Tampere University

JYRKI LAITINEN

Quest for Sustainable Urban Water Services

Management and Practices in Finland

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ACADEMIC DISSERTATION
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The mystery of human existence lies not in just staying alive, but in finding something to live for

Fyodor Mikhailovich Dostoyevsky

When I completed my doctoral studies in Vaasa University in the end of 1990's and I did my licentiate thesis, I thought: "Okay, this is it. Now I have a post-graduate degree in production economics and that is enough for me in my career". But you never know, I started to prepare the dissertation in 2014. So, here we are now.

This dissertation was prepared for the Faculty of Built Environment at Tampere University. I prepared the material for all of the four articles in my projects in Finnish Environment Institute SYKE. I wrote the articles mainly in my spare time but I had priceless assistance and advice from the co-authors. I had profound discussions with the whole CADWES team in Tampere University. Special thanks to all who gave good comments to this dissertation.

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Special thanks go to my wife Marja, who has been consistently supportive during these years. Although she is not a professional in water services, I have had fruitful discussions with her on how to find varying angles to this research, dissertation and, last but not least, to life as a whole.

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Jyrki Laitinen

ABSTRACT

Water services – water supply and sanitation – are a vital part of socio-economic functions. A sustainable society requires adequate and resilient water services for functioning continuously, and for securing proper health and environment for its members. Water services should be available for everyone, but still there are hundreds of millions of people lacking them. Even in urban areas, where communities provide services for citizens, there is insufficiency in providing adequate water supply and/or sanitation for people.

Urban water services can be considered part of municipal services, including the technical solution from water source to water treatment and distribution, and also wastewater collection, treatment and discharge back to natural waters. All this should be managed so that the state of the natural waters does not change, and that there is no risk to human health even in the long run. As part of community technical services, water services are essential for the socio-economic good of a society. They have been considered important especially for women and vulnerable members of a society. Also their significance for the economic development of a society cannot be ignored.

In this study, management and practices of urban water services were explored so that aspects for sustainability and resilience could be found out. Different aspects were studied in four separate studies, and a synthesis was then carried out concluding the results to this dissertation. The four studies concerned different parts of urban water services, and they were approached in various sets of research methods. The rallying point in the studies was sustainability of urban water services. The summary and conclusions in the synthesis of the studies was made by regarding political, economic, social, technological, environmental and legal factors within this theme.

The results showed that for functioning water services, a wide range of expertise about society functions is needed. Basis for proper water services is knowledge about the whole function, and this requires good data management. One important aspect in resilience of Finnish water services is asset management, and in many water

utilities the condition of water pipe and sewer networks are not known. Although the water sector in Finland is well managed, urban water services require attention to good governance and institutional arrangements to ensure continued and sound operation. Competence of water professionals and public awareness are both important for supporting sustainable and resilient water services.

For gaining this objective, a set of recommendations were constituted according to the results of the research. These recommendations were constituted, arising from the results of separate studies of this dissertation, as well as the synthesis of the whole research.

TIIVISTELMÄ

Vesihuoltopalvelut – talousvesi- ja jätevesihuolto – ovat tärkeä osa sosioekonomisia toimintoja. Kestävä yhteiskunta vaatii riittäviä ja kestäviä vesihuoltopalveluja jatkuvan toimintakyvyn sekä asianmukaisen terveyden ja hyvän ympäristön turvaamiseksi. Vesihuoltopalvelujen tulisi olla kaikkien saatavilla, mutta silti maailmassa on satoja miljoonia ihmisiä, joilta ne puuttuvat. Jopa kaupunkialueilla, joilla kuntaorganisaatiot tarjoavat palveluja kansalaisille, vesihuollon ja / tai sanitaation tarjoaminen ihmisille on kestämättömällä pohjalla.

Vesihuoltopalveluja voidaan pitää osana niistä yhteiskunnan palveluista, joihin sisältyy tekninen ratkaisu raakavesilähteestä vedenkäsittelyyn ja jakeluun sekä jätevesien keruu, käsittely ja palautus luonnonvesiin. Kaikkea tätä tulisi hallita siten, että luonnonvesien tila ei muutu ja ettei siitä edes pitkällä tähtäimellä ole vaaraa ihmisten terveydelle. Yhteisön teknisten palvelujen lisäksi vesipalvelut ovat välttämättömiä yhteiskunnan sosioekonomiselle toimintakyvylle. Sitä on pidetty tärkeänä etenkin naisille ja heikossa asemassa oleville yhteiskunnan jäsenille. Myöskään sen merkitystä yhteiskunnan taloudelliselle kehitykselle ei voida sivuuttaa.

Tässä tutkimuksessa tutkittiin yhdyskuntien vesihuoltopalveluiden hallintaa ja käytäntöjä, jotta kestävyyttä ja pysyvyyttä koskevat näkökohdat voitaisiin havaita. Eri näkökohtia tutkittiin neljässä erillisessä tutkimuksessa, ja sitten tehtiin synteesi yhteenvetona tälle väitöstutkimuksen kokonaisuudelle. Neljä tutkimusta koskee kaupunkien vesihuoltopalveluiden eri osia, ja niitä lähestytään erilaisilla tutkimusmenetelmillä. Tutkimusten lähtökohtana on kaupunkien vesihuoltopalveluiden kestävyys. Yhteenveto ja johtopäätökset tutkimusten synteesissä tehtiin ottamalla huomioon aiheen poliittiset, taloudelliset, sosiaaliset, teknologiset, ympäristölliset ja oikeudelliset tekijät.

Tulokset osoittavat, että vesihuoltopalveluissa ei oikeastaan ole kysymys vain yhteiskunnan palvelujen teknisestä ja taloudellisesta järjestelystä, vaan se vaatii syvää tuntemusta yhteiskunnan toiminnoista. Kestävien vesihuoltopalveluiden perusta on koko toiminnan tuntemus, ja tämä edellyttää hyvää tiedonhallintaa. Yksi tärkeä näkökohta suomalaisten vesipalvelujen kestävyydessä on omaisuudenhoito, ja monissa vesilaitoksissa vesiputki- ja viemäriverkkojen kuntoa ei tunneta. Vaikka Suomen vesialaa on hoidettu hyvin, yhdyskuntien vesihuolto vaatii huomiota hyvällä

hallintotavalla ja institutionaalisin järjestelyin jatkuvan ja moitteettoman toiminnan varmistamiseksi. On tärkeää, että vesialan ammattilaisten osaaminen ja kaikkien yhteiskunnan jäsenten tietoisuus tukee kestäviä vesihuoltopalveluja.

Tämän tavoitteen saavuttamiseksi laadittiin tutkimuksen tulosten perusteella joukko suosituksia. Nämä suositukset perustuvat erillisten artikkelien sekä koko tutkimuksen synteesin tuloksiin.

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ABBREVIATIONS

GHG	Greenhouse Gas
IUWM	Integrated Urban Water Management
LCA	Life Cycle Analysis
LCC	Life Cycle Costs
LFA	Logical Framework Approach
PPP	Public Private Partnership
SDGs	Sustainable Development Goals
TWM	Total Water Management
UWWTD	Urban Wastewater Treatment Directive
WWTP	Wastewater Treatment Plant

ORIGINAL PUBLICATIONS

Publication I	Laitinen, J. 2016. Advanced information management enhancing better performance in Finnish water utilities. European Water 56: 13-20. EWRA.
Publication II	Laitinen, J., Moliis, K. and Surakka, M.. 2017. Resource efficient wastewater treatment in a developing area – Climate change impacts and economic feasibility. Ecological Engineering 103 (2017) 217-225.
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Publication IV	Laitinen, J., Kallio, J., Katko, T.S., Juuti, P. and Hukka, J.J.. 2020. Resilient water services for the 21st century society – stakeholder survey in Finland. MDPI Water, 2020, 12, 187, 1-12.

1 INTRODUCTION

1.1 Background

Water services are a vital part of socio-economic functions. Although water is considered as a necessary human right to everyone, it is not even close to adequate in several countries. Globally more than 2 billion people lack safe drinking water and 4.5 billion people are without satisfactory sanitation facilities (World Health Organization & United Nations Children's Fund 2017). This is not a satisfactory situation, and the United Nations Sustainable Development Goals (SGDs) specifically include Goal number 6 for Water supply and sanitation. This Goal is quite clear, from the title "Ensure availability and sustainable management of water and sanitation for all", to the sections 6.1 "By 2030, achieve universal and equitable access to safe and affordable drinking water for all" and 6.2 "By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations".

There are huge differences between available water resources, access to them, use of water resources, organizing of water services and institutional framework in overall water management. Hence, it is quite impossible to give specific common guidelines for water management, yet there are some principles and practices that can be applied in planning of water resources use and especially water services provided and produced to citizens of communities and a society.

In recent years we are often faced with alarming news on water crisis in the major cities around the world (e.g. Chennai, India, and Cape Town, South Africa). Such situations are very likely to be more common in the future due to climate change which will strongly impact especially the most vulnerable people. This is due to water scarcity and changing circumstances which can be resisted by sustainable development and resilient practices in water resources management. Sustainable water services, meaning continuously secure and resilient urban water supply and sanitation for all in communities, are not only an issue of natural resources and technology to use them but a wide socio-economic collaboration between all stakeholders covering decision-making, preparation of legislation and policy, technological development, operation and maintenance of infrastructure, financing, and, last but not least, the whole society as users of water resources and services (e.g. Katko 2016, 240-257).

One already widely used and referred concept is Integrated Water Resources Management (IWRM). This is an empirical concept which was built up from the on-the-ground experience of practitioners. The heart of the concept of IWRM was set in the Dublin Statement on Water and Sustainable Development (ICWE 1992) which stated four principles about water and sustainability. The concept was introduced to discussions in the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in June 1992 in Agenda 21, although many parts of the concept were known and practiced for several decades already. The Global Water Partnership's definition of IWRM states: "IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." (UNEP 2009, 3).

Closely related to IWRM is the concept of Integrated Urban Water Management, IUWM (GWP 2011). In this approach it is stated that in urban development water, sanitation and storm water management should not be planned and implemented separately, without acknowledging cross-scale interdependences in freshwater, wastewater, flood control and storm water. Traditional urban water management has decreased water security and resilience of urban centers towards, for example, impacts of climate change. IUWM also emphasizes the importance of the roles of central and local governments, as well as taking into account the needs and views of all stakeholders including individuals living in the area. (GWP 2011)

Berlin rules (International Law Association 2004) have 73 articles emphasizing sustainable use of water resources and international cooperation to agree on it. It also states a principle that individual people, who are the end users of water resources, should be heard in planning of water management. In Articles 17 (The Right of Access to Water) and 18 (Public Participation and Access to Information) the importance of water services for every individual is emphasized and justified.

In the 1990s in the USA the concept of Total Water Management (TWM) was developed since leaders in the water industry sensed that single-purpose water management was outdated and too limited. A principle idea behind TWM is that the water supply industry should take leadership in resource conservation and in considering water management across the entire hydrologic cycle. The promise of

TWM is that we can promote sustainable development by working together in managing water on the basis of natural systems within watersheds. TWM is a concept to create a framework for principles and practices of sustainable water management. The focus is not only in water supply services, it applies to all water services; supply, wastewater and water quality, agricultural water, hydropower, instream flow management and security against flood losses. It is a similar term to IWRM that describes taking an overall approach to solving water problems. (Grigg 2011)

TWM focuses on both the utility serving its customers and the needs of the broader society. The definition of TWM includes the following: "stewardship of water resources for the greatest good of society and the environment" (Grigg 2011, 56). One issue is that some water stakeholders, when confronted with a problem, will say "it is not my problem". One challenge that can be approached with TWM principles is cooperation between various organizations with varying needs.

An overall review to Finnish water services was made by Katko (2016). His comprehensive book concentrated on institutional practices during the last decades, and compared Finnish practices to those of some other western countries. For example, he cited the Water Poverty Index, which considers five components: water resources; access to resources and services; capacity reflecting socio-economic factors; per capita water use for various purposes; and water quality and environmental impacts. In 2012 Finland and Canada received the highest ranking in this comparison. (Katko 2016, 247)

In Finland water scarcity is not a common problem. There are a lot of lakes and rivers which are of reasonable or good quality, and groundwater which is nowadays mainly used as a source of water supply, is of very good quality. Finnish water services strengths include good water resources, strong and coherent water legislation and administration, good governance, advanced technology and processes, advanced data management and high knowledge and competence within personnel (result in Article IV). The challenges are asset management and especially deteriorating water supply and sewer networks, eutrophication of the Baltic Sea (although nowadays agriculture is the main polluter) and harmful substances in wastewater (current wastewater treatment plants are not designed to purify these substances). The strategies and guidelines for Finnish water services in the near future have been outlined by Silfverberg (2017) and Berninger et al. (2018).

1.1.1 Terms sustainability and resilience in water sector

Sustainability and resilience are terms that are widely used in water services. However, there are no univocal definitions for them, or explanations on the differences of these two terms, especially concerning water services. In 2005, the World Summit on Social Development identified three core areas that contribute to the philosophy and social science of sustainable development; Economic development, Social development and Environmental protection (IUCN 2006). This IUCN report was a result of discussion based on earlier reports on sustainability, especially the Brundtland Report (Brundtland 1987) and the United Nations Conference on Environment and Development in Rio 1992.

Renou and Bolognesi (2019, 995) stated a question for their research about sustainable water services: "What types of social and material support can be deployed to make the institutional rationales developed by the various stakeholders involved in European urban water regimes compatible, in order to co-produce 'shared value' that contributes to their sustainable development?" Their solution could be simplified as proper integration of physical and institutional aspects of natural resource governance.

Resilience in water services has not been definitely defined and interpreted in literature. The term has been increasingly used, especially during the last few years. UNISDR (2009, 24) defined the term resilience as follows: "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner". Johannessen and Wamsler (2017) stated that the resilience concept is generally not operationalized, and they investigated in their study how the resilience concept can be systematized, operationalized and applied better in urban water management. Resilience thinking can also be seen as an integrative approach for dealing with the sustainability challenge (Folke 2016). It can be viewed as a subset of sustainability science with a focus on social-ecological systems of people, communities, economies, societies and cultures.

Ashley et al. (2020) combined water sector to water services more widely than the traditional thinking does. They included flooding as one important part in urban water services considering sustainability. Sustainability is considered to require some balance between environment, society and economy, and according to their view, this also contains resiliency in urban water sector. Bocchini et al. (2014) suggest that resilience and sustainability are complementary and should be used in an integrated perspective. All the above-mentioned aspects are kept in mind when studying and concluding the results of this research.

1.2 Objectives of the study

The objective of this research is to produce novel knowledge and understanding of the role of water services in the 21st century society. The study explores sustainable and resilient use of water resources from the view of urban water supply and sanitation. The target is not to assess detailed technologies in water treatment or distribution, but to search for a novel institutional framework in developing management and practices of urban water services. Issues of rural water services are intentionally excluded from this research. The literature survey takes an international view, while the emphasis of the thesis is on the developmental part of Finnish water management and practices. The following list of significant aspects is set by the author as basic points for sustainable and resilient water services.

I. quantity and quality of water resources concerning all types of water use
II. sufficiency of good drinking water
III. functionality of water services, for human health and the environment
IV. resilience of water services, especially in disasters
V. value of water services to the society

The following research questions are set for reaching the objectives of the study:

a) What is the significance of sustainable and resilient urban water services for a community and a society?

The question concerns various aspects in water services, and this study emphasizes institutional aspects and socio-economic aspects not forgetting technical requirements. To simplify the assessment of the question and the aspects, the operation is divided to core functions and supporting functions. The core functions are crucial to successful water services, such as raw water intake, water treatment and distribution, wastewater collection, treatment and discharge back to natural waters, as well as sludge treatment, recycling and disposal. Supporting functions are needed for making core functions possible, including for example accounting, human resources and training, management of water utility and maintenance of technical facilities.

Such aspects of sustainability and resilience that are seen most relevant by the author are explored in particular. Definitions have been viewed among others in Brundtland (1987), IUCN (2006) and UNISDR (2009) and their applicability to water sector by Koop and Leeuwen (2015) and by Renou and Bolognesi (2019). Resource efficiency, economy of water utilities, pricing policy as well as environmental and social issues are regarded important in sustainability. Competence of personnel, good governance, proper management and practises, climate change effects, asset and data management are taken into account especially in resilient water services.

b) What kind of management and practices provide sustainability and resilience to urban water services?

The question is assessed by studying the scope of green economy and society, stakeholder institutions and their role, and how resilient water services fit in a society obeying these principles. In addition to technological and economic issues, institutional and socio-economic issues, good governance as well as education and knowledge are also important. Important aspects when considering this question is the significance of good management and practices for reaching sustainable and resilient urban water services. For finding answers, a wide range of stakeholders must be contacted for finding out their views and experiences. For understanding these aspects, the whole urban water cycle and its integration to natural water cycle, as well as urban material and energy cycle, have to be recognized.

The research questions set may sound simple as such. However, real world challenges behind those questions are complicated and complex. Population structure, living standards, lifestyle, rules in society, technology, and institutional framework are all changing adding pressure to communities' water services. The objective is to find apprehensible answers to these questions which would contribute towards more rational sustainable and resilient urban water services.

1.3 Structure of the study

This study as a doctoral dissertation dates back to the long experience of the author in several branches of water sector. The author has been working with hydrological survey and research, development of automatic monitoring and modelling of water resources (licentiate thesis), design of automation of water supply, training, operation of water treatment plants, consulting in several national and international projects as well as research and development of water services.

This dissertation includes four scientific articles representing a novel view of advanced water services. The coherent whole connecting these results and visions is expressed in this synthesis. Chapter 1 gives the background of the field of action, as well as this structure of the dissertation. Chapter 2 explains in more details the conceptual framework of the field and its challenges. Research approach and methodology of the study are presented in Chapter 3. The results of the whole dissertation are presented in Chapter 4. First, the results of different articles and their contribution to the whole study are shortly outlined, followed by a summary as a sequential PESTEL and SWOT analysis. Discussion in Chapter 5 includes an assessment of the results considering the objectives and outcomes of the research. Conclusions and recommendations for future activities and targets for development are presented in Chapter 6 which also includes the summary of the answers to the research questions.

This dissertation consists of four articles and this conclusive summary as a synthesis of them and their results. Figure 1 shows the conceptual structure of the whole study, and how different articles contribute to the coherent whole. The whole field of urban water services is included in this research, although some aspects, for example water treatment technologies, have not been thoroughly observed and analyzed. This research concerns on institutional aspects of water services, and it would not be expedient to scatter the main research subject to technical details. Rural water services are also excluded, because the problems and challenges there are quite different to urban ones.

Proper data management is a prerequisite for sustainable urban water services, and it is considered such an important aspect that one study concentrates on it. Secondly, for sustainability and resilience of urban water services in the future, resource efficiency and green house gas emissions have been raised as the key elements, and they are studied in the second article. This dissertation does not include technological details and the third and fourth articles concentrate on water services as part of future society and sustainable green economy.

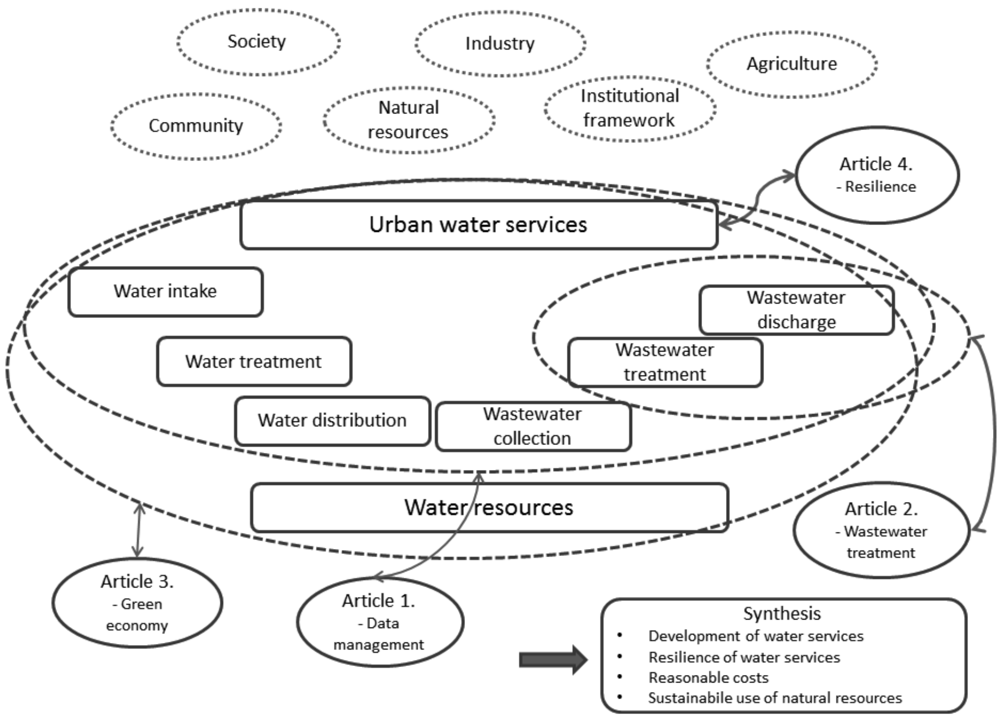

Figure 1. Structure of the study, based on the cycle of urban water services

The first article contains development of data management systems concerning water services and water utilities in Finland. It covers both water supply and sanitation, and mainly concentrates on urban water services. The second article is the only one which somewhat concerns water treatment technology; it is a case study of resource-efficient wastewater treatment in developing economies, in this case Mexico. The reference calculation is, however, a typical Finnish wastewater treatment technology, activated sludge process. Article III is a study of water supply and sanitation in a concept of green economy. It shows how the principles of green economy are closely present in the water sector and how they are very easily applied to water services. Article IV is about sustainability and resilience of urban water services, pointing out the importance of resilient water services for a society.

The research methods that are considered suitable for this approach are mainly qualitative. These methods suit well for a research concerning institutional aspects of water services. The individual methods are chosen to give a wide view to this sector, and they are described more detailed in Chapter 3.

For finding the logic for objectives of this study, a Logical Framework Approach (LFA) is applied. LFA was developed in the US Agency of International Development in the late 1960's to improve project planning and evaluation (EC 2004). It is a strong tool in project management and it can be used throughout the project cycle. In this study it is used for presenting and illustrating the objectives, purpose, results and activities in LFA's Logframe Matrix (Table 1). This gives a possibility to get an overall understanding of the logical framework of the research in one table. The indicators and verification are not applied in this study but are given as an example for long-term action. This matrix shows the logical approach to this research, and its conceptual framework is explained in the literature review in Chapter 2.

