki HSY, % (Tallinna Vesi AS, 2015)



Aluskaart: Eesti Põhikaart 1:10000, Maa-amet, 2022

Joonis 5. Sademevee lahendust vajavad alad

Figure 38 Areas which require stormwater solutions in Tallinn (Tallinn City Council, 2023)