Table 1. Logical Framework Matrix of the study, according to Logical Framework Approach (EC 2004)

Summary description	Performance indicators	Source of verification	Important assumptions
Overall objective Sustainable and resilient water services	Number of incidents in health or environment	Evaluation	
Purpose Good practices and management in water utilities, authorities, device and service providers recognized	Satisfaction of customers and authorities	Authorities, questionnaires	Risk prevention
Results Knowledge of better performance in water utilities	Satisfaction of personnel	Owners and management of water utilities	Qualified personnel
Activities Immediate measures in water utilities are recommended	Number of training occasions, measures started in a year	Management and personnel of water utilities	Resources, appropriate technology in use

2 CONCEPTUAL FRAMEWORK

2.1 Significance of water services

"The global water supply, treatment, and distribution sector is a critical enabler of our society: it guarantees our food, sanitation, health and well-being. Without it, everything else in the €69.8 trillion global economy would fail. Global trends, however, forecast 55% worldwide growth in water use by 2050, due to growing demands from manufacturing, thermal electricity generation, agriculture and domestic use, all increasing the pressure of human activities on our freshwater sources. Furthermore, water quality is declining due to urban, industrial, and agricultural pollution, impacting on the availability of water of sufficient quality for users. Diffuse pollution significantly affects 90% of river basin districts, 50% of surface water bodies and 33% of groundwater bodies across the EU." (The European Water Platform 2017, 8)

The description above gives an idea of the global value and significance of water and water services to communities and societies. Each country has its own challenges to tackle. Some areas have severe problems with water scarcity, some with flooding, some with water quality and some with institutional drawbacks and inactivity. To recognize the value of adequate water services, wide knowledge on activities of society is needed. In managing water sector, there are several policies, approaches and modes of operation, depending on their nature. In the case of water scarcity, environmental and technical solutions play a larger role (Kummu et al. 2016). However, quite often when talking about resilience, adaptation to changing circumstances and equal rights to water services, policy, institutional strengthening and strategic planning become more important (Nikolopoulos et al. 2019; Falkenmark et al. 2018; Rodina 2018).

The aspects mentioned above play a remarkable role especially in developing economies. Hoque et al. (2019) made a social-ecological analysis of drinking water risks in Bangladesh. They were especially concerned about policy, management and practice of building water supply infrastructure without adequate hydrogeological analysis and institutional coordination. In this manner the country is failing to provide basic drinking water services for millions of poor people in difficult hydrogeological contexts. They applied a social-ecological approach in their research and argue that institutional coordination and hydrogeological monitoring at the system level is necessary to mitigate socio-ecological risks for more equitable and efficient outcomes.

In developing economies development of data management improves management of water services. Van den Homberg and Susha (2018) examined data ecosystems in Malawi with relation to reporting on SDG 6.1.1 (Proportion of population using safely managed drinking water services). They concluded that the characterization of the data ecosystem using the framework proved useful as it unveiled gaps in data at geographical level and in terms of dimensionality (attributes per water point) as well as collaboration gaps.

Water affordability problems in developed countries were explored by Vanhille et al. (2018). According to them, public authorities that define water tariffs face the challenge of reconciling environmental and cost recovery objectives with equity and financial accessibility for all. This is an important part of SDGs (SDG 6), and a challenge not limited to developing economies. The paper illustrates how the constructed needs-based indicators can complement existing affordability indicators, and capacity to reveal important risk groups. The SDG 6 aspects were also observed by Robina Ramirez and Sanudo-Fontaneda (2018) in Soweto, South Africa. They emphasized the ethical view of managing water policies through principles of 'human dignity' and 'human equality'. Their results showed that water services can be highly improved through human water management, a model that can be applied to other developing areas in the world.

Usually in developed economies, although water is considered as a human right for everyone, it is recognized that water services have a cost to be paid by consumers. In developing economies this is not always the case and there are different kinds of tariff policies. For example, in Ecuador the government has defined the minimum quantity of water required to be provided for free by drinking water utilities (Martinez Moscoso et al. 2018). This is a novel approach to water rights in the world. The authors integrate and assess how this approach affects the most vulnerable people. In Spain the water services costs reflected to other uses of water resources have been calculated by Pedro-Monzonis et al. (2016). They linked water planning and Integrated Water Resources Management (IWRM) to a tool called the System of Environmental-Economic Accounting for Water (SEEA-W). Water pricing is an important policy tool in urban water management and it is assessed for example in Italy by Romano et al. (2015), and in Finland by Heino et al. (2011) as well as by Heino and Takala (2015).

2.2 Institutional setup of water services

Water crises and challenges concern all communities and societies worldwide. It is especially a problem in rural areas in some developing economies but in recent years there have been alarming news on severe water crises in urban areas (Mitlin et al. 2019). There are studies that indicate that it is a challenge in some cases also in the developed world. Mosley et al. (2015) compared situations of water scarcity in Detroit, USA, and in Monrovia, Liberia, especially from the point of view of women. They found out parallels between these water, human rights, and reproductive justice crises. Increasing meteorological and hydrological phenomenon, like floods and droughts, have been studied as impacts of climate change. Manouseli et al. (2018) combined this inspection to population and lifestyle changes, and concluded that the UK may face a supply-demand gap by the 2080s.

Privatization and corporatization have been seen as solutions for water problems by some countries and large multi-national water companies. In recent years it has been discovered that this is not the case and, on the contrary, these measures may decrease access to water services for the most vulnerable people (Mitlin et al. 2019). Caldaza et al. (2017) studied the effect of lack of economic resources and the geographical dispersion of the population to the water provision in Peru. They stated that water services are not operating well, and community-managed water systems might emerge as an alternative mechanism to provide safe water. According to their results, it seems that that kind of approach would work in Peru, provided that there is adequate supervision to ensure that water systems are correctly designed and managed and that internal governance problems do not compromise their sustainability.

Private sector is nowadays an important partner to public water providing organizations, but rules and practices must be clear and agreed on. Ameyaw et al. (2017) considered private sector participation important and presented the results of an investigation of critical success factors (CSFs) required for attracting the private sector in water supply projects. In water projects, they found out that to attract private sector to public private partnerships (PPP), what is required is political commitment, existence of a dedicated PPP unit, strong and competent public water authority, adequate fiscal capacity of a national authority, public acceptance and support of involvement of the private sector in water services, a well-designed PPP contract, existence of enabling policy and legal frameworks to support water PPPs and profitability of water supply projects to attract investors and lenders.

In Kosovo, after the war in the late 1990s, as an emerging economy, water services were slow to develop to provide sufficient potable water and adequate wastewater services to their citizens (Begolli and Lajci 2016). They describe how they succeeded to complete the reforms concerning institutional and legislative framework by 2008. This work required a totally new view to sustainable water services and implementation of new water administration. This is a good example that institutional and technical development of water supply can succeed even in relatively short time, when ambition and motivation is high.

2.3 Sustainability and resilience

2.3.1 Sustainability and resilience in urban water services

Butler et al. (2016) identified four types of intervention to negative consequences; mitigation, adaptation, coping and learning. These actions all strengthen a system's sustainability and resilience. They explored water management which include water services, and that was in a major role in their study. Adaptation measures are often considered to be adaptation to climate change, but they are part of resilience concerning any threat to the system. Adaptation measures include functional failures and techniques how to manage towards them.

In a recent study on resilient water services Juuti et al. (2019) give definitions and views about sustainability and resilience concerning water services. In the conclusions they emphasize local knowledge and bottom-up approach when increasing resilience. Good governance and awareness of historical development are important aspects when developing resilient water services. Flexibility and adaptability are essential components of resilience according to Leigh and Lee (2019). They studied the development of decentralized water systems which they considered more resilient and resource-efficient than a conventional centralized system. Adaptive management would give a practical approach to increased resilience of urban water systems by combining physical and institutional development to resilience strategies.

Koop and Leeuwen (2015) analyzed 45 municipalities in 27 countries using the improved City Blueprint Framework (CBF). They categorized five different levels of sustainability of urban Integrated Water Resources Management (IWRM): i) cities lacking basic water services, ii) wasteful cities, iii) water-efficient cities, iv) resource-efficient and adaptive cities and v) water-wise cities. They emphasized the importance of effective governance, environmental awareness and community involvement for sustainable IWRM.

There are different views on the scheme of physical water systems. Some researchers and experts endorse centralized systems while others prefer decentralized ones. Sapkota et al. (2016) compared the combination of centralized and decentralized water systems approaches with an existing centralized system in Melbourne, Australia. They discovered that this kind of a hybrid water system both reduced potable water demand and altered wastewater flow and contaminant concentration. This improved resilience to the water system and to variable climate conditions.

The paradigms of sustainability and resilience in the built environment were studied by Lizarralde et al. (2015). They found out different interpretations of these terms which might explain tensions that occur when the paradigms of sustainability and resilience are translated into policy instruments. They called sustainability 'green' and resilience 'blue' and concluded that more refined tools and conceptual frameworks are needed to successfully achieve a turquoise agenda in the built environment.

The nature of urban water services is that they are somehow invisible; drinking water comes from a tap and used water goes to a sewer, and outside a building these pipelines cannot be seen. A major challenge is to make the currently largely invisible water services and infrastructure more visible to decision-makers and citizens. Howe et al. (2011) listed various scales in urban water systems depending on users (households, communities, cities), institutions (service providers and regulators), technologies and ecosystems for considering urban water resilience.

In some projects concerning resilient water services, scientists have defined new methods or applied methods earlier used for some other purposes. Diao et al. (2016) developed a new method for assessing the resilience of water distribution systems which they called a global resilience analysis (GRA). It is for approaching the problem by defining three typical failure modes: pipe failure, excess demand and substance intrusion. The analysis proceeds in four steps, giving approaches for different situations with different failure modes and range of strains. Lehrman (2018) used the so-called Sankey diagrams for engaging water policy makers on issues of social and environmental justice, ecological water use, sustainability, recreational access and urban/rural issues. The purpose was to create resilience by graphically combining different stakeholders' views so that different views are illustrated.

Cities generate more than 80 percent of the gross world product (GWP), and therefore the resilience of cities is necessarily important to maintain (Koop and Leeuwen 2017). For this, sustainable water services are crucial and in the transition towards smarter cities, water issues play a significant role. Urban water security is strongly related to resilience and mechanisms of good governance (Hoekstra et al. 2018). It is also significant that the performance of water utilities could be measured for indicating their sustainability and resilience. This needs a wide variety of relevant indicators (Berg and Marques 2011; Seppälä 2015). It is important that, in addition to indicators for the performance of the physical infrastructure and operation, there are also indicators illustrating management and financial performance. These include for example indicators of asset management, capital procurement, renovation of networks and financial performance. Hoekstra et al. (2018, 12) point out that "We need to better understand the full potential of water-sensitive design, rainwater harvesting, recycling, reuse, pollution prevention and other innovative urban water approaches". This is highly applicable with the approach of IUWM (GWP 2011).

2.3.2 Aging water infrastructure as a risk to resilient water services

Aging water infrastructure is an ongoing debate and an increasing concern in providing and producing continuous water services. In countries where legislation makes municipalities responsible for providing or arranging water services, it is important to see the distinction between service providing and production. For example, in Finland, it is often the same water utility, but this is not always the case. Katko and Hukka (2015) emphasized this distinction and visualized it with a four-level scheme; a) institutional framework, b) water services provision, c) water services infrastructure, and d) water services production. This clarifies the asset management responsibilities quite well.

Cardoso et al. (2016) developed and applied an infrastructure asset management (IAM) methodology. It requires water utilities to consider that the infrastructure has system behavior and lifespan, which are indefinite and guarantee the full-alignment of IAM planning with organization objectives. Alegre et al. (2016) required long-term vision and sound transition paths for water utilities in their asset management of urban water infrastructure. They examined the concept of sustainability, explored pressures and drivers, and developed and tested a road mapping methodology to cope with the implementation of disruptive solutions. In Finland, asset management in the water sector has been studied by Vinnari and Hukka (2010).

Aging water supply and sewer networks in cities are subject to risk resilience of urban water services. Krueger et al. (2017) studied how to enhance water and sewer network resilience to external and internal threats. They implicated the connection of efficient planning of networks and observation of expected topological features. Water supply and sewer networks are technically and financially remarkable parts of sustainability and resilience in water services, although these are not the only aspects in water and sewer network management. Sustainable water demand management (SWDM) was defined by Arfanuzzaman and Rahman (2017) in their study on Dhaka city, Bangladesh. In their analyses, they covered the present condition of water demand, supply, system loss, pricing strategy, groundwater level and per capita water consumption. The main idea was to reduce the water footprint and pollution. To achieve SWDM, a variety of methods in political, financial, technical and legal control are needed, e.g. 100 per cent coverage of metering, pricing policy on water withdrawal, development of surface water sources and penalty or discount in relation to the consumption goals.

2.4 Resource efficiency and circular economy

Resource efficiencyand circular economy have become more and more significant issues of policy and development debate during the recent years. They are remarkable aspects in planning urban management, including water services. Water is often connected with energy and environmental issues when considering circular economy and sustainability (Baleta et al. 2019). Also Water-Energy-Food Nexus has been used as a systematic approach in policy settings (Albrecht et al. 2018). This nexus has been documented among others by the United Nations Food and Agriculture Organization (FAO 2014) suggesting that these three resources are thoroughly interrelated.

Albrecht et al. (2018) found out that for addressing complex resource and development challenges, mixed-methods and transdisciplinary approaches are needed that incorporate social and political dimensions of water, energy, and food; utilize multiple and interdisciplinary approaches and engage stakeholders and decision-makers. Some scientists have expanded the Water-Energy-Food Nexus scope with land use and climate (Laspidou et al. 2019). Water was found to be the resource most prone to be influenced by the other nexus elements.

These approaches are discussed with the challenges of resource scarcity, climate change, global warming and environmental burden. Current challenges in the water sector, such as increasing population, mounting environmental pressures, and aging infrastructure all require better efficiency in resource use. Life Cycle Analysis (LCA) and Life Cycle Costing (LCC) are methods that can be used for assessing the sustainability of water services from water intake, treatment, and distribution to wastewater collection, treatment, and discharge (Arden et al. 2018). One important part in wastewater management, when talking about resource efficiency and circular economy, is recycling of energy and nutrients, especially phosphorous (Leaf 2018).

Urban water services form a man-made water cycle within a community. This cycle is related to and dependent on natural hydrologic cycle where water comes from the atmosphere down to earth by precipitation, runs to surface waters, infiltrates to soil and groundwater and evaporates, directly or via vegetation, back to the atmosphere. Communities draw raw water for domestic water, purify and distribute it via their water supply networks. Wastewater is collected to the sewer network and led to wastewater treatment plants. After the treatment process, purified wastewater is discharged back to natural waters where it is again part of the hydrologic cycle. This urban water cycle also obeys the rules of circular economy where material and energy are recycled as efficiently as possible. Relationships between these cycles are illustrated in Figure 2, taken from article III of this dissertation.

Effective water use, and integration of water and waste issues in urban development, are approached in Integrated Urban Water Management IUWM (GWP 2011)). Traditional urban water management does not consider water, sanitation and storm water management, and water resources pollution as a whole in urban water management. Instead, each has been planned and implemented as a separated service. IUWM is closely interrelated with IWRM, and together they could grant a good possibility for sustainable and resilient water management and practices within watersheds including both urban and rural water use.

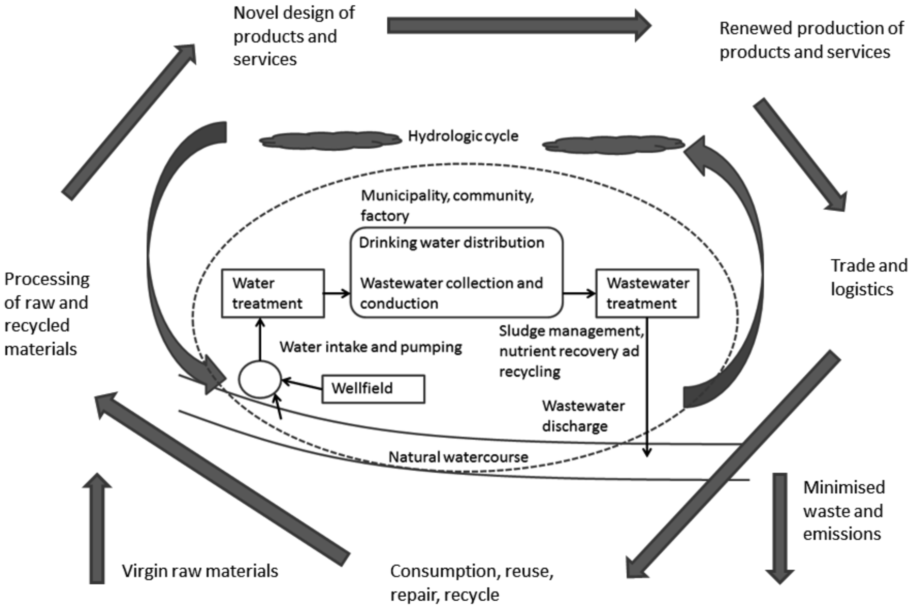

Figure 2. Relationships between hydrologic cycle, urban water cycle and principles of circular economy, presented in Article III

This water cycle and its relationships are crucial to understand when developing sustainable and resilient water services. In situations of water security, efficient use and recycling of water gives a possibility to assure the best possible water services for the community. Resource efficiency and resilient urban water cycle has been assessed in New York City, Boston, Milwaukee, Phoenix, Portland, and Los Angeles, USA, by Feingold et al. (2018) and as a comparison between China and Europe by Moro et al. (2019).

In talking about new approaches in wastewater management, some experiments have been made in source separation of black water and grey water, which could provide better possibility to treatment, reuse and heat recovery. This infrastructure solution has been tested in Frankfurt, Germany (Zimmerman et al. 2018), Qingdao, China (Tolksdorf et al. 2018) and Tampere, Finland (Malila et al. 2019). New approaches have been invented because of exhaustion of non-renewable resources and environmental pollution exceeding the capacity of the planet (Tretyakova 2019). Eco-city and eco-development thinking have increased, giving a start to new water and environmental policy, decision-making and urban nexus in resource management and infrastructure planning (Xie et al. 2019, Schramm and Nguyen 2019).

2.5 Management and practices in Finnish water services

First water and sewer networks in Finland were built in the early 19th century (Katko 2016, 87). The main length of the networks has been built after 1960, and for the time being more than 90% of the population is connected to water network and more than 80% to sewer network. The majority of the urban population is served by a municipal water utility. However, in small settlements, water supply and sanitation is often organized by water cooperatives where citizens arrange their water services themselves. This has resulted in a situation where there are more than one thousand water utilities in Finland, a country of 5.5 million people. Large water utilities are operated by a very well educated staff, whereas small organizations are operated more or less by voluntary workers.

According to Water Services Act 681/2014 municipalities are responsible for water services. However, a municipality can purchase services from private companies, and even the whole operation of a water utility can be managed by a private service provider. This is not common at the moment but cooperation between public and private operators is common and functional. Government, municipalities, private companies, NGOs and individuals all have their important roles in successful water services. The institutional framework of Finnish water services is illustrated in Figure 3.

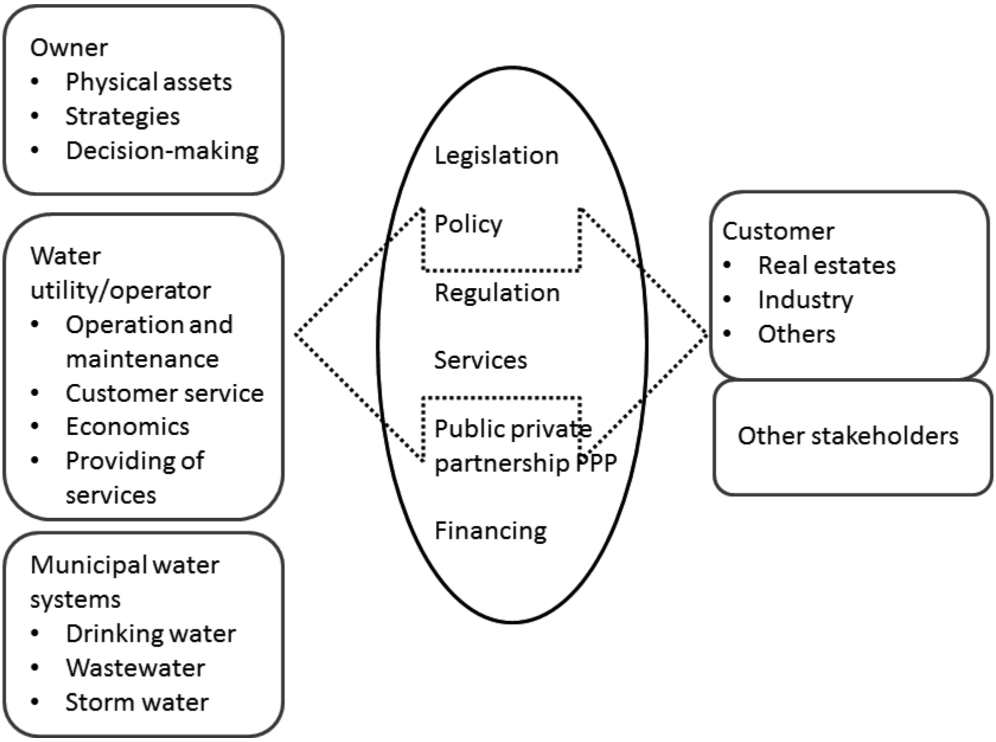

Figure 3. Illustration of institutional framework of municipal water services, presented in Article I

It can be stated that Finnish water services are operational, as the tap water in all households connected to networks is potable and wastewater is treated properly. Water utilities mainly operate with full cost recovery principle, making the operations economically sustainable. There are exceptions, especially in small utilities, but large water utilities are working independently with the income from water fees. The future challenges include climate change impacts, deteriorating networks, and security both in drinking water and in wastewater (Silfverberg 2017, 32-33; Katko 2016, 86-103).

This chapter indicates the conceptual framework of this study. It concludes the main subject that is studied using the approach and methods presented in the next chapter.

3 RESEARCH APPROACH AND METHODOLOGY

3.1 Methods used in the studies

This chapter describes the research approach, materials and methods applied in the separate studies of this research. To best respond to the set objectives and outcomes of producing new and novel knowledge and understanding to achieve more sustainable and resilient water services, a variety of research methods were used. Specific methods used in different studies and articles are outlined in Table 2 alongside article titles and objectives.

In Article I, the action research method is used, added with workshops and interviews of stakeholders. The action research method is often applied in organization development projects but its philosophy may also be applied in other development processes. This method was found practical to be used within a study and an implementation of a new data management system. Design and programming of the system took three years. The size of the active project team including experts in water services and information technology varied from six to ten persons during these years. Additionally, there were several workshops and interviews of stakeholders and future users of the system, concerning e.g. data entering, reporting, and benchmarking.

Table 2. Summary of articles' specific objectives and research methods

No.	Article	Objectives	Method
I	Advanced information management enhancing better performance in Finnish water utilities	To form an understanding about data and knowledge management needed for administration of advanced water supply and sanitation. For reaching this objective the study is divided into three parts: a) a literature survey of the corresponding studies b) a thorough study of the needs in data and knowledge management in Finnish municipal water sector and c) an assessment of the impacts of the new approach and system.	Literature review, action research, workshops, interviews (semi-structured or non-structured).
II	Resource-efficient wastewater treatment in a developing area – Climate change impacts and economic feasibility	To compare CO_2 emissions and economic viability of constructed wetland and an activated sludge process as a wastewater treatment technology.	Literature review, Life Cycle Analysis (LCA), economic viability analysis
III	Water supply and sanitation in a green economy society: the case of Finland.	To enhance the general understanding of the role of water services in a society that has adopted the principles of green economy by applying resource efficiency and circular economy. Water services are considered as part of the water supply and sanitation drawn from natural water resources for households and also the wastewater management, treatment, and discharge back to recipient waters.	Literature review, phenomenology, workshop (n = 68) of stakeholders and experts
IV	Resilient water services for the 21st century society – stakeholder survey in Finland	To find out what kind of institutional aspects should be developed to strengthen the resilience and sustainability of Finnish water services. This study concentrated on Finnish urban water services and their resilience by surveying points of view of stakeholders regarding the value and best practices of community water services.	Literature review, stakeholder survey by a questionnaire (net-based, pretested by 4 experts, n = 99)

The study was carried out along with the implementation of the water services data management system, and basic data was received through questionnaires, workshops and interviews with the stakeholders and experts. A questionnaire on data communication was sent to 65 utilities, out of which 45 (69%) replied. The questions were closed-ended with a possibility for open comments. The questionnaire was not tested beforehand but it was planned by an expert group of four persons. The action research approach was used by making an identification of the situation, then drawing up a scenario of the objective and assessing the effectiveness with a group of future users of the system, and finally by planning how this new system will become an established practice. The related data security and quality aspects are dealt with in other projects and thus they are not included in this paper.

In Article II, for assessing and comparing the effects of greenhouse gas emissions and economic viability of two wastewater treatment processes, Life Cycle Analysis (LCA) and economic viability analysis were carried out. The analysis concentrates on the climate change impact of wastewater treatment but uses a system expansion by allowing for the so-called substitution or avoided burden method (Guinée et al. 2002) by including the emissions avoided from activities that may potentially be replaced by the use of wastewater-derived outputs. Therefore, the analysis distinguishes between direct contributions from wastewater treatment, and indirect upstream contributions (e.g. provision of energy to the treatment processes), but also accounts for downstream contributions from processes that may potentially be replaced by end products from wastewater treatment. The start of the system boundary in the analysis is drawn at the raw sewage arriving at the wastewater treatment plant and the end is at the point where the outputs have been transformed into a form where they can be utilized instead of virgin resources.

Further in Article II, the analysis of economic viability is performed by comparing the investment and operational costs of the planned constructed wetland in Mexico (including sludge and water hyacinth biomass digesting) with a conventional activated sludge process (including sludge digesting). Estimated costs of the wetland are based on values provided by a consultant designing similar plants in Latin America and a financing proposal prepared by North American Development Bank in 2012. The costs of an activated sludge plant are based on Finnish data reported for a compilation of best available technologies (BAT) of municipal wastewater treatment plants in Finland (Laitinen et al. 2014). In this case the main part of the costs are the investment costs including equipment, and these costs can be considered as comparable in Finland and Mexico. Social and environmental conditions between these countries are different but this brings no significant difference to these calculations as the need for labour in the plant operation is low.

A large workshop (n=68) for stakeholders and experts was carried out in Article III. This was done after a thorough review of literature and international declarations of the theme. The approach is phenomenological; first the concepts were studied thoroughly and then the relevance of different views were compiled after the discussions and interviews. Phenomenology is defined in Stanford Encyclopedia of Philosophy as following: "Phenomenology is the study of structures of consciousness as experienced from the first-person point of view. The central structure of an experience is its intentionality, its being directed toward something, as it is an experience of or about some object. An experience is directed toward an object by virtue of its content or meaning (which represents the object) together with appropriate enabling conditions." (Smith 2013, 1). This approach was considered to fit this study due to its nature of combining different aspects in human life and society. In the workshop, invited speakers (n=9) from several stakeholders first presented their special topic's views of the water sector related to green economy. Further, four questions (presented in the results of this paper) were considered in four discussion groups while the facilitators (n=5) offered additional topics. The 68 experts included representatives of authorities, research institutes, water utilities, consultants, and NGOs.

The study in Article IV was carried out via a literature survey and a questionnaire sent to 470 experts representing key water services stakeholders. Altogether, 99 replies were received (response rate 21%). The coverage of respondents was as follows: water utilities (44%), other water companies (19%), governmental organizations (14%), private companies (7%), municipalities (6%), universities (4 %), and other miscellaneous bodies (6%).

The questions were formulated to gain an understanding of expert and stakeholder points of view regarding the following major aspects:

i. Significance of water services failures and their significance in urban water services.
ii. Policy instruments and impact methods for ensuring continuous service in water supply and sanitation: a. pricing policy b. institutional strengthening c. service reliability, d. development planning.

The majorityof the 15 questions were formulated, out of them 10 dealt with substance and five with the background of the respondent. In three questions the respondents were asked to assess statements or arguments using a scale from 1 to 5, one question was completely open-ended. The majority of the questions included several alternative means or proposals for improving the current situation, out of which 1 to 3 were selected and ranked. This way it was possible to get a balanced overview on how the experts in water services prioritize the selected questions related to resilient water services in Finnish conditions.

Before sending the web-based questionnaire, it was pre-tested by five experts. In the beginning of the survey, a short description of all the questions was presented for giving the respondents an overview before they replied specific questions.

3.2 Sequential PESTEL and SWOT analysis used for synthesis of the research

For synthesizing the results of the four articles to the coherent whole of this research, a sequential PESTEL and SWOT analysis was carried out. This analysis was implemented by the author himself but the data came from the workshop and questionnaire that carried out within these studies. PESTEL and SWOT are analytical tools that are usually used for strategic planning, decision-making and action planning. When used together sequentially, they help in identifying key internal and external factors that should be taken into account in projects and initiatives. (UNICEF 2015)

According to UNICEF (2015) the SWOT framework is illustrated as a matrix, Table 3.

Table 3. Summary of articles' specific objectives and research methods

	Favorable or achieving the objectives	Unfavorable for achieving the objectives
External origin	**Opportunities**	**Threats**
Internal origin	**Strengths**	**Weaknesses**

PESTEL is often considered as a complementary tool to SWOT for looking in detail at external issues. The term PESTEL comes from the domains that are considered in the analysis: Political, Economic, Social, Technological, Environmental and Legal. Sequential PESTEL and SWOT analysis is mainly used in specific project strategic and action planning as a basis of decision-making. They have been used in infrastructure and energy projects and, especially when evaluating environmental aspects (e.g. Darabpour et al. 2018; Turkyilmaz et al. 2019; Quiceno et al. 2019). In water initiatives they have been used e.g. by Srdjevic et al. (2012) in a reconstruction of a water intake structure and Ortega et al. (2019) in river basin management.

Usually sequential PESTEL and SWOT analysis is carried out by a group of eight to ten people representing different expertise groups. Especially in PESTEL analysis, it is recommended to give consideration of different factors to respective experts. In this study, a sequential PESTEL and SWOT analysis is used to define a conclusion of considerations of water services from the point of view of a water utility. This is done by the author himself, whereas the conclusions are made using the results of the workshop (n = 68) presented in Article III, and questionnaire (n = 99) presented in Article IV. Additionally, some recent books and reports concerning strategies of water supply and sanitation in Finland have been reviewed and taken into account in this analysis. These reports include Finnish Water Services (Katko 2016), Guidelines on water and wastewater services for 2020's (Silfverberg 2017) and Sustainable water services for the future – direction, steering an organization (Berninger et al. 2018). Results of the PESTEL analysis is compared to previous PESTEL analysis of Finnish water services carried out by Pietilä et al. (2010) and the by Katko (2016, 243-245).

The basis for carrying out this analysis is similar to UNICEF (2015). Execution of the analysis is adapted from Srdjevic et al. (2012), and was considered an appropriate mode of operation in defining significant factors in prospective urban water services. Srdjevic et al (2012) applied it for project preparation in a reconstruction of water intake construction. A modified scheme of this process is presented in Figure 4.

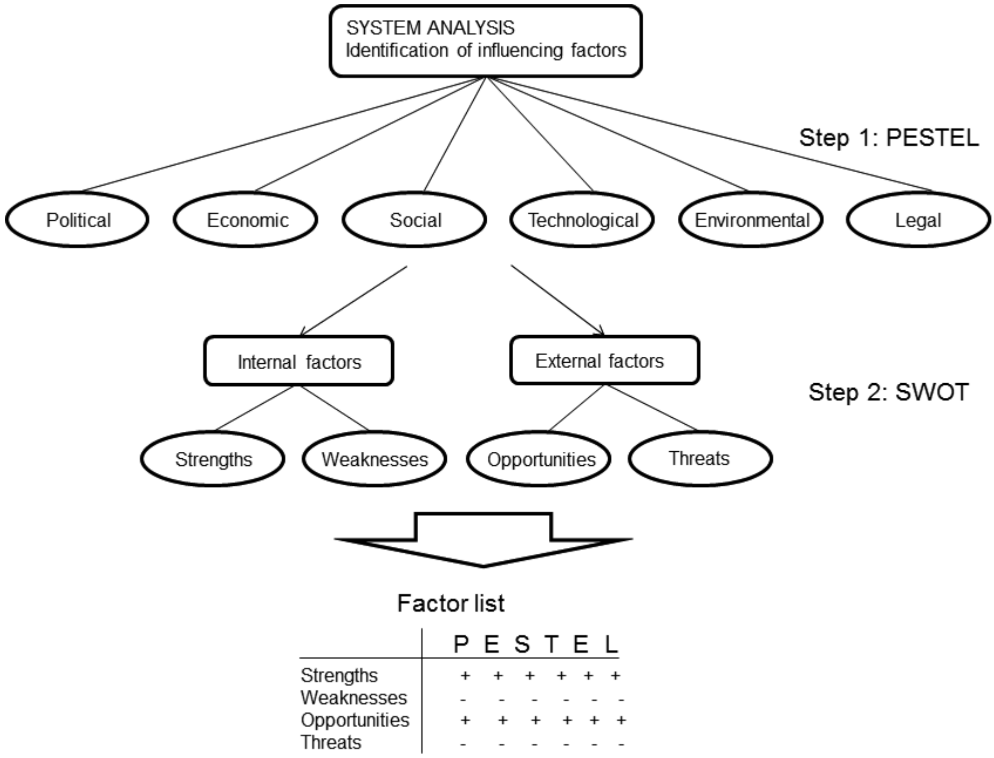

Figure 4. A scheme of a sequential PESTEL and SWOT analysis used in this study, modified from Srdjevic et al. (2012) by the author

The results and main findings gained using these methods are presented in Chapter 4. First results and main findings of the component studies are concluded, and then the results of the sequential PESTEL and SWOT analyses are presented.

4 RESULTS

4.1 Main findings of component studies

This chapter outlines the main results from the four peer-reviewed articles in relation to management and practices of sustainable and resilient water services.

The significance of appropriate data and knowledge management for running adequate water services as well as asset management was studied in Article I. The study was based on a literature review and an action research. The action research was applied by making an identification of the situation, then making a scenario of the objective and assessing the effectiveness with a group of future users of the system, and finally by planning how this new system will become an established practice. The article describes a case where a new data management system was defined and established within this process. The new procedure is that the water utilities use this system themselves and they are, in accordance with the new modified Water Services Act 681/2014, responsible for entering their data into this national data management system. In principle this procedure is more effective and flexible than the previous system, and it gives the water utilities as well as other stakeholders a real possibility to manage the data and knowledge of water services. The added value compared to the previous centralized system is not only in a more advanced data management, but also the decentralized responsibility. Through this procedure the data and information that is disseminated will be more reliable and useful not only for water utilities, but also for authorities, researchers and citizens. It is also noticed that asset management needs systematic data and knowledge management to be successful.

A chart of the new data management system (VEETI) for Finnish water services is illustrated in Figure 5. The new system is integrating all national data management systems, including information on urban water supply or sanitation. Water utilities are the main users of the system, and responsible for the quality of the data.

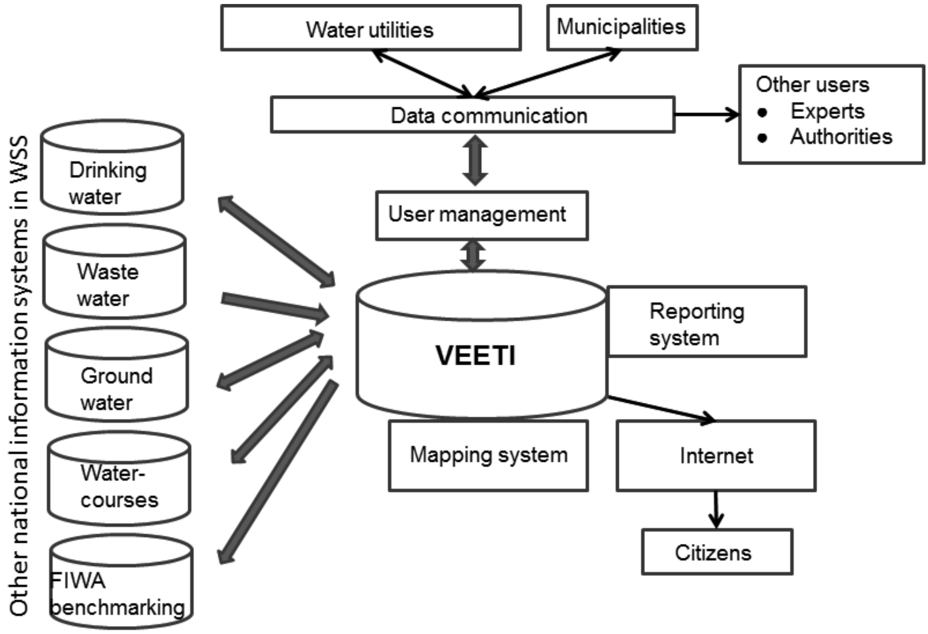

Figure 5. New national water services data management system

Article II assesses Life Cycle Analysis (LCA) and economic viability of two wastewater treatment technologies. Applicability of constructed wetland and an activated sludge process were compared in a case in Mexico. LCA was used for assessing greenhouse gas (GHG) emissions in CO_2 equivalents for the whole life cycle of a wastewater treatment plant. Besides purifying wastewater without chemicals, the aquatic vegetation in a constructed wetland can also be used as a bioenergy source. The analysis shows that not only does a constructed wetland do far better in comparison to a traditional activated sludge process where chemicals are used, but when used as a bioenergy source, it produces net greenhouse gas savings during the wastewater treatment life cycle. These results might have policy implications for Mexico and other warm climate countries. The application of water hyacinth for wastewater treatment, coupled with the production of biogas and utilization of nutrients and reclaimed water, addresses the needs for water pollution control, renewable energy development, and the emission reduction targets of the country. Furthermore, these gains can be achieved with lower costs than those incurred through traditional chemical wastewater treatment.

Due to savings in energy and chemical use as well as in investment costs, the cost-efficiency of a constructed wetland in a warm climate is two times better than that of a conventional activated sludge process. Economic considerations give further indication of the sustainability of the alternatives studied. The analysis shows that the process produces more energy than it consumes, gives satisfactory treatment results, and provides the possibility to reuse treated wastewater and nutrients on an economically sound basis. However, as the water hyacinth growth rate and its utilization potential for biogas production are crucial for both the WWTP's life-cycle GHG effects as well as economic profitability, the matter must be studied further to produce additional evidence.

Article III enhances the general understanding of the role of water services in a society that has adopted the principles of green economy by applying resource efficiency and circular economy. Water services are here considered to include water supply drawn from natural water resources for households and also the wastewater management, treatment, and discharge back to recipient waters. This article focuses on the Finnish case and Finnish water services. The research material was collected from literature, international declarations and through a large workshop of experts (n = 68). Key findings of this study were that for running water utilities more according to the principles of a green economy, attention should be paid especially to capacity building, sufficient legislation, circular economy, digitalization development and new business models. This particularly concerns the situation in Finland. In developing economies investments in the water sector are needed especially to enhance the benefits of green economy. These benefits can then be seen in health, environment, economic and social sectors. Although drinking water supply is often the first issue in the water sector, wastewater management is also essential in green economy. In the built environment, decent sanitation is a prerequisite for well-being and a good quality of life. Hence, green economy has to be just one part of overall community, urban, and land-use planning. Proper wastewater management is also necessary for safeguarding good raw water quality and other use of water bodies.

According to the structured discussions in the workshop, a summary was concluded illustrating the significance and probability of realization of the aspect. This classification is presented in Figure 6. It shows that challenges with capacity building, sufficient legislation, digitalization development, circular economy, and new business models were considered as the most significant, with the highest probability of realization.

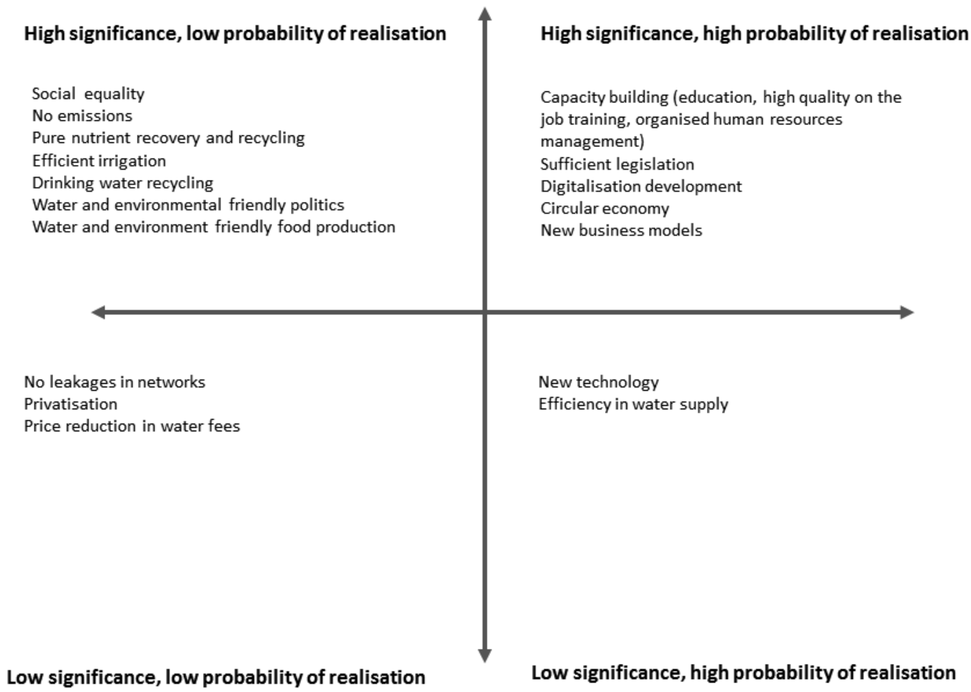

Figure 6. Key classification regarding the water supply and sanitation in the context of a green economy, presented in Article III

Article IV explored the development of resilient water services, especially the case of Finland. The research gap filled by this study was to develop a wider perspective on technical, institutional, and socio-economic aspects of resilient water services in Finnish conditions. The results show that reliable water services were considered a very important part of municipal services. Within water services, safe drinking water was considered the most important issue, while environmentally adequate wastewater management was seen almost as important. It is noteworthy that the price of water was not considered that important. This indicates that in Finland the price of supplied water is reasonable and fair, and in developing more sustainable and resilient urban water services, willingness to pay is considered quite high by the stakeholders. Concerning water utilities, economy was still regarded an important part of their operational management. The open question on major concerns in urban water services revealed that 23 percent of the respondents found economy one of the most important issues in management and practices.

According tothis study, technical resilience is considered strong in Finland. When water utilities are run in accordance to full cost recovery principle, it is easy to keep technical preparedness in good order. Institutional preparedness requires good consensus among water professionals, authorities and decision-makers. This necessitates continuous discussion and mutual understanding in development and implementation of water services. This is not only a question of technical service, but a question of wider socio-institutional principles, and how health and environment issues are dealt within the whole society.

Skillful and sufficient personnel were considered very high when asked which factors will ensure proper water services (Figure 7). Other topics that stand out in the chart are financing of rehabilitation, and also here raw water sufficiency, meaning both quantity and quality.

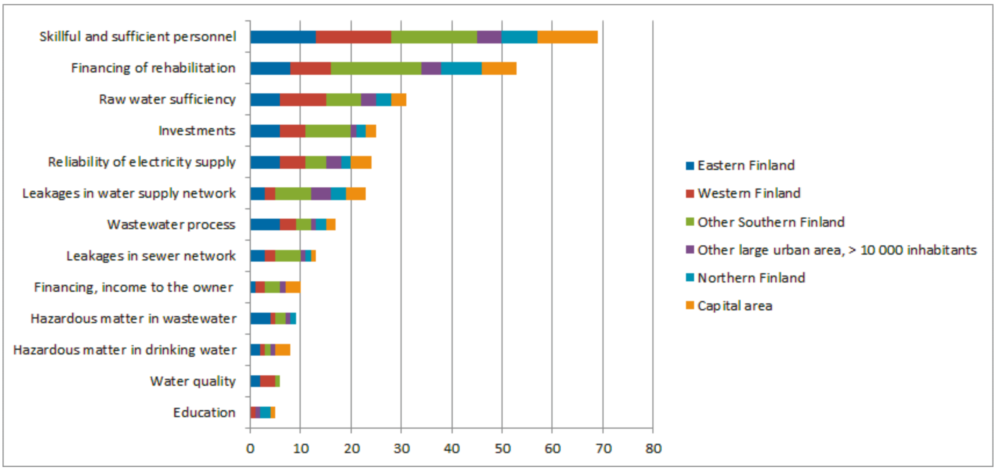

Figure 7. Topics for ensuring sufficient water services, illustrated by regions (in % of all answers), presented in Article IV

4.2 Observations of component studies

Providing adequatedrinking water for a community is essential for life and often considered as the most important part of water services. However, proper wastewater management is also essential for keeping water resources clean for any water use, and especially for source of water supply. One sustainable principle in wastewater management is that purified wastewater is at least of the same quality as the recipient natural water.

The principles of circular economy and resource efficiency can be assured by good management and practices, good governance, smart data and energy management, operation as well as balanced economy. Proper water services should be a human right for everyone. Operational water services need responsible participation not only from water professionals and decision-makers but also from all members of the society. This can be expressed with a subsidiary principle when management starts at the lowest level of a community. Individuals recognize the requirements, and developments are planned together with other stakeholders, water professionals and decision-makers. Keeping our water resources as well as the community water utility equipment in good condition requires common rules, understanding, and awareness of all members and individuals in the society. Full cost recovery is also an important principle for good and equal water services. For poor people this can be managed by an equitable pricing policy; it is important that people feel and know that although water is common resource and free for everyone, water services must be organized and paid by individuals of the society.

4.3 Sequential PESTEL and SWOT analysis

4.3.1 Basis to sequential PESTEL and SWOT analysis

The PESTEL analysis was used to find out the impact to the following factors (Darabpour et al. 2018):

- Political Factors: including pressures and opportunities brought by political institutions and the degree of the impact of government policies on water sector.
- Economic Factors: including economic structures and to what extent the economy impacts decisions can influence the trend for sustainable and resilient water services.
- Social Factors: including cultural aspects, attitudes, and beliefs that will affect the demand for adequate water services for all.

- Technological Factors: including technological aspects, innovations, barriers and incentives, and what kind of an impact these have on creating sustainable and resilient water services.
- Legal Factors: laws, regulation and legislation that will affect the operation of water utilities.
- Environmental Factors: ecological and environmental aspects that will affect urban water services.

Analytical tools PESTEL and SWOT are widely used in strategic planning, decision-making and action planning (UNICEF 2015). When used sequentially, the tool is stronger in identifying the internal and external factors. In urban water services these factors are also significant to assess. Various factors might be difficult to identify as internal or external, as well as whether their effect is positive or negative. Hence, in this study, sequential PESTEL and SWOT analyses were used for recognizing all PESTEL factors that affect urban water services and for finding a way to describe significant aspects in IUWM. Strengths, weaknesses, opportunities and threats can be assessed and shown in upcoming challenges in IUWM. Sequential PESTEL and SWOT analysis also gives an opportunity to summarize important results of this research.

The sequential PESTEL and SWOT analysis is executed for finding out a consistent view to sustainable and resilient water services management and practices in Finland. The result of the analysis gives also answers to the research questions set for this study.

4.3.2 Sequential PESTEL and SWOT analysis on Finnish water services

Starting with Step 1 in Figure 4, a PESTEL analysis was carried out for identifying the factors in PESTEL scope that are relevant in water services. PESTEL factors are studied both using the factor list given by UNICEF (2015), and checking for possible additional factors in this case. This is a different factor list and interpretation in various countries, and this analysis is done only concerning the Finnish situation. The statement for this analysis is ‘Sustainable and resilient urban water services from a point of view of a water utility’ (the top box in Figure 4).

4.3.2.1 Step 1, PESTEL analysis

POLITICAL

- Government and municipal policies. This is a very remarkable factor in this case. The main policies concerning water services and water utilities providing them are local, municipal level policies. According to the Water Supply Act 119/2001, the municipalities are responsible for providing water services in urban areas. There is no governmental regulator in Finland, and municipalities commonly both own and regulate this sector. This is the case for example in pricing policies. According to the legislation, a water utility has to be economically independent and do its accounts annually. However, it is stated that a water utility may only make a reasonable profit. Hence, the right practice is that a water utility and a municipality agree on the pricing policy according to the full cost recovery principle.
- Government resource allocations. This factor is important, but it is mainly a matter on local level. Often the water utilities are owned by a municipality, and there have been cases where a municipality as the owner of a water utility has collected remarkable profits from water accounts to cover other expenses. This is called hidden taxation and cannot be considered as good governance.
- Stakeholder needs or demands. A water utility has typically a diversity of stakeholders, such as customers, service providers, decision-makers or NGOs. According to good governance principles, the rights, benefits, and responsibilities of all of them have to be taken into account.
- Lobbying/campaigning by interest groups. There are EU directives that directly or indirectly concern water services. In some cases, politicians and NGOs very actively lobby on how those decrees should be applied in Finland. Also new or changing national legislation sometimes invokes active discussion, one example being the Decree on Rural Wastewater Treatment 157/2017 that has been under formulation and reformulation for almost 15 years. It was enacted on 1st of January 2004 (542/2003).
- Changes in power, influence, connectedness of key relevant actors/groups. This is an influential factor in practically all countries, and new governments might change legislation or institutional practices. The impacts may be seen after a change of government, or before elections when political parties are trying to gain votes.

ECONOMIC

- Economic situation: local, national, regional, global. Although water utilities are economically independent, common economic situation has an impact on water services too. In many Western countries the water infrastructure, and especially the water supply and sanitation networks have deteriorated without adequate renovation. This is, however, mainly due to lack of awareness and recognition more than economic constraints.
- Economic situation of specific relevant communities or population groups (including employment, taxation, mobility, etc.). According to United Nation's SDG 6 Clean Water and Sanitation, proper water services would be provided for everyone by 2030, special attention to be paid to women, girls, and those in vulnerable situation. While not a major problem in Finland, this is a huge challenge globally.

SOCIAL

- Demographics and population trends. In communities it is vital for land use planning as well as for water use planning to have good estimates about population trends. Migration from rural to urban areas is a significant factor considering water services.
- Health among populations. Water services are strongly affecting population health and well-being.
- Education levels, knowledge, attitudes and practices. Average education level of people can be seen in public awareness, which is a remarkable factor in common behavior, especially concerning sanitation. Attitudes to public services also play a remarkable role in water use and saving.
- Media views. Media has a large role in modifying perceptions, and this is reflected in all other PESTEL factors as well.
- Management style, staff attitudes, organizational culture (within a major relevant organization). This can be considered as the institutional framework of urban water services. It has traditionally been the responsibility of a municipal water utility which also takes care of operation and maintenance. In Finland there are also a lot of water cooperatives, which are owned and operated by the residents themselves. Regional cooperation and public private partnership (PPP) might sometimes be working solutions but there is actually no legislation or

regulation for that. Finnish water experts and stakeholders are quite unanimous that this institutional framework should be kept like it currently is.

TECHNOLOGICAL

- Patterns of use of existing technologies. Technology is developed continuously and it affects water services as well. During the last 20 years, water treatment technology used in Finland has been quite static. Now, when harmful substances, pharmaceutical residues and micro plastics have become a larger concern, also treatment technology is likely to change and improve with higher removal efficiency.
- New technologies that could impact the context significantly or that could be used to achieve objectives. One clear change in new technologies has been the so called smart water applications; use of advanced data and information processing systems. This gives an opportunity to continuously monitor and manage large amounts of data. This can be seen in sensor technology, automation, databases and modelling. This also makes it possible to disseminate good quality information to the public. Proper data and knowledge management is a prerequisite for adequate asset management which is considered a critical function in Finnish water utilities for the time being.
- Potential for innovation. It is very crucial for the success of future technological development that there is a possibility for innovations. This requires a good education system, the possibility to maintain skills, and sufficient resources. Adequate institutional framework and continuous capacity building are prerequisites to this, and also for the adoption of existing technologies.

ENVIRONMENTAL

- Contextually relevant environmental issues. The first impact of poor sanitation can be seen locally as contaminated water resources. This might dramatically impact water intake and the quality of water supply services. Climate change is a global issue affecting local water services in several ways. Increasing extreme weather conditions will bring more droughts and floods with direct impacts to water services, both to water supply and sanitation.

- Environmental impacts of planned or ongoing activities. Land use, urbanization, industrial activities, agriculture and all other forms of water use affect environment and quality as well as probably quantity of water resources.
- Climate and seasonality. Finnish climate has four clear seasons with warm summer and cold winter. Especially the winter with fluctuating low temperature, snow and ice is a challenge for arranging water services. Impacts of this aspect are expected to be stronger in the future due to climate change. This has to be taken into account in all stages of water services; water intake, treatment, distribution, wastewater collection, treatment, and discharge back to natural waters.
- Trends or expected future developments in the environment. Knowledge on the impacts of environmental issues to environmental state and human health increases all the time. This aspect is a factor that has to be taken into account when developing future water services.

LEGAL

- Human rights and ethical issues. It is a prerequisite for sustainable society that its water services are considered equal and equitable for everyone.
- Pending or future legislation. Legislation changes and becomes more complicated over the years. Water infrastructure should be continuously operative and major new investments should be made systematically. Major investments are made only seldom when environmental, health-related, or technological factors require them.
- International treaties/agreements, either existing or in preparation. EU countries have to follow EU legislation and regulation and be well aware of future requirements.

4.3.2.2 Step 2, SWOT analysis

The next step in sequential PESTEL and SWOT analysis is the SWOT section; to brainstorm the external (Threats and Opportunities) and internal (Weaknesses and Strengths) categories considering and reflecting those to the objectives and outcomes of the study. In processing the external categories, the results of PESTEL factors are the starting point. The factors were ranked (scale very important – important, not important ignored) considering the potential impact of them to the objectives and outcomes, and the likelihood of such impact. The results of the analysis are first listed with reasoning, and after that, as a conclusion, there is Table 4 with all the factors illustrated in a SWOT table. There are some factors that may be considered as threats or opportunities, or as weaknesses or strengths at the same time, depending on the local circumstances. An attempt at explaining this is made in reasoning of the factors.

OPPORTUNITIES

Governmental and municipal policies are considered a very important factor. It is an opportunity because the awareness of the importance of adequate water services in all stakeholder groups is very high. The likelihood of right decisions in policy-making is remarkably high when the views of the stakeholders are taken into account. One factor listed in the PESTEL analysis is **stakeholder needs**. This closely refers to the previous factor but due to its importance, it is considered separately.

Economic situation in Finnish water utilities has been quite stable during the last decades and it is a clear opportunity also in the future. The principle of full cost recovery is one important aspect for succeeding in strengthening the economy of all water utilities of the country. There are a lot of small water utilities with financial problems but it is more a matter of will and attitude than an economic constraint.

Management and operation of water utilities is on a high level in Finland and it can be considered as a very important opportunity to develop further water services. One important factor linked to this is **educated and skilled personnel** in water utilities, water authorities and research institutes as well as in private service providers.

Future legislation, international agreements and cooperation form a great opportunity for development. Finland is a small country with limited resources, and it is essential to have active global cooperation in all fields of operation, in research, education, legislation and technology development.

New technologies must be considered an opportunity, though we do not know yet what will be needed and what can be achieved in future. For the time being, at least data and information technology is developing fast and is also applied in water services.

Health and environmental issues are significant in water services. These issues may be both opportunities as well as threats, depending on several other factors outside the water sector. For turning these into opportunities, we need wide understanding and cooperation of several sectors in a society; land use, industry, agriculture, tourism and transportation.

THREATS

Government, and more importantly, **municipal resource allocations** can be considered as a very important threat for water services. Although water supply and sanitation should be an independent sector within municipal services, it is sometimes a part of municipal policy without any logical reason. Pricing policy should be completely defined according to the needs of water services, including all investments as well as operation and management costs. This sounds simple, but still, water infrastructure, especially water supply and sewer networks have deteriorated to an unacceptable level in several urban areas. Pricing of water and water infrastructure investments have not necessarily been planned according to the needs of water services but according to political preferences.

Lobbying in favor of ratifying EU directives or how to adopt them to national legislation might be a threat in some situations. Some issues, sometimes quite unexpectedly, lead to active debates among some political groups or NGOs. This might also present an opportunity to listen to different views but often the topic is something else than providing adequate water services for the people.

The population of Finland is growing slowly but the urban population is growing faster due to migration from rural to urban areas. This is already happening, so the likelihood is maximal but the impacts for water services are not precisely known.

The other factor that is happening already is **climate change**. This is a real and very important threat and challenge to urban water management, both in drinking water and wastewater management. Increasing amount of droughts and floods has direct negative impacts to urban water services.

Existing water infrastructure was designed and built to battle the challenges that existed several decades ago. For example, the requirements of wastewater treatment concern decreasing the amount of suspended solids, organic material and nutrients (phosphorous and nitrogen). During the last few years it has been discovered that there are remarkable amounts of harmful substances which the current wastewater treatment process does not necessarily remove. These impurities include harmful organic substances, pharmaceutical residues and micro plastics.

Technological innovations may be considered opportunities. However, they will turn into threats if the potential of innovations is not utilized and the resources needed are not allocated.

STRENGTHS

Political stability makes it possible to make long term plans for developing public services. This is one of very important strengths in Finland concerning also sustainable and resilient water services. There is some dispute every now and then about how to value different aspects but adequate water services have not been challenged by any instance. This means that the basis for fruitful development can be seen in future. It also partly includes the economic stability of the water sector.

Economic and financial system and resources form a very important factor which may be considered a strength in some cases but a weakness in some other situations. A water utility recognized by the modification of Water Services Act 681/2014 should have an operating area confirmed by the municipality. According to VEETI database, there are 1,100 such water utilities in Finland, and their economic and financial situations are greatly varied, mostly depending on the institutional strength of the organization as well as the connections and cooperation with owners and the municipalities. Full cost recovery is recognized as good governance in the pricing policy. Yet, it is not always implemented, especially in small water utilities.

Institutional framework in water sector is clear and strong in Finland. The combination of public responsibility and strong private sector know-how is working well. This kind of public-private cooperation is considered to work flexibly and efficiently among all stakeholders. For succeeding in this cooperation, **good governance** is needed so that all stakeholders know their rights and responsibilities.

Educated and skilled personnel is a very important strength according to the questionnaire carried out in Article IV in this dissertation study. There is high-level education and training for all levels working in water sector, giving a good possibility to water utilities to operate and develop their performances. **Awareness** of health and environmental issues also gives good working conditions for water utilities.

Water infrastructure in Finland was mainly constructed in the 20th century, and especially in the 1960's and 1970's. For the most part, it is still working well and may be considered a strength but now it starts to be the time for major investments for renovation and new technologies. So, this may also be a weakness if asset management is not properly managed. According to the latest study on the state of the constructed infrastructure in Finland, the rehabilitation of water supply and sanitation networks should be 2-3 times that of the present rate (RIL 2015).

It is often stated that for succeeding in asset management, **data management** must be appropriate and functional (e.g. Alegre et al. 2016; Cardoso et al. 2016; Arfanuzzaman and Rahman 2017). This may be considered a strength in several cases, although especially small water utilities do not have the resources for proper data and knowledge management concerning their asset management and operation. **Smart water systems** including continuous monitoring, automation and modelling is a strength in large water utilities but not yet in small utilities.

WEAKNESSES

In Finnish water services, **deteriorating water pipe and sewer networks**, as well as **treatment of harmful substances**, such as organic harmful substances, pharmaceutical residues and micro plastics have been considered the most important weaknesses. These factors have been well-known for several years already but it takes some time to change attitudes and financial structures for developing such a new institutional scheme that these aspects start being effectively managed. In tackling these challenges, it is important to recognize them and to be unanimous about their importance among all stakeholders.

The large number of small water utilities has often been considered a weakness in Finnish water services. There are several project reports written in recent years where it is argued that decreasing the amount of the water utilities would improve institutional scheme and decrease risks in Finnish water sector. However, it is more a question of how the utility is managed and operated than of small size alone.

The above-mentioned factors are shortly presented in a SWOT table as a summary of this analysis (Table 4).

Table 4. SWOT table of 'Sustainable and resilient urban water services from a point of view of water utility'

	Favorable for achieving the objectives	Unfavorable for achieving the objectives
External	**Opportunities** • Government and municipal policies • Stakeholder needs • Economic situation • Management and operation • Educated and skilled personnel • Future legislation, international agreements and cooperation • New technologies • Health and environmental issues	**Threats** • Municipal resource allocations • Lobbying • Climate change • Population structure • Existing water infrastructure • Technological innovations
Internal	**Strengths** • Political stability • Economic and financial system and resources • Institutional framework and good governance • Educated and skilled personnel • Awareness • Water infrastructure • Data management and smart water systems	**Weaknesses** • Deteriorating water pipe and sewer networks • Treatment of harmful substances • A large number of small water utilities

4.4 Assessment of results

Currently, environment, economy, policy, and social matters are kept too separate in the development of urban water management technology. Even in technology, water supply, wastewater management and storm water management have been managed without a common view of urban development, as the concept of IUWM emphasizes (GWP 2019). The pillars in IUWM and sustainability have to be considered so that they will together support the development of municipal services, including water services. Sustainability and resilience of urban water services require strong technological, economic and social view so that this common service would be equitable and benefit the whole society. When carrying out a sequential PESTEL and SWOT analysis on urban water services, it is evident that none of these aspects can be neglected, and they must all be considered when planning, implementing and operating these services. Flexible cooperation between stakeholders is needed, so that their roles, rights and responsibilities are recognized.

The subsidiary principle – management at the lowest level – is one principle that could function in water services. Citizens recognize their requirements in cooperation with other people and water professionals. The information flow should be stronger from local conditions to governmental decision-making than the other way around. This message is one of the knowledge contributions of this dissertation and it is illustrated in Figure 8.

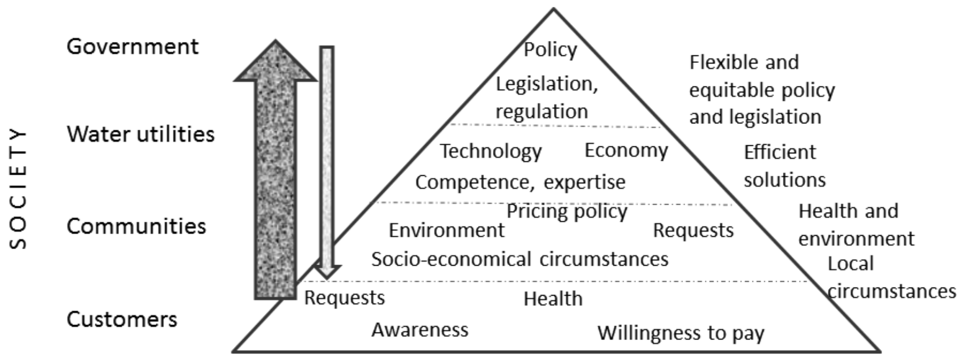

Figure 8. Bottom-up approach in management and practices of sustainable and resilient urban water services. The main information flow is upwards from customers to professionals and decision-makers

The results presented in this chapter are pure outputs of this scientific study. Discussions on them, comparisons to other studies of the theme and considerations on their contribution to development of urban water services will follow in the next chapter.

5 DISCUSSION

5.1 Water services and future society

The objective of this study is to create new, novel knowledge on water supply and sanitation as municipal service, and how to keep them functional and develop them taking into account the foreseen challenges and needs. Future needs are dependent on changes in population, environment, economy, politics, and attitudes. This research included four independent studies, reported as published peer-reviewed scientific articles. Each article focused on some parts of urban water services, while the synthesis assembles the coherent whole from these articles. This approach is illustrated in Figure 1 in the beginning of this report, and as a summary in Table 5, which is a summary of the objectives, elements and key findings of the four studies. Each country has its own challenges depending on its geographical, geological, hydro-meteorological and socio-economic circumstances. This study concentrated on the Finnish situation, although it also has reflections to other countries, mainly through literature reviews. The current situation as well as challenges and needs are explored and reflected to previous studies (for example Katko 2016; Silfverberg 2017).

Table 5. Summary of objectives, elements and key findings

Objective	**Elements**	**Key findings (Article No)**
Data and knowledge management in urban water management	National data management system, better asset management by better knowledge	Adequate data management is a prerequisite to adequate water services and asset management (I)
Resource efficiency in water services	Greenhouse gas emissions and economic viability of wastewater treatment by activated sludge process vs constructed wetland	Different processes may have remarkable differences in resource efficiency (II, III)
Water services in society of green economy	Concept of green economy and how adequate water services are connected into it	Principles of green economy can be applied in adequate water services (III)
Towards resilient water services	How Finnish stakeholders perceive resilient urban water services	Institutional and socio-economic aspects; education and skills; good governance, subsidiary principle with bottom-up approach (IV)

In Finland, current strategies concerning water services have been defined by the Ministry of Agriculture and Forestry (Beringer et al. 2018) and Finnish Water Utilities Association (Silfverberg 2017). Finnish government published an international water strategy for Finnish water sector in 2018, titled Finnish Water Way, written in cooperation between five ministries. This dissertation covers similar elements as these studies. Yet, it is not any kind of strategic or official guideline, but rather an approach of conceptualization developing integration of water services in a society.

Asset management and aging infrastructure are among the major challenges in urban water supply and sanitation in Finland in the near future (Heino et al. 2011; RIL 2015). Aging infrastructure and its renovation debt is a health and environment hazard), as well as inadequate attention to asset management. It is also a hindrance to resilient water services due to the uncertainty of adequate and continuous performance of water infrastructure. The renovation debt in Finland has been assessed by the Ministry of Agriculture and Forestry (2008). Although this kind of key ratio is very difficult to calculate, it is still an expert estimate. For the time being, the renovation rate of the water supply and sewer networks is about one percent of the total assets (according to national water services data management system VEETI) when it should be approximately 2–3 percent for guaranteeing a resilient situation in urban water services.

Based on the views of 48 water experts on future challenges of Finnish water services in 2008, the most important aspect was aging infrastructure (Heino et al. 2011). So far, there have not been too many severe situations that would have threatened health or environment in Finland. However, there are some incidents per year, and some of them have even caused deaths. These incidents have been caused by poor knowledge of water supply and sewer networks, poor condition of these networks or both.

In Article I, adequate data management was studied and, in Article IV, operational management of water utilities and their owner organizations was explored concerning good governance for better asset management. In the questionnaire, the challenge of aging infrastructure was not asked directly addressed but the results still show that for tackling this issue, education, skills development, and good governance should all be kept on a high level. Flexible, high-quality cooperation between water utilities, municipalities, decision-makers, private service providers as well as customers is one key issue for success.

According to the results of the workshop in 2014 in Article III (n = 68) and the questionnaire in 2018 in Article IV (n = 99), a sequential PESTEL and SWOT analysis was carried out by the author. Compared to the results of PESTEL analysis (n = 16–30) by Pietilä et al. (2010) and in Katko (2016, 243-245) it can be said that in general the results are consistent (Table 6).

Table 6. Summary of objectives, elements and key findings

Dimension	Important factors by Pietilä et al. (2010)	Important factors by Katko (2016)	Important factors by this study
Political	Long-term policy vs local policy, pricing policy	National security of supply, institutional framework, local level involvement	Local policy, pricing policy
Economic	Long-term nature of decisions, full cost recovery, unfairly high return to owner organization	Tariff structure, unfairly high return to owner organization	Full cost recovery, unfairly high return to owner organization
Social	In general no problems experienced	Diversity of water services, consideration of local circumstances	Land use and water use, migration to urban areas
Technological	Water quality control, hygienic quality, preventing planning	Information technology, new innovations	New technologies and innovations
Environmental	Sustainability, safe practices	Separate sewers and appropriate wastewater treatment	Climate change
Legal	Strong institutional framework, municipal ownership	Continuous development, local conditions taken into account	Strong institutional framework, municipal ownership

Some differences, probably because of the expert group and some years between the studies, can be found. Slightly different factors are also used within these studies. It must also be noticed that in Katko (2016, 243-245) the research question in the PESTEL analysis is about the change of water services over time, and thereby the analysis was processed from a somewhat different view. A comparison of these results is presented in table 6, not as a comprehensive list of factors, but as a summary of findings.

Current institutional structure in Finland has been considered an important factor and good practice in many studies carried out in recent years (e.g. Pietilä et al. 2010; Heino et al. 2011; Katko and Hukka 2015). According to the Water Services Act 119/2001, municipalities have the responsibility for urban water services but they can purchase or outsource operational services from private or public organizations. In rural areas there are numerous water cooperatives producing water supply or/and sanitation services to communities. Municipal water utilities usually cooperate with these cooperatives, of which especially the small ones are often based on voluntary work (Arvonen et al., 2017). This study concentrated on urban water services, mainly operated by municipal water utilities. The Finnish system with flexible public private cooperation is considered to function well, to be equitable and to provide good-quality water for everyone, according to the results of Article IV, Katko and Hukka (2015) and Katko (2016).

Due to the Finnish institutional framework, most of the water services professionals are employed by water utilities. They are fully occupied with their responsibilities for the utility, and it is not necessarily possible for them to work for example in international projects at the same time. This has been considered as a challenge, due to the objective of Finnish Government that Finland should share its knowledge through international development projects as well as increase water business globally.

Finland participates in and obeys EU legislation, directives and guidelines. The one that concerns water services is the Water and Health protocol, declared by UNECE and WHO (UNECE 1999). According to it, each country is to report how water supply and wastewater services are implemented concerning health issues. This reporting requirement concerns several ministries and organizations and it is done in close cooperation between them. A proper data management system is helpful in this work and, vice versa, reporting gives good information to the government water professionals and decision-makers on how to develop water services on a long-term basis. Monitoring and reporting also grants a good possibility for benchmarking with other countries.

Further international reporting requirements in the water services sector come from the Water Framework Directive (EU 2014) and the Urban Wastewater Treatment Directive (UWWTD) (EU 1991). This means consistent monitoring and data management about water management and its environmental impacts. Concerning wastewater management European Environmental Agency (EEA) receives this information from the EU council and prepares a map-based summary that is available on the internet. This can also be seen as functional benchmarking, not only as bureaucratic supervision. For several decades, wastewater has been treated by activated sludge process in Finland. The process has been further developed during these years and it gives very good results compared to UWWTD requirements, as well as to national and local requirements. However, during previous years, the attention has been focused on harmful substances (organic harmful substances, pharmaceutical residues and micro plastics) and climate change impacts that are not yet taken into account when designing current wastewater treatment processes. This will bring new regulations, technologies and operational approaches in the near future. An outline of comprehensive wastewater management process concerning environmental issues is presented in Figure 9. The situation is never actually comprehensive but there are aspects that should be recognized when developing new practices and technologies.

It is most effective wastewater management to prevent harmful substances from reaching the sewer system, already in the source, which means households, industry and institutions like hospitals and nursing homes. As e.g. pharmaceutical residues go through people, there will always be some of them going to sewers and wastewater treatment plants. To minimize this problem, awareness and responsibility from individuals as well as industry and institution operators is needed. An important aspect is better knowledge about the sources of harmful substances and their impacts to humans and nature. The condition of networks has been mentioned in several chapters already, and it is important also to know the leakages of sewers regarding harmful substances that might be critical to for example groundwater.

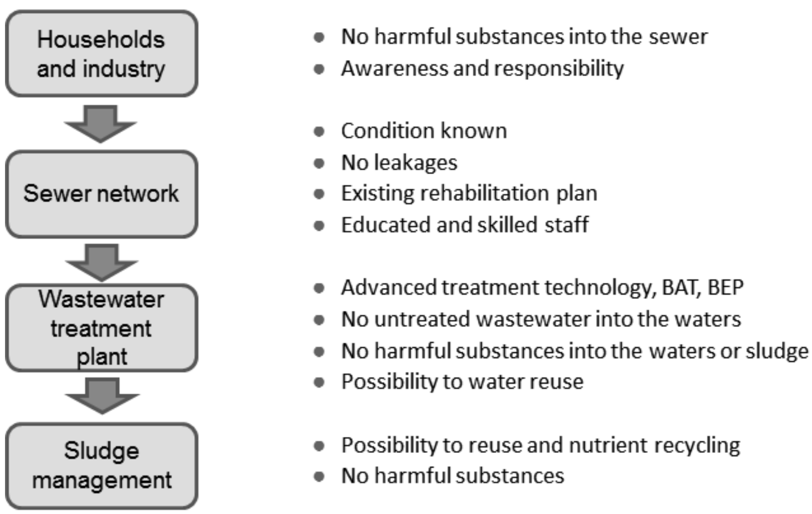

Figure 9. Outline for comprehensive wastewater management by the author, presented in UNECE Water and Health meeting in Bonn, February 2019

Treatment processes are developing, and currently there are some membrane bioprocesses (MBR) installed in Finland. This process includes membrane filtering which has an effect on some harmful substances and micro plastics. Still, the remaining sludge contains these substances, and new technologies are needed to avoid negative environmental impacts. Sludge management is a challenge to water services; for the time being it is a problematic waste for water utilities. On the other hand, it could be a source of useful nutrients and minerals when treated with a suitable process. Crucial in all this is citizen and stakeholder awareness as well as education and competence of water professionals.

Resource efficiency and circular economy are currently actively debated in the Finnish scientific society. It is also an important political issue due to foreseen climate change. Water services are not necessarily the most important factors in this discussion but there are some aspects worth noticing. Reuse of water is important in some areas suffering from water scarcity, while it is not considered as a viable process to be developed and implemented in Finland. During the urban water circle, illustrated and explained in Chapter 2, treated wastewater is commonly at least as good quality as the recipient water where it is discharged to. Although this is not directly water reuse, when considering the total natural water circle, water might be reused from a lake or river.

The recovery of nutrients and energy from wastewater or sewage sludge is commonly applied in water services when it comes to resource efficiency and circular economy. Energy is recovered directly from wastewater in some of the larger cities in Finland. It relies on rather simple technology and has been profitable in these cases. Nowadays, energy production from sewage sludge by anaerobic digestion is also well-known technology and it is in use in several waste and wastewater treatment plants.

Nutrient recovery is relatively complicated. It is easy to compost sludge, digested or not, and use it as a fertilizer. However, there are some amounts of harmful substances in sewage sludge, which usually require more thorough process than just composting if used in cultivating plants for food production (Ramon and Lull 2019). Reuse, or even just disposal, is a problem for water utilities, and it contains risks because we do not know enough of the health or environmental impacts yet. It is stated that according to the principles of circular economy, sewage sludge should be considered as a resource, not waste, and sludge treatment plants as processing industry in agricultural management (PURE 2012).

There is a large variation of processes that can be used in sludge treatment for nutrient recovery and reuse. The nutrients that are important for agriculture are phosphorous and nitrogen, and they can be recovered and reused directly from wastewater or sewage sludge, processed microbiologically or chemically, or sludge can be incinerated and phosphorous reused from ash. In Finland, anaerobic digestion and composting are the most common treatment methods, while for example in Germany and Japan, sludge is mainly treated thermally. Article II contains comparative analyses with the assumption that both sludge and vegetation from constructed wetland are treated with anaerobic digestion.

Education and continuous skills development were considered very important factors for the resilience of Finnish water services according to the questionnaire in Article IV. The Finnish education system, from elementary school to university, is assessed to be on a very high level in international evaluations, (OECD 2018). This gives a very good basis for operating water services and utilities. It is also fruitful to organize on-the-job training when the basic know-how and skills are at a good level.

5.2 Water services and future society

Often in scientific discussion, research approach and methodology are divided into quantitative, qualitative or mixed methods. In natural and engineering sciences, quantitative methods are traditionally used, while qualitative methods are mainly used in social and education sciences. Use of mixed methods is argued in several papers concerning different fields and traditions of research (e.g. Leppink 2017; Shekhar et al. 2019; Tulumello 2019). While quantitative methods can provide results that can be generalized, qualitative methods generate rich, descriptive understanding of the investigated phenomenon. Mixed methods can provide benefits of the two approaches by incorporating them in a single study.

One debate between quantitative and qualitative approach is that qualitative research assumes multiple truths while quantitative research assumes a single truth. For example, engineers consider the error embedded in the limits of available systems of calculation, ending up with substantial factors of safety as countermeasures. Quantitative, positivist researchers, in their search for generalizations, might forget about omnipresence of error (Tulumello 2019). In the case of qualitative analysis, there is always a risk of the beliefs and experiences of the researches to affect coding of narrative information. (Leppink 2017)

This research, made a compilation of four independent studies, used a mixed approach including different methods in various articles. This seems to be an increasing trend for the time being in engineering sciences. The research approach and methodology are presented in Chapter 3. Some parts of the research use quantitative methods, such as Life Cycle Assessment (LCA) and economic viability analysis which are used in Article II. This is reasonable, because it includes a comparison of two wastewater treatment methods and its calculations give explicit results. Action research used in Article I, workshop and interviews used in Article III, and the questionnaire used in Article IV may be considered qualitative methods that have given a largely exploratory approach to the whole research.

It might sometimes be difficult to see the premises between the approaches. Leppink (2017) concludes his reasoning: 'Perhaps we should no longer think in terms of qualitative-quantitative divides but rather in terms of more-less replicable distinctions, and do all that is possible to document all choices and decisions made throughout a study to enable others to replicate our work. This will allow us to work together towards stronger conclusions and implications for future research and practice.' This thinking gives more freedom in approaching better knowledge of phenomena. In many cases, even in exact sciences, seeking for single truth is not justified or reasonable.

When used mixed research approach, the role of the researcher might be remarkable in the qualitative parts of the study. In this research, the role of the author and thus a possible excessive bias was minimized by selecting the object group in workshops and questionnaire in cooperation with an expert team, and not by the author himself. The sequential PESTEL and SWOT analysis in this synthesis part was carried out by the author himself, reflecting the guidelines that give instructions to use a working group of eight to ten people (UNICEF 2015). This gives, of course, a possibility to sensibility and errors in interpretation. However, this analysis is made on the basis of the workshop described in Article III and the questionnaire in Article IV which had 68 and 99 participants, respectively. The result of this analysis is also mentioned to be not only a result of a specific study but a clearly presented summary of the results of these four studies.

Potential applicability of this research in other contexts is a difficult question but it is necessary to include it in the discussion of the results. The results mainly concern Finnish water services but their applicability may also be considered in other time and space. One objective of this study has been to increase knowledge about water services in the future. This is achieved by a proper selection of target groups in separate studies, appropriate research methods and thorough discussions with stakeholders. The long and diverse experience of the author also gives good perspective to interpretations and conclusions of the results. However, being largely of qualitative nature this research is undoubtedly subject to the interpretations of the author. Although the research cannot be directly applied to other countries as such, the approach, results, and conclusions will be helpful for other researchers within the same theme.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main issue in this research was to find key aspects in urban water supply and sanitation for providing continuously healthy, environmentally sound and economic services. The crucial concepts as basis of the approach were IWRM and IUWM. Sustainability and resilience of urban water management and practices were studied in several aspects: data, knowledge and asset management, resource efficiency and circular economy, concept of a green economy society and stakeholder views on maintaining and developing resilient water services. The results of the separate studies were summarized in this synthesis part with a sequential PESTEL and SWOT analysis. Key conclusions may be briefly stated as following:

a) Proper data, knowledge and asset management are prerequisites for sustainable and resilient water services
b) Resource efficiency and circular economy are already applied in urban water services, although there are several possibilities to develop in water utilities' operation and management
c) Principles of green economy are close to sustainability and resilience of water services
d) Resilience of urban water services requires not only proper technology and economy, but also educated and competent staff, good governance and good institutional framework.

6.2 Sustainability and resilience of future urban water services

The whole urban water cycle and its integration to natural water cycle, as well as urban material and energy cycle, have to be recognized. This is a basic principle in IUWM as well as in sustainable and resilient water services. One relevant aspect is also the data and knowledge flow within the functions and stakeholders. This aspect is simplified and illustrated in Figure 10. In the cycle of information and knowledge, the sequence is not necessarily always the same due to all functions being interrelated but the figure illustrates the operational environment of water services in a society.

According to the results of this research, the main aspects in sustainable and resilient urban water services include health issues, environmental impacts, data and knowledge management, education and skills management, resource efficiency and circular economy, economy and financing, as well as appropriate technology. For reaching a high-level solution covering all these aspects, government and local policy and legislation should be coherent to the commonly defined and agreed objectives.

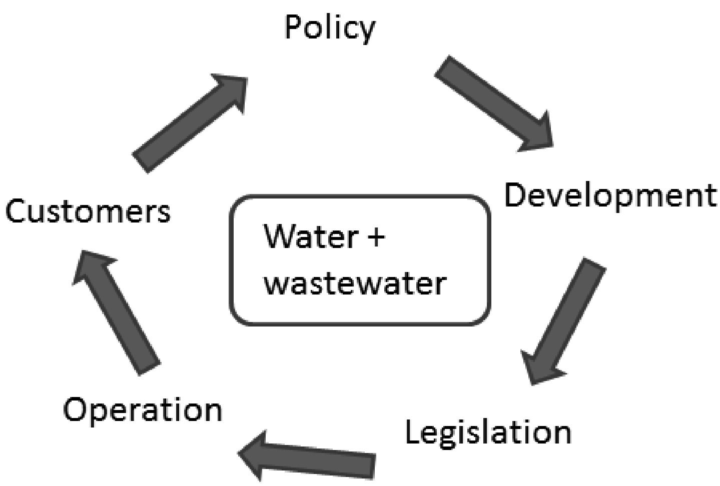

Figure 10. Functions, stakeholders and main information and knowledge flow in development of urban water services

This research has been carried out by the responsible author. In articles II, III and IV we had a project team where the co-authors, through their own special know-how, brought wide-ranging views. The objectives, materials, methods and interpretation of the results were discussed thoroughly during the writing process.

The results of the different articles as well as the synthesis of the whole research are presented in Chapter 4, and then they are discussed and interpreted in Chapter 5. The answers and reflections to research questions are presented below.

1. What is the significance of sustainable and resilient urban water services for a community and a society? This includes institutional aspects, socio-

economic aspects and assessment of core functions and supporting functions in water services.

According to stakeholders and water experts in Finland, it can be concluded that water services are considered as crucial services in a society. They are very important for health and environmental aspects but also for convenience and economy. In some developed economies like Finland, they are nowadays taken as granted. However, the urban water cycle contains several focal points which might be sensitive to malfunction that could result in serious outcomes. To resist any major negative incidents, resilience in water services is needed. This is not only a technical issue but one that needs coherent function of the services, also including institutional, socio-economic and economic aspects. The core functions that can be considered prerequisites for a water utility to be able to produce sustainable and resilient services are:

i. high-quality raw water sources
ii. proper water purification technologies, both in drinking water and wastewater treatment plants
iii. properly operated and maintained water supply and sewer networks
iv. adequate data, knowledge and asset management.

Fluent and flexible supportive functions are also important for a water utility to operate well continuously and 24 hours a day. These functions include, in particular, technical repair and maintenance, water pricing and financial management, human resources management, and real estate management. To provide adequate service, the institutional framework should be developed carefully and all the players, no matter if within a water utility or external service provider, must recognize their role and responsibility in the operation as a whole.

2. What kind of management and practices provide sustainability and resilience to urban water services? The specific aspects covered by this question are water services and green society, resilience of water services, stakeholder institutions and their role, good governance, as well as education and knowledge.

Water services support the whole society and they can be seen as one essential part of a society that has adopted the principles of green economy. Water services cannot be considered a separated function but they have to be integrated into municipal services. There are numerous stakeholders that have to be acknowledged when planning and implementing water services in a community. When carrying out a PESTEL analysis (see Chapter 4), it can be seen how water services are influenced and do themselves influence in several functions in a society. The outcome that was targeted in the objectives of this research was 'Sustainable and resilient urban water services'. In Figure 11 pillars supporting and having effects to this outcome are illustrated. The pillars are both internal and external but they are all crucial for successful sustainable and resilient urban water services.

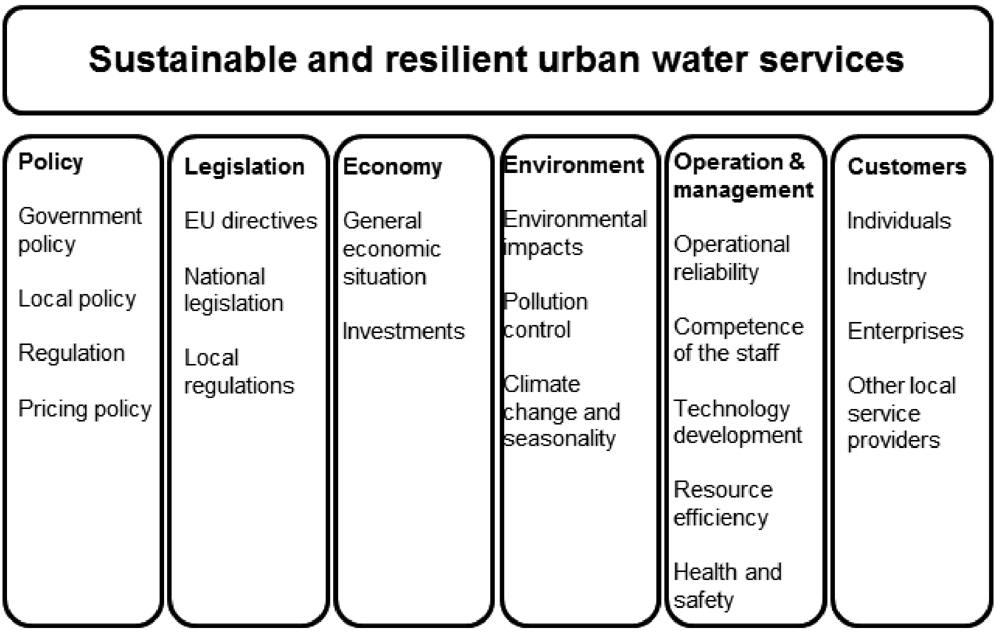

Figure 11. Pillars of sustainable and resilient water services

6.3 Knowledge contribution

New and novel knowledge produced by this study comes from a variety of point of views in the field of urban water services. Research approach and methodology was selected according to the section of each study. Former studies in this field have concentrated on technology and water quality, both supplied and natural waters. In this study, mixed approach (quantitative and qualitative) was used to find out more about socio-economic and institutional aspects, too. This approach is explained in more detail in Chapter 5.3.

In Finland, some some studies are published in the context of institutional development of water services (e.g. Rajala 2009; Pietilä et al. 2010; Katko and Hukka 2015; Katko 2016; Heino et al. 2011). This research gives a broader perspective, especially to sustainability and resilience in water services management and practices. Each of the four articles concerns some part of this field and the coherent whole enlightens new aspects of future challenges. Quite often they concern the so-called soft part of the business, meaning that technology and economy are not considered major challenges as much as education and institutional issues.

Added value from this research is diversified approach to urban water services in a community and a society. The starting point is the current situation in Finland, and in the research future challenges are examined. The challenges are assessed considering political, economic, social, technological, environmental, and legal changes of the whole society, and what effects they have on urban water services. This approach is seldom used in studies on urban water services, and due to using the results from four independent studies, new knowledge of the field is gained. In forthcoming studies and in development of the services, the results of this research may be used in diversified assessment of future requirements.

One knowledge contribution and message given by this dissertation is the subsidiary principle with the idea of management at the lowest level. This means that individuals recognize their own requirements and give signals to water professionals and decision-makers for what is needed in water services. The awareness of citizens must be on a high level and respected by organizations which provide water services. The direction of the information flow is mainly bottom-up and this approach gives a possibility for decision-makers to know the real requirements in a community.

6.4 Recommendation, policy implications and suggestions for further research

The basis and background for this research has been the current Finnish situation of water services. For future recommendations, the point of view might be too narrow, however, the number and representativeness of stakeholders in all the studies included in this coherent whole, give moderate ground for the recommendations. Recommendations are prepared both to maintain the current good situation, and to improve those aspects that were now considered challenges. Based on this research the following recommendations and suggestions are made:

1. To keep institutional framework and its development consistent. It is obvious that continuous development is needed but while the services are working properly, only cautious steps should be taken. (In accordance with Articles III and IV)
2. Pricing policy works so that it is equitable and everyone can afford good quality with both drinking water and wastewater services. One principle, not fulfilled yet, is the one of full cost recovery. It is good for running a water utility, both for the utility itself and its owner organization that the pricing policy is in balance considering the operation and investment costs. (In accordance with Article IV)
3. Good governance in all functions concerning water services. This concerns not only water utilities but all other community functions that are involved in water services. Management at the lowest level should be one principle used in decision-making. (In accordance with all articles and supported by results of the sequential PESTEL and SWOT analysis)
4. There are approximately 1,100 water utilities in Finland, and additionally a few hundred water companies that are not considered as water utilities according to the modification of Water Services Act 681/2014. This has resulted in a situation where there are a lot of water services produced by voluntary work. It might work satisfactorily but, due to lack of expertise, there might also be health or environmental risks. Water services must be implemented professionally and sound operation of these systems has to be ensured. This can be achieved e.g. by assistance from municipalities, cooperation of water utilities, or merging of small utilities. (In accordance with Article IV)
5. Water experts in water utilities, especially in small ones, have to do all kinds of routine tasks concerning fluent operation of the utility. This is waste of expertise and it might also be frustrating to the experts. It would be good if the water experts could participate in large national or international projects where they could learn more and contribute lessons learnt in their duties. (In accordance with Article IV)
6. One prerequisite for sustainable and resilient water services is proper data and knowledge management. A water utility must know its assets and have a systematic database for them. There are several different data

management systems; for technical equipment, for water supply and sewer networks, for water intake and distribution as well as wastewater collection and treatment, and for accounting. There is also one national database for statistics and benchmarking. A functional combination of these data management systems allows water utilities to be aware of their current situation and future needs. (In accordance with Article I and II)

7. New technology gives possibilities to enhance technological performance of treatment processes, network management or accounting. After installation of for example new processes, it is important to follow development and be open to introducing new technologies. In recent years there have been new technological innovations especially in monitoring and automation, and in water, wastewater and sludge treatment methods. (In accordance with Article II and III)
8. Educated and competent staff is considered very important for water utilities' performance. It is important to have a good education system at several levels from technicians to university professionals. It is the government's responsibility to provide enough resources for high schools and academies. Besides, water utilities must allow adequate training and continuous education for their staff. (In accordance with Article IV)

So far, the bulk of research on water services has concentrated on technical development of treatment processes or monitoring and modelling in network planning. Institutional development has been studied but it still needs more systematic research by universities' research groups. In sustainable and resilient water services, the emphasis has been on the impacts of climate change and management during and after disasters. More research should be carried out for maintaining a reasonable level of services in challenging situations, as well as recovering from disasters. For this, all relevant aspects need to be taken into account, ranging from policies and legislation to socio-economic, economic, environmental, and technical aspects.

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RESOURCE EFFICIENT WASTEWATER TREATMENT IN A DEVELOPING AREA – CLIMATE CHANGE IMPACTS AND ECONOMIC FEASIBILITY

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Resource efficient wastewater treatment in a developing area – climate change impacts and economic feasibility

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Abstract

Resource efficiency in wastewater treatment (WWT) is widely needed, not least in developing areas. Natural, less capital intensive processes in wastewater purification may offer developing economies an alternative to traditional biological processes. In this paper, we compare a constructed wetland (CW) based wastewater treatment plant to an activated sludge process (ASP) in Matamoros, Mexico. Greenhouse gas (GHG) emissions are calculated using life cycle assessment (LCA) and an economic viability assessment is carried out. Based on a literature review, both treatment methods are considered to produce sufficient treatment efficiency.

Water hyacinth was chosen as the aquatic plant in the CW due to its fast growth rate and the possibility of using it in anaerobic digestion (AD) to produce energy and fertiliser for agricultural land. In our calculations, the biogas produced from the water hyacinth biomass is the decisive factor when the two methods are compared. Direct GHG emissions from both methods are of the same order and are dominated by the GHG releases from the purification phase. However, if the water hyacinth can be used for energy production, the CW-based WWT not only fares better in economic terms, but also produces significant net climate benefits. Both methods studied have their downsides, increasing the need for risk evaluation. Although water hyacinth's fast growth rate is a crucial factor in the analysis, careful management is needed when cultivating the plant, as it has led to serious problems due to uncontrollable spreading. Furthermore, environmental and health risks must be identified and managed properly if wastewater-derived digestate is to be used on arable land, as assumed in the analysis. Additionally, N_2O leakages from the ASP and CH_4 and N_2O releases from the CW must be studied further to obtain reliable values for future analyses.

1 Introduction

Resource efficiency and reduction of environmental impacts is one key priority in all production and manufacturing processes. The issue is also discussed and developed in water treatment technologies, where water, energy, chemicals, and nutrients are increasingly considered resources to be conserved, reused and recycled. Water-energy nexus as an expression describes the interlinkage of the water and energy sectors (e.g. Scott et al. 2011, Siddiqi and Anadon 2011, Siddiqi et al. 2013). In recent years, the expression has been amended with nutrients to establish that within water technology, wastewater treatment (WWT) provides possibilities for nutrient recycling, and therefore water, nutrients and energy cycles should be seen as interrelated (e.g. Frijns et al. 2013).

Advanced WWT in developed countries is based on mechanical, biological, and chemical treatment, which is effective but requires resources for pumping, aeration, chemical production and transportation. With more stringent nitrogen (N) removal, infrastructure resources, operational energy, costs, direct greenhouse gas (GHG) emissions, and chemical consumption generally increase, which is challenging, particularly for small communities or developing countries. More demanding objectives, coupled with scarce resources of both financial and physical nature, create a need to develop innovative solutions both in technologies and operation models (e.g. Gunes et al, 2012). These solutions must fulfil the environmental requirements in a way that is also acceptable according to society's economic and social restrictions (UNEP 2011 and OECD 2011).

When reducing the use of chemicals and energy in WWT on environmental grounds, whilst at the same time demanding a reduction in organic material and nutrients, other technological methods have to be introduced. Decentralised technologies, such as land-based treatments, have been shown to have more potential in developing economies than conventional systems based on a set of sustainability indicators

(Muga and Mihelcic 2008). Engineered wetland systems, constructed wetlands (CW), biological filters, and sand filtration systems have been proposed as feasible alternatives with lower environmental impacts, compared to conventional technologies, by a number of studies (Corominas et al. 2013). Although a decade ago CWs were still largely ignored as a WWT alternative in developing countries where effective, low cost WWT strategies were critically needed (Kivaisi 2001), an up-to-date look into the literature shows that CWs are now more widely applied than other technologies. Most of the studies evaluating the effectiveness of CWs as a WWT method, however, ignore the water-energy-nutrients nexus by classing outputs of the wastewater treatment plant (WWTP) as environmental burdens (e.g. Chunkao et al, 2012 and Gunes et al, 2012).

All resources in WWT processes could be used more effectively. In addition to decreasing energy and chemical consumption of WWT processes, the heat energy of the influent wastewater as well as the energy of the solids – mainly sludge that is separated from the water – could also be utilised. Besides energy, purified water itself has resource potential due to the lack and periodic fluctuation of water resources. Moreover, nutrients recovered rom the wastewater can be used as soil amendments or fertiliser (Mo and Zhang 2013). Recovery of water, energy, and nutrients is a key consideration in discussion of what makes a particular WWT technology sustainable (Guest et al. 2009).

In this paper, the feasibility of a CW as a WWT method is evaluated from the resource efficiency point of view. Our case study focuses on a developing area: the state of Tamaulipas in North-East Mexico. The country is among the first developing countries to commit to reducing their GHG emissions. By 2020 and 2050, the reduction targets are 30% and 50%, respectively. Simultaneously, Mexico is aiming to produce 35% of its energy from renewable sources. According to USAID (2013) projections, improved WWT is among the ten measures with largest abatement potential in Mexico, equivalent to12 Mt CO_2eq by 2020, or 7% of the potential of the ten highest abatement methods.

We will calculate the energy balance of the CW-based WWT, assess the climate change impacts, and compare the results with a conventional treatment alternative: activated sludge treatment. In addition to this, we will evaluate the economic feasibility of the plant. Life cycle analysis (LCA) is used as method for evaluating the climate change impacts. The core research question in this study is whether developing economies should prioritise low technology WWT over more capital- and input-intensive processes for sustainably achieving a good level of sanitation. The cost of land required for CW is not considered in this paper because it is designed to be constructed on the same site using the same area as current WWTP. The additional land needed is not very large due to the efficiency of water hyacinth. The discussion on the land usage is in section Results and discussion.

2 Approach and methods

2.1 Life cycle assessment (LCA)

Life cycle thinking (LCT) is used to gain a holistic view of the environmental performance of the product, process or system being analysed. LCT expands the viewpoint beyond the more traditional view of process-specific environmental impacts by including all relevant upstream and downstream activities that potentially affect the life-long impacts. Within the field of WWT, LCA has been applied since the 1990s (see Corominas et al. 2013 for a review). In wastewater management, LCT can incorporate the key notion of avoided impacts, that is, activities that could potentially be avoided by utilising the resources in wastewater. In our analysis, such resources are energy from biomass and sludge, water for irrigation, and the nutrients in sludge.

Our analysis concentrates on the climate change impact of WWT, but we use a system expansion by allowing for the so-called substitution or avoided burden method (Guinée et al. 2002) by including the emissions avoided from activities that may potentially be replaced by the use of wastewater-derived outputs. Therefore, we distinguish between direct contributions from WWT, and indirect upstream contributions (e.g. provision of energy to the treatment processes), but also account for downstream contributions from processes that may potentially be replaced by end products from WWT. The start of the system boundary in the analysis is drawn at the raw sewage arriving at the WWTP and the end is at the point where the outputs have been transformed into a form where they can be utilised instead of virgin resources.

As energy consumption and possible energy gains from the system are of interest and serve as the basis from which the LCA proceeds; the energy balance of the system studied during its life cycle is also presented. A key issue in LCA with a system expansion is what kind of energy is replaced by the energy created in the system. This matter has been discussed rigorously in LCAs concentrating on waste management, since the replaced energy typically has the most significant impact on the outcome (e.g. Fruergaard et al. 2009). LCAs studying WWT in the same manner are still scarce, but the same discourse applies for wastewater, when energy is utilised and potentially replaces other energy sources. In the analysis, we use average data on Mexican electricity production (Swiss Centre for Life Cycle Inventories 2014), but allow for variation in the sensitivity section, which shows how choices of different marginal energy forms affect the overall outcome. The life cycle chain includes emissions created during extraction and transportation of different fossil fuels. In the analysis we use the same energy sources for both upstream and downstream unit processes (e.g. Fruergaard et al. 2009). The upstream process energy data includes the effects of energy transition.

In evaluating the GHG impact we first employ a life-cycle inventory analysis (LCI) (Guinée et al., 2002; ISO 14040; ISO 14044). The derived GHG accounts are then reported as global warming potential (GWP) according to the rules of the Intergovernmental Panel on Climate Change (IPCC) (Solomon, 2007). We report the GWP as CO_2-equivalents per 1000 m^3 of influent wastewater. The emissions included are fossil carbon dioxide ($CO_{2,foss}$), biogenic carbon dioxide ($CO_{2,bio}$), methane (CH_4), and dinitrogen oxide (N_2O). Their characterisation factors used for converting each emission into its GWP are 1, 0, 25, and 298, respectively (Solomon, 2007). The calculations are carried out simply by using an equation that gives the emission by adding direct and indirect emissions and then subtracting the avoided emissions of the process in question.

We use 1,000 m^3 of influent wastewater as the functional unit of the study. All inputs, outputs, emissions and results are quantified relative to 1,000 m^3 of influent wastewater.

2.2 Economic viability analysis

The analysis of economic viability is performed by comparing the investment and operational costs of the planned CW (including sludge and WH biomass digesting) with a conventional activated sludge process (ASP) (including sludge digesting). Estimated costs of the CW are based on values provided by a consultant designing similar plants in Latin America and financing proposal prepared by North American Development Bank in 2012. The costs of an activated sludge (AS) plant are based on Finnish data reported for a compilation of best available technologies (BAT) of municipal WWTPs in Finland (Laitinen et al. 2014). In this case the main part of the costs are the investment costs including equipment, and these costs can be considered as comparable in Finland and Mexico. Social and environmental conditions between these countries are different, but it does not give a remarkable difference in these calculations due to a low need of labour in the plant operation.

The estimated investment for a CW plant without anaerobic digestion (AD) of organic material like sludge and harvested plants is 64 million USD and for an ASP plant 81 million USD. The estimate for investment of an AD for separated wastewater sludge is 6 million USD. If the capacity need for the biomass produced by the CW is added, the investment cost for the AD increases roughly by 6 million USD. These figures do not include the cost of land.

Operational costs of the WWTP are assumed to be similar to other facilities with similar technology. We assume a plant with 15 person-years and annual operation and maintenance costs of 2% calculated from the initial investment. As the effluent and digestate are assumed to be used for irrigation and fertilising, disposing of the sludge does not cause additional costs for the WWTP. Although the digestate has fertilising potential, we do not assume any income from it.

In the analysis, for the WH to be utilised in the AD, the aquatic vegetation must be harvested. In the tropics, where growth rates are high, the harvesting costs must be assessed before choosing the vegetation (Kivaisi 2001). The harvesting cost can be significant depending on the vegetation type, equipment used, and circumstances at the site. In this calculation, harvesting is estimated to be included in maintenance costs, i.e. 2% of investment.

The alternative plants generate income from electricity sales. The calculation period is 50 years and the reference cost for the technologies is calculated as USD/1,000 m^3 of wastewater treated. This calculation is not carried out in strict accordance with the life cycle cost calculation method due to lack of data on equipment and maintenance costs, yet it allows for the comparison of results of two different systems. An interest rate of 5% is used in calculations for estimating the costs in current value.

3 Details and data of the case study

3.1 Case study area and wastewater quality

The planned WWTP is located in Matamoros, Mexico. The city of about 500,000 inhabitants is located in the North-East of the country at the U.S. border and its wastewaters are currently only partially managed. The facility studied would provide a first-time WWT service to the unserved areas of Matamoros.

Data for the LCI are derived from measurements in the case study area, the Ecoinvent Database (Swiss Centre for Life Cycle Inventories 2014), and literature. If not referenced, data is provided by Conagua and North American Development Bank in their project documents or derived from a wastewater management consultant designing similar plants in Latin America. The latter applies to, for example, the energy and chemical consumption of the WWT processes.

The estimated load on the new plant is 43,200 m^3/d, with TSS 3,240 kg/d, BOD_7 7,450 kg/d, P_{tot} 260 kg/d and N_{tot} 2,460 kg/d. The BOD_7 load corresponds to approximately 106,000 person equivalents (p.e.). If average water consumption in Matamoros is assumed to be 200 l/person/day, 43,200 m^3/d would indicate 216,000 persons, however. The difference in p.e. could be explained by industrial water use and/or higher than average personal water consumption in the area. The incoming wastewater seems to be quite diluted, which indicates either a high degree of dilution from households or leaking or combined sewers. The data on Matamoros' wastewater quantity and quality were received from the National Commission of Water (Conagua) in Mexico and are based on actual measured values in the study area (Table 1).

Table 1. Quality of the influent wastewater

Parameter	Influent mg/l
BOD_7	172 average, maximum measured value 629
TSS	75 average, maximum measured value 433
P_{tot}	6 average, maximum measured value 10
N_{tot}	57 average, maximum measured value 66

3.2 Constructed wetland (CW) based WWT

As a first alternative, we are creating a model for a CW for the secondary treatment of wastewater, and assuming that the effluent is utilised for irrigation, the biogas produced by AD for energy production, and the digestate from AD as a fertiliser on agricultural land. Biogas is produced both from wastewater sludge from the upflow anaerobic sludge blanket (UASB) reactor and the biomass harvested from the wetland. CW as a purification technique decreases the need for chemicals in the process. An illustrative design of the WWTP, energy consumption of the processes, and the use of outputs is given in Figure 1.

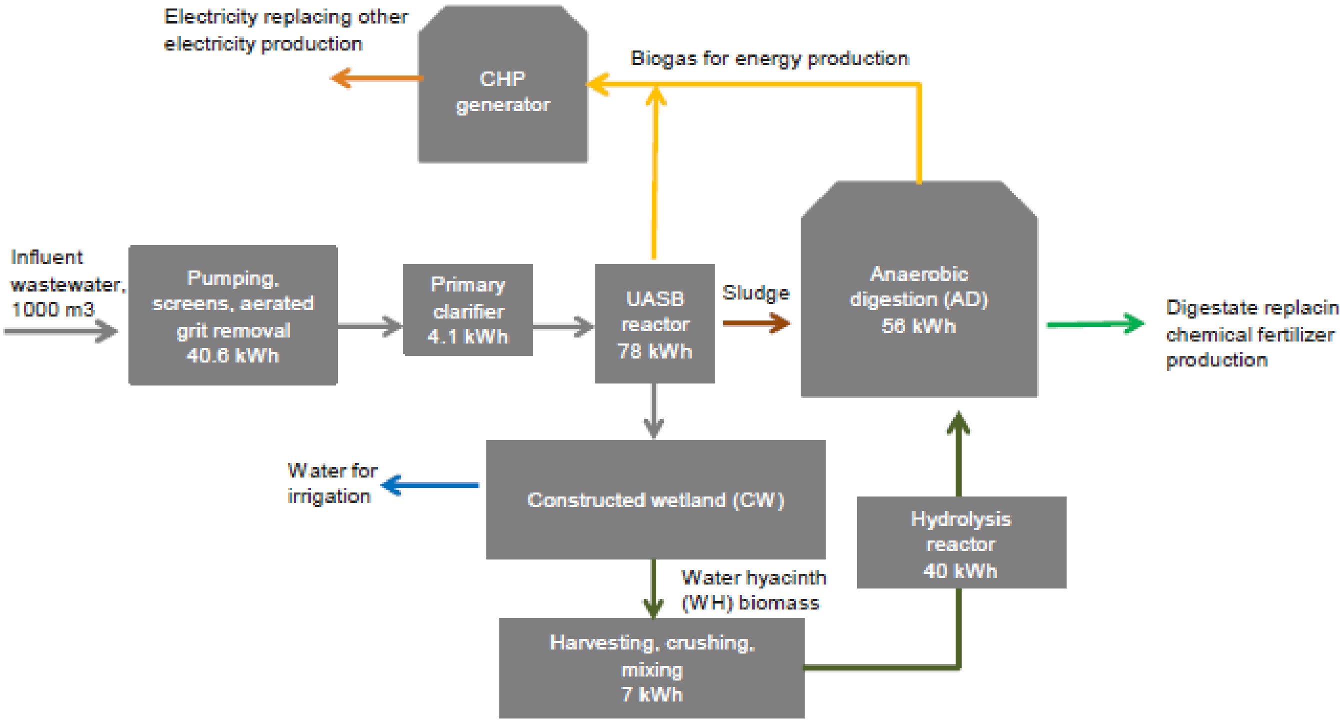

Figure 1. Process flow and energy consumption (per 1,000 m3 of influent wastewater) of the planned CW-based WWT

3.2.1 Primary treatment

Preliminary treatment includes wastewater pumping, screens, aerated grit removal, and preclarification. In the primary phase, chemicals could be used, although in developing countries their use is typically reduced to a minimum, as they induce extra costs. In the case study area, as purified water is used for irrigation in areas close by, nutrients (P and N) are reused and chemical use is not seen as a necessity.

3.2.2 The constructed wetland

Several aquatic plants could be used in free water surface CWs (FWS CW) (Vymazal 2013a). In the case study, water hyacinth (WH) (*Eichhornia Crassipes)*, a tropical invasive weed, was chosen due to its shown effectiveness in removing TSS, BOD, P and N. Additionally, WH has been shown to have ability to absorb impurities, such as heavy metals, toxins and sulfur. (e.g. Zimmels et al. 2006) The magnitude of N removal varies depending on many factors, including inflow concentration, the chemical form of N, water temperature, the season, organic carbon availability, and dissolved oxygen concentration (Kadlec and Wallace 2008, Vymazal 2011). Theoretically, WH can achieve an exceptionally high reduction rate for N, but in practice a rate close to 100% is unlikely. In the analysis, the assumed reduction rate based on previous studies (e.g. Gunes et al, 2012 Kadlec and Wallace 2008 and Vymazal 2011) is 65%. FWS CWs remove P by adsorption and precipitation, but at relatively slow rates, as in the FWS system removal is limited by the limited contact between the water column and the type of soil (Mander et al., 2013). P reduction with WH is assumed to be 45%. Estimated reduction rates are presented in Table 2.

As WH has a vigorous growth rate, is very adaptive, and grows with very variable N:P ratios, it has also potential in bioenergy production (Gunnarsson and Petersen 2007, Fedler and Duan 2011, Buller et al. 2013). The assumed harvesting rate is 16.2 tonnes of fresh matter/1,000 m^3 of influent. On a small scale, harvesting and transport of WHs can be conducted manually (Gunnarsson and Petersson, 2007). In the case study, an energy consumption of 4 kWh/1,000 m^3 is assumed and emissions are derived on the basis of known emissions from combine harvester use (VTT 2011). Emissions from production of the diesel fuelare included in the life cycle (Swiss Centre for Life Cycle Inventories 2014).

Table 2. Estimated reduction rate and effluent characteristics (Gunes et al, 2012, Vymazal, 2013b and consultants estimate)

Parameter	Influent (mg/l)	Reduction rate (%)	Effluent (mg/l)
TSS	75	99	0.7
P_{tot}	6	45	3.3
N_{tot}	57	65	20

3.2.3 Biogas production

The planned facility produces biogas from the wastewater sludge, 75 kg/1,000 m^3, in AD and before in the UASB reactor. The mesophilic bioreactor, which is an anaerobic digestion process in a temperature of 33 to 35 °C, has a retention time of 21 days. The harvested WH, which are crushed and go through hydrolysis, are also used an input in the AD. The biogas yields assumed by consultant, are 500 m^3/t total solids (TS) for WH and 80 m^3/t TS for sludge. The biogas production of the plant is 706 m^3 of biogas/1,000 m^3 of influent, approximated also by consultant. Possible methane leakages in the process are not known and are assumed to be negligible (1–3%).

3.2.4 Utilising water, digestate and energy

Treated water – the effluent – is expected to be used for irrigation in the surrounding area, in the state of Tamaulipas, which has about 400,000 ha of irrigated cropland. The leachate from CW is a potential liquid fertiliser, as it has high N and P concentrations. The collection is carried out continuously by simple and light equipment. However, further research on the treated wastewater is required to ensure that the nutrient ratio and form are suitable for plants and the water does not contain any compounds that may be inhibitory or toxic to plant growth or to the use of the cultivated plants (O'Sullivan et al. 2010). In the LCA, no credits are counted for irrigation use due to these uncertainties.

The separated sludge from AD can potentially be used as fertiliser in farming. Digestate (TS 4–5%) yield is 13.2 tonnes/1,000 m^3, with 42.0 kg of N and 2.8 kg of P (see chapter 2). The digestate is assumed to replace commercial calcium ammonium nitrate and diammonium phosphate production (Swiss Centre for Life Cycle Inventories 2014). The impacts of chemical fertiliser production avoided are 9 kg CO_2 eq, per kg of N and 3.7 kg CO_2 eq per kg of P. In general, P is the limiting nutrient when replacing chemical fertilisers (Foley et al. 2010a). Use of the digestate as fertiliser can be restricted by the potentially significant toxicity effects of to heavy metals, priority and emerging pollutants in the wastewater (Hospido et al. 2010). Wastewater-derived fertiliser has been shown to have substantially larger heavy metal loads compared to synthetic fertilisers (Foley et al. 2010a). However, not all metals in the digestate will be bio-available to crops (Peters and Rowley 2009). In the assessment, we do not take into account the emissions from the actual spreading of the digestate on the agricultural land, and similarly the emissions from chemical fertiliser application avoided are not accounted for. It is likely that spreading the wastewater-derived fertiliser causes more emissions, since it cannot be done simultaneously with tillage, as is often the case with industrial fertilisers.

3.3 Conventional activated sludge process (ASP)

Alternatively, the wastewater of Matamoros could be treated in a conventional WWTP (e.g. activated sludge technology). An ASP is illustrated in Figure 2. The technology is widely used and documented, and its performance is well known from literature and experiences.

A trade-off between removal rates and recovery does not apply to N, as higher removal rates correspond typically to higher air emissions (including N_2O), rather than toimproved recovery of N in the digestate (Foley et al. 2010a). Recently, Ahn et al. (2010) reported a large range of N_2O emission factors – from 0.28 to 140 g/year per capita for AS plants – depending on the biological nutrient removal process. The variation in N_2O emissions between plants and even temporally within a given plant has been shown to be substantial (Aboobakar et al. 2013, Foley et al. 2010b), which indicates that N_2O releases could be mitigated through proper process design and operation. In the analysis, we assume 0.013 kg of N_2O is released per kg of N denitrified based on the median value reported by Foley et al. (2010b). This figure is varied in the sensitivities section.

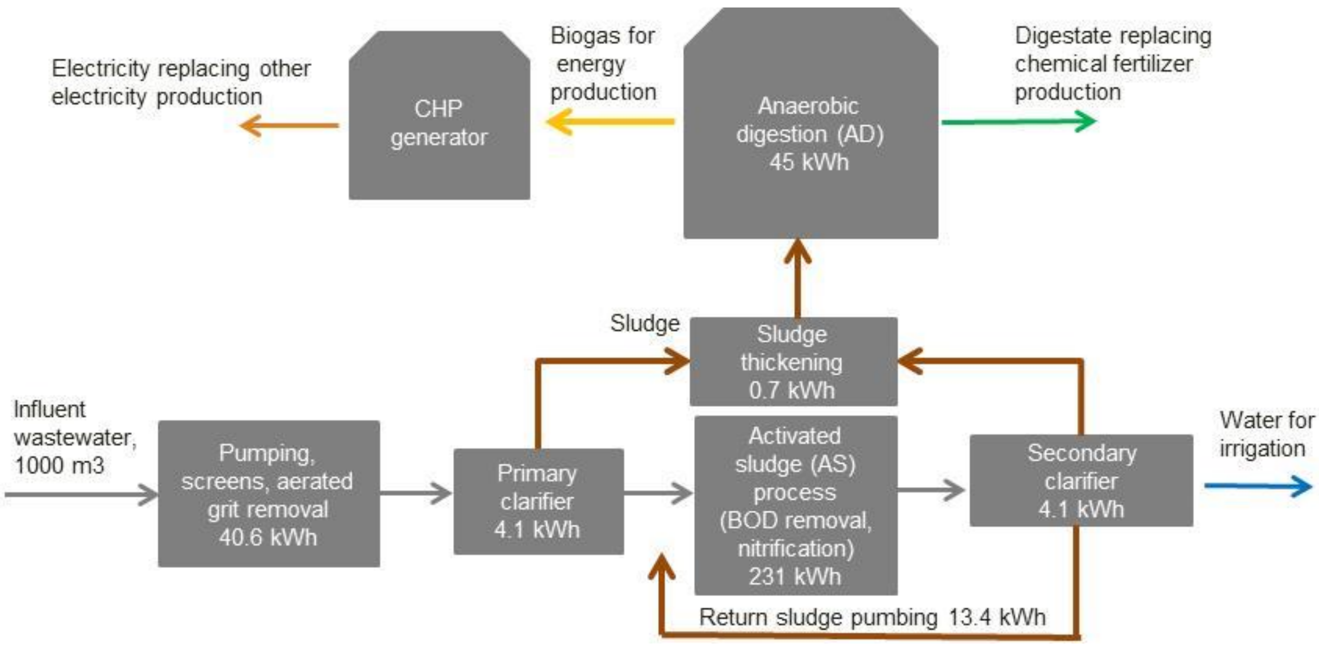

Figure 2. Process flow and energy consumption (per 1,000 m3 of influent wastewater) of a typical ASP (the numbers used are explained in chapter 2)

4 Results and discussion

4.1 LCA results

The life cycle energy use of the CW-based treatment is 108 kWh/1,000 m^3 compared to 351 kWh/1,000 m^3 in the ASP. The CW-based process has slightly lower direct CO_2eq emissions (420 kg CO_2eq/1,000 m^3) compared to 490 kg from the AS-based process (Figure 3 and 4). From the direct emissions of the WWT processes, 30% and 80% originate from the CW and ASP phases, respectively. From the CO_2eq emissions released from the CW, CH_4 accounts for 60% and N_2O for 40%. Emissions from the ASP are dominated by N_2O releases (60%). The basis of these calculations is explained in chapter 2 and 3, and is based on the data provided by Conagua, North American Development Bank and the consultant as well as Ecoinvent database.

A difference between the alternatives emerges when both the electricity use and emissions avoided are studied. By utilising the biomass of the CW, the biogas generation of the AD is two orders of magnitude higher than in the case where sludge alone from the ASP is used for biogas production. Taking this into account results in a net energy balance of -1,700 kWh/1,000 m^3, compared to a positive balance of 330 kWh/1,000 m^3 in the case of ASP. Therefore net GHG balances differ significantly: the CW-based process creates potentially large emission savings, whereas the ASP produces a positive value for GHG emissions. It is noteworthy that no savings were calculated for the heat generated, the utilisation of which would increase the magnitude of GHG emissions avoided.

Crucial in the analysis is the WH growth rate and its utilisation potential, since without biogas production from the WH biomass, the ASP fares better than the CW-based process due to slightly smaller direct GHG releases from the process. The issue is discussed in the sensitivities section.

In the analysis, we assumed that the N and P content in the digestate would allow for the equivalent N and P mineral fertiliser substitution. The emission savings between the two WWT alternatives do not differ much due to the fact that the nutrient content remains constant, whatever technology is used. Replacing chemical fertilisers with the nutrients of the digestate is somewhat obscure and different studies have used different practices for accounting for the substitution effect. Renou et al. (2008) did not include the substitution effect on the grounds that safety practices require that sludge is spread on soil before the growth of crops, whereas mineral fertilisers are spread on growing crops. As a consequence, sludge does not have the same fertilising effect and it is used more to improve soil quality than to fertilise it. Johansson et al. (2008) and Lundin et al. (2004) took into account the impact of chemical fertiliser use avoided, although they emphasised that sludge can transfer heavy metals to soil when spread on agricultural land. Further studies are needed; Singh and Kalamdhad (2013) conclude that in composted WH heavy metals concentrations are not above the threshold limits for compost use for agricultural purposes. On the contrary, Chunkao et al. (2012) conclude that WH compost can only be used for fertilising non-edible plants, as in growth experiments with vegetables the heavy metal content has been too high. Moreover, although recent research on aquatic vegetation’s absorption capacity regarding emerging pollutants is on the increase (see Zhang et al. 2014), further research is needed on WH specifically, and this research needs to be linked with the discussion on safe nutrient recycling.

In the analysis, we did not take into account the spreading phase of the competing fertilisers. Lundin et al. (2004) have shown that the pasteurisation, transportation, and spreading of sludge cause more emissions than are saved by the replacement of the N fertiliser. Moreover, the P in the sludge is bound as ferric phosphate, which is considered to be less available to plants if chemicals are used in the purifying process (Lundin et al. 2004, Marttinen et al. 2013). In our analysis, ruling out the impact of nutrient recycling entirely would decrease the emissions avoided from the CW-based WWT by 20%. The ranking of the alternative WWT methods would not change, but the ASP would produce almost no GHG savings.

Other possibilities for digestate utilisation methods exist, incineration being one example. Several studies have shown case-specifically that these alternatives can outperform agricultural use (e.g. Lundin et al. 2004, Peters and Rowley 2009). Moreover, the evidence of the negative environmental outcome associated with heavy metals in the digestate, compared to the equivalent application of synthetic fertilisers, implies that other uses need to be studied further. It should be noted that source control is one mechanism to tackle the problem, as the quantity of heavy metals in digestate is fixed by the quantity of heavy metals in the influent wastewater (Foley et al. 2010a).

In the case area there is a need to use the reclaimed water for crop irrigation. Given the quality of the recycled water is not fully known, we are not taking into account any credits for the effluent in irrigation use. The existence of heavy metals, other priority pollutants, and also non-regulated pollutants such as pharmaceuticals and personal care products and their effect on eco-toxicity and human toxicity would need to be studied case-specifically. In addition to this, the microbiological quality of the water should be investigated to allow for irrigation use on crops. Previous studies have shown that the addition of a tertiary treatment to the traditional WWTP somewhat increases the environmental impact of the treatment, yet the impact is considerably smaller than that of other water production methods (Chen et al. 2012, Muñoz et al. 2009). Additionally, recycling water for irrigation has been shown to diminish the fertiliser requirement in agriculture (Meneses et al. 2010).

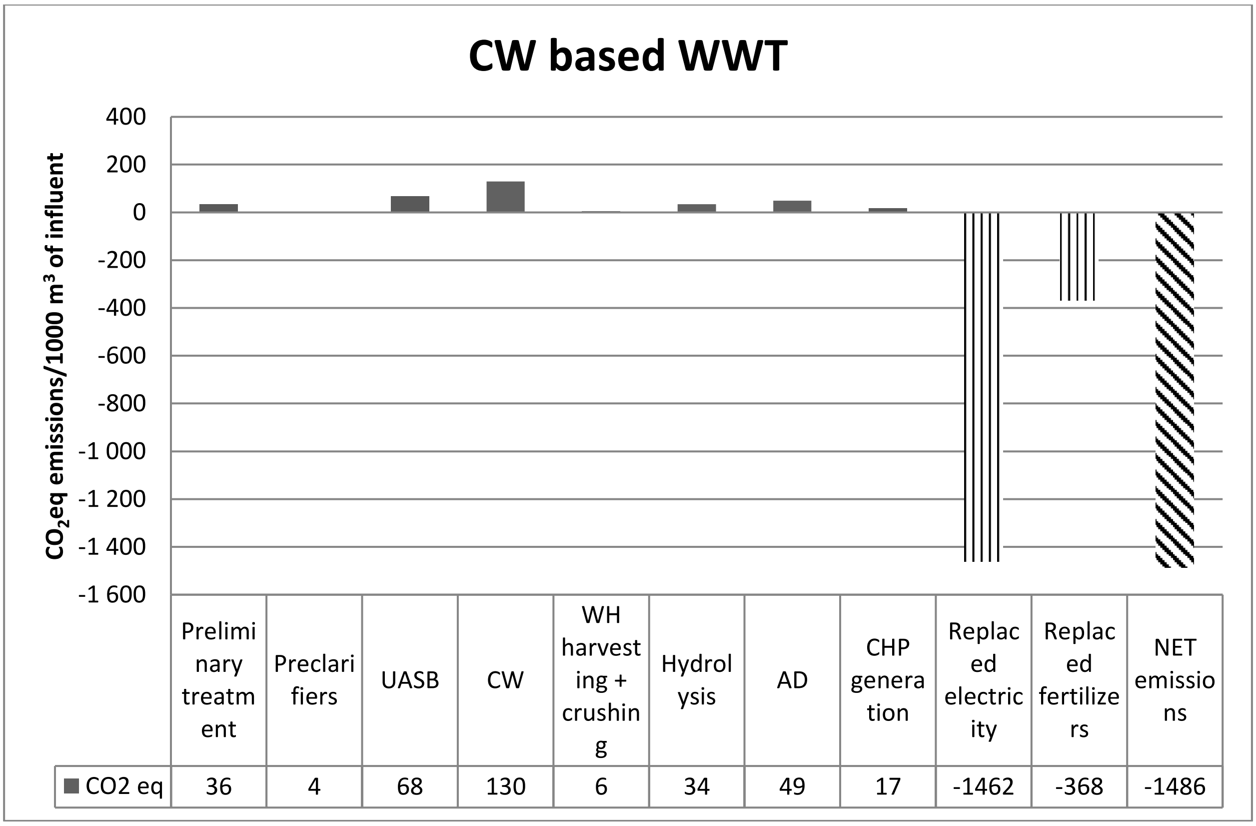

Figure 3. CO_2 equivalent emissions per 1,000 m^3 of influent wastewater during the life cycle of the CW-based WWT studied

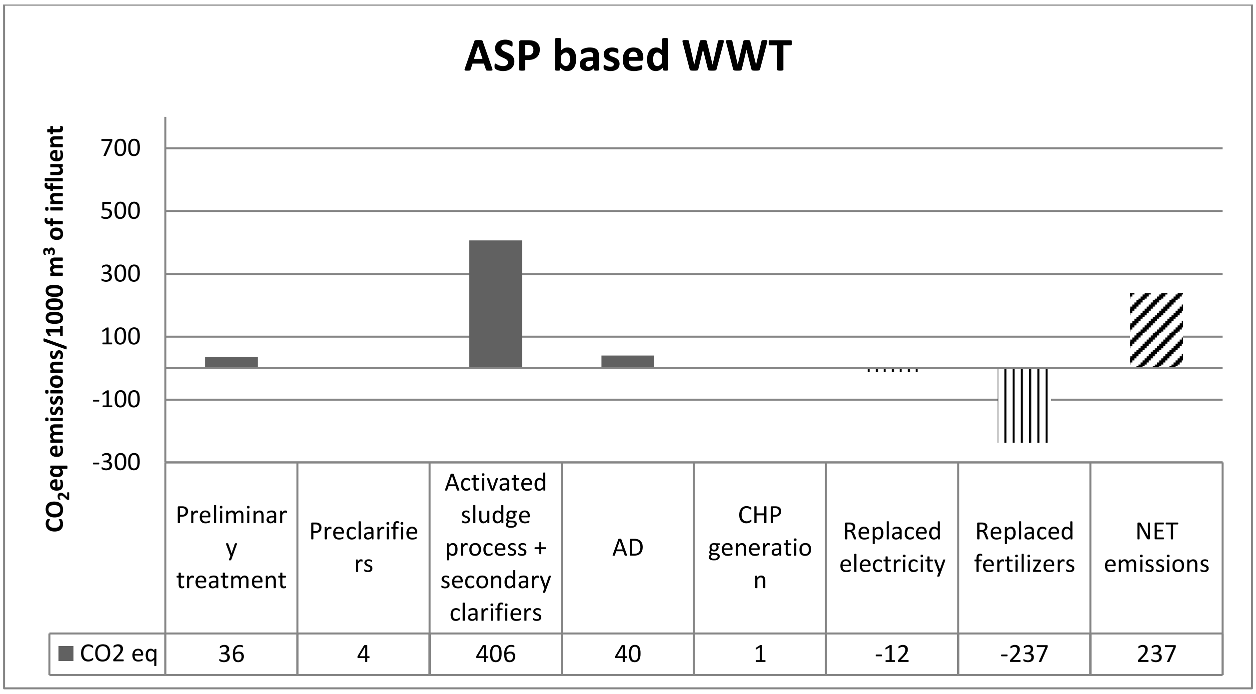

Figure 4. CO_2 equivalent emissions per 1,000 m^3 of influent wastewater during the life cycle of the CW-based WWT studied

4.2 Economic viability

The profitability calculations for the WWTP are performed for the ASP- and the CW-based WWT. In the latter, both wastewater sludge and WH biomass are digested, whereas in the ASP, sludge is the only input into AD. Wastewater treatment in the ASP costs twice as much as in the CW-based WWTP. The residual costs per 1,000 m^3 are USD 400 in the ASP and USD 200 in the CW-based plant (Table 3). The difference in residual costs results from the difference in investment costs and income from the plants' electricity production. The derived results are rough estimates. A more detailed design of both plants on the site studied would be needed to gain more exact estimates of the costs. The accuracy of the income from electricity could be improved by utilising local knowledge of the network and consumption points in the area studied. One shortcoming of this assessment is that the cost of land is neglected. That might be a considerable cost in some cases. In this case, however, the land cost is considered to be almost the same in both technologies used, so there would be no remarkable difference in the comparison.

The derived results are in line with USAID (2013) estimates, where improved WWT is considered to be among the ten most important measures for decreasing GHG emissions in Mexico. However, although 69% of Mexico’s GHG reduction potential is estimated to come at zero or negative cost, WWT is among the measures that would cause net costs for society. Our analysis confirms that even if a low cost method were to be used, WWT would be costly for society. However, increased environmental health is a considerable benefit in decision making. Langergraber (2013) concludes that CWs meet the basic criteria for sustainable sanitation systems by preventing diseases, protecting the environment, and being an affordable, acceptable, and simple technology. This is an important point of view, especially in developing economies, where CWs can produce treated wastewater of high quality with simple technology, thus promoting reuse and in turn making them applicable for resource efficient sanitation systems.

Table 3. Profitability calculations, comparison between ASP- and CW-based WWT

	Conventional ASP including AD for sludge only	**CW plant including AD for sludge and WH**
Income from AD (USD/a)		
Amount of solids (t)	1,200	23,000
Gas potential (m^3)	95,000	11,000,000
Electricity potential (MWh)	250	29,000
Sales price of electricity (USD/MWh)	100	100
Annual income (USD/a)	25,000	2,900,000
Costs (Investment and operation)		
Investment in the plant	81,000,000	64,000,000
Investment in AD	6,000,000	12,000,000
Comparison calculation period (a)	50	50
Interest rate (%)	5	5
Annual investment costs (USD/a)	4,800,000	4,100,000
Annual operation costs (USD/a)	2,100,000	1,900,000
Residual cost	6,800,000	3,100,000
Residual cost of treated wastewater USD/1,000 m^3	400	200

4.3 Sensitivities

In the LCA of the CW-based system, the energy replaced is dominant in the life cycle. In the consequential LCA, there are differing perceptions on replaced energy forms, i.e. the debate between marginal and average energy sources. In the case study, changing the replaced average electricity production to coal, oil, or natural gas based production increases the net benefits from the CW system. In the baseline hydro power accounts for 16% of the production. Replacing natural gas, which accounts for 50% of the average production, has only a minor effect. On the other hand, if coal is avoided, net emissions avoided grow by more than 50%. Assuming a dirtier replaced energy source also improves the results from the CW-based system in comparison to the ASP, since the latter produces only a limited amount of replaceable energy.

In the ASP, direct emissions are mostly caused by N_2O releases from the process. In the baseline, a reported median value was used. Ranging the value of N_2O emissions on the scale 0.006–0.253 kg N_2O-N per kg N denitrified, as measured by Foley et al. (2010b), decreases or increases the direct emissions from the ASP significantly. Using the lowest measured release, N_2O emissions decrease by 40%, cutting the net emissions of the entire life-cycle to 136 kg CO_2eq compared to 237 kg CO_2eq in the baseline. Using the highest reported value, N_2O releases would grow by more than an order of magnitude. The latter can be expected to happen only in special circumstances, as most of the values measured by Foley et al. were lower than 0.03 kg N_2O-N per kg N denitrified.

In the CW-based alternative, releases from the wetland cause most of the direct emissions. In the analysis, GHG emissions from the CW were based on average estimates from FWS wetlands. In their review, Mander et al. (2014) report high variability of emissions. Whilst exchange of gases with the atmosphere and fluxes within the wetland system vary depending on the wetland type, choice of vegetation, seasonal and regional characteristics, to name a few, within a wetland large spatial and temporal variability is also reported (e.g. de Klein and van der Werf 2013). As to the best of our knowledge no measured data on GHG emissions from WH wetlands exist, we used reported average values. Using the 25% and 75% quartile values of CH_4 and N_2O releases reported by Mander et al. (2014) decreases and increases GHG fluxes from the CW by 70% and 35%, respectively. Yet due to the dominance of the replaced energy, the net emissions from the WWTP change only by few percentage points. It should be noted that the maximum values reported in the literature for releases from a FWS CW are significantly higher than the 75% quartile. For instance, the maximum value of CH_4 emissions is approximately 80% higher than the average value reported. Due to these high uncertainties, knowledge about GHG emissions from WH vegetation needs to be included in other further research on GHGs and their management in CWs. A pulsing water regime and enhancing aquatic vegetation's growth are the most recommendable methods for mitigation of both CH_4 and N_2O emissions (Mander et al. 2013). Pulsing water regime was studied by Mander et al (2013), and they reviewed results of the studies with intermittent load (e.g. 8 to 10 pulses a day) to CW.

5 Conclusions

Besides purifying wastewater without chemicals, the aquatic vegetation in a constructed wetland can also be used as a bioenergy source. Our analysis shows that not only does a constructed wetland fare better in comparison to a traditional activated sludge process where chemicals are used, but when used as a bioenergy source, it produces net greenhouse gas savings during the life cycle of wastewater treatment. These results have policy implications for Mexico and other warm climate countries. The application of water hyacinth for wastewater treatment, coupled with the production of biogas and utilisation of nutrients and reclaimed water, addresses the needs for water pollution control, renewable energy development, and the emission reduction targets of the country.

Furthermore, these gains can be achieved with lower costs than those incurred through traditional chemical wastewater treatment. Due to savings in energy and chemical use as well as in investment costs, the cost-efficiency of a constructed wetland in a warm climate is two times better than that of a conventional activated sludge process. Economic considerations give further indication of the sustainability of the alternative studied. The analysis shows that the process produces more energy than it consumes, gives satisfactory treatment results, and provides the possibility to reuse treated wastewater and nutrients on an economically sound basis. However, as the water hyacinth growth rate and its utilisation potential for biogas production are crucial for both the WWTP's life-cycle GHG effects as well as economic profitability, the matter must be studied further to produce more reliable data.

Both wastewater treatment methods have their downsides, increasing the need for risk evaluation. Careful management is needed when cultivating water hyacinth, as it has led to serious problems due to uncontrollable spreading. Inexpensive and sustainable control and harvesting methods for the vegetation are needed. In the activated sludge process, unskilful maintenance can similarly cause severe problems and failures in the plants' service. Excessive N_2O leakages have been shown to be one of the main reasons the activated sludge process produces GHG emissions. In both treatment alternatives, environmental and health risks must be identified and managed properly when reusing treated wastewater and digestate on arable land.

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III

WATER SUPPLY AND SANITATION IN A GREEN ECONOMY SOCIETY: THE CASE OF FINLAND

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Water Supply and Sanitation in a Green Economy Society: The Case of Finland

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Abstract

A green economy specifically considers the welfare of the environment and is closely aligned with sustainable development—in both, the use of natural resources should be less than their natural production. In this article, the concept of a green economy is discussed from the viewpoint of water services, a crucial part of a sustainable society, with the objective of enhancing knowledge about sustainable and resilient water services that will meet society's future demands. Drawing from a literature review and a stakeholder workshop attended by 68 experts, it seeks to answer three research questions: (a) What are appropriate and sustainable urban water supply and sanitation policies for a society that is adopting the basic principles of a green economy? (b) What should be the role of water supply and sanitation in a green and circular economy and what are the current challenges to meeting this objective? and (c) What actions are needed in the Finnish water and sanitation services (WSS) sector to effectively meet the requirements of a green and circular economy? The results are applied to the specific case of Finland, and recommendations and conclusions for the Finnish society and its water services are presented.

Keywords

green economy, water supply, sanitation, sustainable development, water services

Introduction

Water is one of the basic necessities of life but it is still not readily available to a large part of the world's population. In 2015, approximately 2.1 billion people in developing

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countries lacked safe drinking water and 4.5 billion were without satisfactory sanitation facilities (World Health Organization & United Nations Children's Fund, 2017). The quantity and quality of water are important worldwide issues, as inadequate water supply and poor sanitation cause millions of deaths and cases of illness annually. This situation has severe health, environmental, and economic impacts, which creates major problems for both individuals and communities in low- and even middle-income economies. Global water challenges are huge. Organisation for Economic Co-operation and Development (OECD, 2012) has assessed and determined that the global demand for water will increase by 55% from 2000 to 2050. Another assessment indicates that the supply is 40% below demand, and that difference increases as the world moves closer to 2050 (Water Resources Group, 2009). This problem is exacerbated by the fact that water and sanitation services (WSS) are often not well managed due to a combination of social, technical, and financial issues.

Because water is a naturally occurring resource, many people believe that drinking water should be a cost-free commodity. However, it is not the water itself that has a cost, but rather, the services necessary to acquire, treat, pump, and distribute it; manage the disposal of wastewater; and maintain the physical components of all these systems. Hence, the problem is not just the quantity and quality of the water but also the knowledge, awareness, attitudes, and appropriate policies and finances required to provide a safe water supply and sanitation for all (Katko & Hukka, 2015).

This article has three objectives. The first is to describe and present the case for a green economy, the second is to demonstrate the role that WSS play in implementing a green economy, and the third is to assess WSS in Finland in the context of a green economy.

Moving Toward a Green Economy

In 2012, the United Nations Conference on Sustainable Development (UNCSD) in Brazil aimed to define clear pathways to a safer, more equitable, cleaner, greener, and more prosperous world for all, by focusing on the concept of *a green economy* within a context of sustainable development and poverty eradication.

Although several definitions of a green economy may be found in recent publications, the definition selected for the theme of this article is from United Nations Environment Programme (UNEP, 2011), which defines the green economy as "one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. It is low carbon, resource efficient, and socially inclusive." A green economy is also a means to achieve a more resilient economy that provides a better quality of life for all within the ecological limits of the planet. It seeks to link the economic, environmental, and social considerations of sustainable development in such a manner that long-term economic development is achieved by investing in environmentally friendly and socially equitable solutions. Economic and environmental aspects are emphasized, but social aspects are not neglected (Young & Esau, 2013). This shift would change many operational economic preconditions and also offer new opportunities for businesses.

The circular economy is a related concept that the European Commission's (EC's) Circular Economy Package describes as follows:

> In a circular economy the value of products and materials is maintained for as long as possible; waste and resource use are minimized, and resources are kept within the economy when a product has reached the end of its life, to be used again and again to create further value. (European Commission, 2015)

UNEP (2011) has identified three challenge areas in the transition to a green economy: ecosystem, economy, and human well-being. In this context, ecosystem equates to natural capital, economy to manufactured and financial capital, and human well-being to social and human capital. Esposito, Terence, and Soufani (2018) present the circular economy from a sustainable production and consumption point of view and describe some activities that fit well within the context of water services. For example, a resilience-based approach in a circular economy model explores how interacting systems of resources and technologies can best be managed to ensure a sustainable and resilient supply of essential materials, resources, and technologies. The outcome document from the 2012 UNCSD conference, "The Future We Want," recognized water as the core of sustainable development because it is so closely linked to many of today's key global challenges. In particular, the report underscored the critical importance of water and sanitation as key elements of successful sustainable development (UN-Water, 2012b).

Water Services in a Green Economy

The green economy strives to increase social justice by decreasing poverty, maintaining better employment, and having a more responsible distribution of property. In the international context in particular, social aspects are fundamentally related to water issues. The United Nations has indicated that water is one of the most important aspects of the green economy and also outlined key messages concerning the use of water (UN-Water, 2012a):

- The success of a green economy depends on sustainable, integrated, and resource-efficient management of water resources and the safe and sustainable provisioning of water supply and adequate sanitation services. This approach must be underpinned by a timely measurement of economic performance in terms of the indicators of social and environmental sustainability.
- Effective management of water variability, ecosystem changes, and the resulting impacts on livelihoods for a changing climate scenario are central for a climate-resilient and robust green economy.
- In line with UN General Assembly Resolution 64/292 on the human right to water and sanitation, the highest priority must be given to the "bottom billion" of people while addressing the inequities regarding the access to water, which are also closely linked to energy security and food security.

- Universal coverage of water supply and sanitation services must be a central development goal in the post-2015 period. In that regard, UN-Water also urges national governments to set realistic intermediate targets and goals.

The role of water in a green economy is vital because it is linked to many sustainable development goals, including health, food security, and poverty reduction. Proper water supply and sanitation services benefit health, life expectancy, and education and increase the time available for business activities (UN-Water, 2012a). UNEP (2011) further stated that water is important in a green economy in three ways:

- Water is essential for life.
- Water is a factor in production and economy for financial welfare.
- Water is an essential environmental resource for maintaining ecosystem services that are needed for sustainable production and consumption of services for human communities.

In 2012, United Nations Children's Fund (2012) quantified the main objectives for water supply and sanitation as follows:

- Decreasing the number of people lacking a decent water supply and sanitation by 50% by 2015.
- Increasing the standard of living for at least 100 million people now living in slums by 2020.

Other relevant findings in this regard may be found in OECD (2013), which posits that water is closely tied to a green economy with the complementary benefit of decreasing poverty; the German Development Institute (2012), which emphasizes the positive role of adequate water supply and sanitation for the sustainability of a community; and Allen and Clouth (2012), who explored the green economy and found that the main challenges to its implementation are lack of political support, inadequate institutional systems and commitment of the Ministries of Finance, no successful cost–benefit analyses, inadequate monitoring, and failure to widely implement necessary policies. Ocampo (2011) suggests that a workable investment strategy should include public investments that support the implementation of a related industrial strategy, substantial public sector investment, and target to provide reasonable water services for the poor. The Life Cycle Approach, which assesses environmental impacts from the acquisition of raw materials to their end use and the disposal of their waste, can be a useful organizing structure for these production structures (Antikainen, Lähtinen, Leppänen, & Furman, 2013a). Total water management (TWM) balances the competing uses of water through efficient allocation of that resource to address social values, cost effectiveness, and environmental benefits (Grigg, 2008), which is also a clear goal of sustainable water management in a green economy society. TWM principles are quite relevant to the successful development of WSS policies to achieve a green economy.

According to UNEP, the benefits of a green economy can be realized by making simple decisions to invest in services that concern water and sanitation (UNEP, 2011). It has been determined that water recycling and reuse, for example, could offer considerable savings in both the use of energy (90%) and water (70%). Fulfilling these objectives not only is a question of natural resources and technology but also involves institutional, ownership, economic, and legal issues. Similar findings were reiterated by the European Union (EU) in "A Blueprint to Safeguard Europe's Water Resources" (European Commission, 2012). This document recognized the link between water resources, a green economy, and resource efficiency, and determined that business opportunities related to the green economy in Europe alone could be quite large, with three areas deserving specific attention:

- institutional design
- water supply and sanitation needs, both globally and nationally
- problems and new approaches to further development.

The so-called Berlin rules (International Law Association, 2004) on water resources law contain important sections about preferences in water use, stating that although there are no inherent preferences of one user over another in international water law, domestic uses (i.e., for drinking, cooking, and washing) are described as "vital human needs" and recognized as a preference in water uses. Berlin rules concern the rights of individuals and especially their right of access to water. In Articles 17 (the Right of Access to Water) and 18 (Public Participation and Access to Information), the importance of WSS for every individual is emphasized and justified. These two articles also support the principles of a green economy with respect to economic, environmental, and social factors.

According to the EU's action plan for a circular economy (EU, 2016), WSS offers an opportunity to reinvent economies to make them more sustainable and competitive. Doing so will bring benefits to businesses, industries, and citizens alike, making the economy cleaner and more competitive. However, this will require ambitious measures to cut resource use, reduce waste, and boost recycling. Figure 1 depicts how urban WSS is integrated into the natural framework, hydrologic cycle, and circular economy.

Certain transitions in society systems are a prerequisite for the full implementation of a green economy (Weber & Rohracher, 2012). According to this, changes are needed from the local to regional, national, and international levels. Furthermore, political and technological changes, as well as changes in governing knowledge and political attitudes, are necessary. Some researchers have tried to develop metrics for the green economy. Lutter, Giljum, and Bruckner (2016) presented a comprehensive review of existing methodologies to calculate material footprint-type indicators. Gouvea, Kassicieh, and Montoya (2013) studied the concept of a green economy in terms of economic growth and development strategies. Both sources concluded that the importance of water resources was mainly due to its role in production processes. Topi, Esposto, and Govigli (2016) concentrated on urban water efficiency for the economics of a green transition and its strategies for cities. They used the Economics of Low

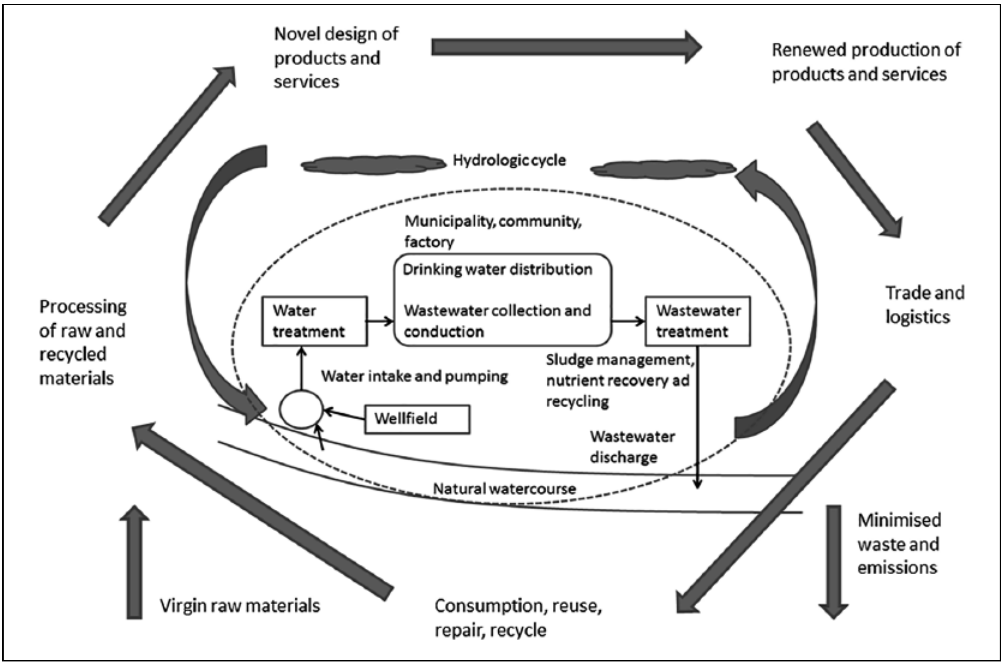

Figure 1. Water supply and sanitation as the framework of a circular economy.

Carbon development strategies for Cities (ELCC) to verify how to extend low carbon energy efficiency strategies to other priority resources, water in particular. They also studied the impacts of behavioral, technological, and hybrid measures.

The ELCC is adaptable, and it was successfully extended to develop a cost-effective scenario for domestic water efficiency (Topi et al., 2016). One important part of a green economy is material efficiency and recycling. This aspect is assessed in the EU's waste policy (Davidova & Horvathova, 2015), and water recycling is a key element in sustainable water resource management.

The challenges and objectives related to urban water supply and sanitation in a green economy are described in different papers prepared by the UNEP (2010), the EU (European Environmental Agency, 2013), the OECD (2011), and nationally in Finland by the Ministry of Agriculture and Forestry (2011). The entire water sector as a part of green economy in Finland has also been studied by Antikainen et al. (2013a, 2013b) and Laitinen et al. (2014), whereas Hukka (2013) emphasized the role of education, good governance, and institutional structure.

The State of Finnish Water Services

In Finland, neither water scarcity nor purity is a major problem. In 2007, 99.9% of the analyses of Finnish drinking water indicated that the water was of good or excellent quality (Katko, 2013). In 2011, drinking water networks served approximately 92%, and sewage networks approximately 85% of all Finnish households. The remainder rely on on-site systems and are likely to continue to do so in the future. In 2013, the length of the drinking water networks was approximately 113,000 km, and the sewage networks approximately 47,000 km (figures from Finnish water services data management system VELVET). These figures continue to increase due to the expansion of water service areas and the introduction of new, separate sewer systems. Currently, there are approximately 1,500 water service providers in Finland. Municipalities own about 400 of these enterprises, which distribute 90% of the total quantity of domestic water. Approximately 1,100 user-owned water associations supply the remaining 10% of the domestic water sold to approximately 13% of the population (Luukkonen, 2013).

Much of the water network is considerably old, and its actual condition is often not precisely known. Although the networks continue to age, only a few water utilities have increased their rehabilitation funding accordingly (Ministry of Agriculture and Forestry, 2013). Several studies indicate that aging infrastructure, especially deteriorating pipe, is the most significant challenge for the water services sector in Finland (Heino, Takala, & Katko, 2011; Windischhofer, 2007). In a recent report by water and wastewater experts on the condition of the built environment in Finland, the state of its water and wastewater infrastructure received a rating of 7 on a scale of 4 to 10 (RIL (Finnish Association of Civil Engineers), 2016). Other studies emphasize that the actual condition of the Finnish water and wastewater network, as well as the need for rehabilitation and replacement, is not accurately known and that rehabilitation needs vary significantly between municipalities and networks (RIL, 2016). During the next 15 to 20 years, the funding needs for water infrastructure rehabilitation are estimated to be approximately 320 MEUR/a (million euros per year), which would require an increase in funding over current levels in the range of 200 MEUR/a. This amount would be necessary to rehabilitate the aging infrastructure continuously and reduce the investment gap accumulated in previous years (Ministry of Agriculture and Forestry, 2008). This issue was explored by Vinnari and Hukka (2010) who concluded that based on Finnish water utility asset management practices, two main problems impede sustainable asset management at the utility level: systemic underestimation of the significance of long-term maintenance and renewal planning and a lack of the necessary knowledge and skills. At the highest policy level, vague wording in relevant legislation allows much room for interpretation, which often leads to inaction.

In "Guideline on Water and Wastewater Services for 2020s," the Finnish Water Utilities Association recently outlined the strategy for water supply and sanitation in Finland and highlighted five priorities (Silfverberg, 2017):

1. strengthening of utility resourcing
2. strengthening of research and development (R&D) work and education
3. strengthening drainage area–based approaches
4. connecting water and sewerage services more tightly with bioeconomy processes
5. strengthening international cooperation.

In *Finnish Water Services*, Katko (2016) documents the long-term development of the Finnish water services sector and presents 28 major conclusions, several of which duplicate those raised in Silfverberg (2017) as well as those promulgated in international guidelines. Some of the issues emphasized are as follows:

- The best allocable technology that is most appropriate for Finnish conditions should be used for water services.
- In land use, water service planning and associated requirements must be taken into account.
- Water services are provided on different levels, from on-site solutions to supramunicipal systems—this institutional diversity provides flexibility.
- Full cost recovery is an essential principle in water services.
- The major current challenge to water services in Finland is aging infrastructure and the cost of its rehabilitation.
- Service supply should be secured by infrastructure resilience and operational reliability.
- In addition to technoeconomic issues, the political, ecological, social, legislative, and ethical dimensions must also be considered.

These recent strategic publications reflect the international guidelines well.

In Finland, water resources are not as limited as they are in arid or semiarid areas, and except for some coastal regions, adequate sources for a water supply are normally found. Yet, it is never sensible to waste natural resources, so there are opportunities to manage WSS resources more efficiently. Laitinen et al. (2014) concluded that over the past 40 years, municipality water consumption has decreased by 30%, and forest industrial alteration has been particularly remarkable for internal circulation of water.

The production of energy is also an important part of sanitation. For sludge treatment in particular, anaerobic digestion, which produces energy, has become a common treatment method following dewatering in a wastewater treatment plant. Also, the nutrients of sludge should be recycled for a better circular sanitation economy (Laitinen et al., 2014). The problem for the time being is that the recovery of phosphorus would bring 60 to 90 MEUR in additional annual costs. Yet, the value of the recovered phosphorus with current prices would only be 2 to 4 MEUR (VVY (Finnish Water Utilities Association), 2016).

Research Approach

Assessing WSS in Finland is done both to better explain the connection between WSS and a green economy and to describe the Finnish experience in implementing the concept. Although there are numerous studies and articles that address the green economy (e.g., Allen, 2012a, 2012b, European Environmental Agency, 2013) as well as sustainable water services (e.g., Katko & Hukka, 2015; World Health Organization & United Nations Children's Fund, 2017), the gains possible from operating WSS according to the principles of a green economy have not been well studied. This article attempts to fill this knowledge gap and identify the main steps on the road to WSS in a green economy society. It examines, through a lens of resource efficiency and sustainability, the role of water services in supporting the environmental, economic, and social services that people depend upon to implement their way of life. To do this, three main research questions are posed:

Research Question 1: What are appropriate and sustainable urban water supply and sanitation policies for a society that is adopting the basic principles of a green economy?
Research Question 2: What should be the role of water supply and sanitation in a green and circular economy and what are the current challenges to meeting this objective?
Research Question 3: What actions are needed in the Finnish WSS sector to effectively meet the requirements of a green and circular economy?

The responses to these research questions are developed by means of a thorough literature review and a stakeholder workshop on the water issues present in a green economy. The approach taken is phenomenological; the concepts are studied thoroughly, and the relevance of different views is then compiled based on follow-up discussions and interviews. A phenomenological approach was considered appropriate for this study due to the sociotechnological nature of both the green economy and WSS.

The literature review was augmented by a workshop attended by 68 subject matter experts in October 2013 on how water supply and sanitation in Finland supported or hindered the transition to a green economy. The attendees represented public authorities, research institutions, water utilities, nongovernmental organizations (NGOs), financing organizations, consultants, and other private companies. There are more than 1,000 water utilities in Finland, and the water utility representatives were from large- and medium-size utilities, which was considered adequate to represent the interests and views of the overall Finnish water service sector. The workshop opened with presentations by representatives of public authorities (one), research institutions (three), private companies (two), NGOs (one), and financing organizations (two). Following the presentations, four questions were raised:

a. What concrete examples of changes regarding a green economy are seen in Finland and globally?
b. What kind of business prospects in a green economy can be seen in Finland and globally?
c. What kind of barriers and challenges are present in the water sector to fulfill the green economy concept?
d. What investments and development of services are still needed in the water sector?

The participants were divided into four groups to discuss each question, while the organizing group made notes of the discussions. The conclusions presented in this article were drawn by the authors after the workshop.

The common view of the experts was that the transition to a green economy is already occurring in Finland and can clearly be seen in the water sector. The transition offers concrete business opportunities in the water sector for stakeholders in Finland, as well as globally, although there are still many challenges to its full implementation. The outcomes of the discussions of the four main questions posed in this workshop are summarized below.

> Question a: What concrete examples of changes regarding a green economy are seen in Finland and globally?

The participants could see a clear change of attitude in the water services community. Topics related to a green economy, such as recycling, utilization of side streams, and environmental impact assessments, have become widely accepted, both as everyday functions and also as part of business efforts. The clearest move toward a green economy can be seen in food production, waste and water management, and the energy sector. This trend is supported by how quickly and widely the ecosystem approach is being adopted. The ecosystem is considered as a functional whole, and the environmental impacts of different activities are assessed separately. In food production, the use of water and energy is becoming more efficient. One example is the recycling of water in fish and greenhouse farming. The utilization of nutrients in wastewater sludge follows the principles of a green economy but the possibilities for utilizing sewage sludge in the cultivation of food plants are limited due to concerns regarding possible harmful substances in the sludge.

Although there is generally no water scarcity in Finland, more opportunities should be explored for improving technology for water reuse. In wastewater management, several methods for increasing the efficiency of wastewater treatment have been developed, for example, coprocessing of municipal and industrial wastewater discharged from pulp and paper manufacture. These improved processes offer synergistic advantages and resource efficiencies but must be designed and operated professionally. Wastewater treatment can produce energy by recovering the heat generated during anaerobic digestion, which clearly supports the principles of a green economy. There are also many opportunities for better resource efficiency through energy saving in wastewater treatment.

> Question b: What kind of business prospects in a green economy can be seen in Finland and globally?

Potential new business opportunities are particularly visible in knowledge export and cooperation with other sectors. These opportunities are global as well as national because a green economy offers new possibilities for the export of Finnish knowledge in the water sector. However, knowledge and reputation must be acquired in the national market before moving on to global business. New business areas in water supply and sanitation related to a green economy include smart monitoring, data management, data interpretation, and dissemination.

The strong Finnish knowledge base in the water sector and how it can support the green economy can provide Finland with a competitive edge in the global marketplace. Finland is very strong in WSS fields such as arctic infrastructure construction, water and nutrient recycling, integrated and smart concepts for water and energy, and advanced information and communication technology (ICT) applications, and could market these skills for technical assistance and human resource development. These can be applied to enhance a resource-efficient water supply and sanitation, for example, in the recovery of excess energy from wastewaters.

Question c: What kind of barriers and challenges are present in the water sector to fulfill the green economy concept?

Improved cooperation between different sectors was identified as a challenge that should be addressed to achieve better results in the development of the water sector and the full transition to a green economy. Other barriers identified included management, regulation, research, and financing as well as social and cultural aspects. In many countries, management of the water sector is scattered over many agencies and sectors, and, thus, it is difficult to see the whole picture clearly and develop comprehensive solutions. Furthermore, the concept of a green economy is broad by nature and not always well understood, and its benefits tend to accrue over long time horizons. As a result, it can be difficult to muster the cooperation needed to implement consensus approaches in the near term. Promoting better green economy thinking for water supply and sanitation will require that social and political aspects, in addition to technical factors, must also be considered.

One major issue that will affect full realization of a green economy in the water sector is the price of water. For water policy to be fully integrated into the green economy, the price of water services must be set to cover operation and service costs, including long-term capital investments and renewals. A challenge facing Finnish water services is an abundance of old and deteriorating infrastructure, which will endanger the safety and reliability of the water supply if the rehabilitation and renewal of these service systems and facilities are not organized and implemented more efficiently. Finland is moving toward water tariffs that will achieve full cost recovery, whereas in several other developed countries, the flat rate policy, which generally does not provide adequate revenue to meet all expenses, is still in use, which causes problems in water resource stress and management of water assets (Katko, 2016). Several studies indicate that meaningfully reducing the rehabilitation gap would require doubling or trebling the annual amounts budgeted for network renovation (Ministry of Agriculture and Forestry, 2008; RIL, 2016; Vinnari & Hukka, 2010). Romano, Masserini, and Guerrini (2015) studied water pricing in Italy and how utility ownership affects the water fees there, concluding that ownership in itself does not influence the tariffs set by the water utilities.

Question d: What investments and development of services are still needed in the water sector?

To fully achieve a green economy, the Finnish water sector needs to change its business approaches. In Finland, water supply and sanitation have been operated using the same business model for decades, with municipalities responsible for providing water services in their operating areas. It has worked well, but new modes of operation could offer new opportunities and possibilities for international water business. For example, certain technology areas, such as sludge management and energy and nutrient efficiency needs, are already prompting new approaches. This transition requires the cooperation of all stakeholders; government, municipalities, water utilities, private enterprises, and civil organizations should all participate.

In financing and investment, the importance of the rehabilitation of deteriorating infrastructure, especially water pipes and sewer networks, was raised. Yet, this problem is not just a question of financing; it is also a contentious political issue. Because these networks are buried underground, many municipal politicians tend to support more visible projects and programs in their budget negotiations.

Current issues regarding the water sector and a green economy vary significantly in different countries depending on the quantity and quality of their natural water resources, nature of the economy, and water policies and technologies used. If there is any water scarcity, the main issue is how to provide enough water for people, agriculture, and industry; where water quantity is not a problem, the issues shift to water quality, sanitation, nutrient recycling, emissions, and pollution. This is the situation in Finland and in several other European countries.

The strength of the Finnish WSS is in political consensus, good governance, and efficient implementation of strategy. Although Finland does not suffer from major quantity and quality problems nor social challenges in the water sector, Finnish water management knowledge is not directly transferrable to other countries and cultures. Studying results from similar countries and applying the lessons learned could lead to a remarkable leap into sustainability in WSS.

Key Findings From the Workshop

Given the broad nature of the topics discussed at the workshop, the key findings were grouped by their significance and probability of being realized in the near future as displayed in Figure 2. The levels of significance and realization were developed by analyzing discussions and interviews during and following the workshop. Organizing the findings in this manner provides a ready means of targeting the three research questions posed earlier in this article regarding the role of WSS in achieving the principles of a green economy. It also offers guidance for the timing of future actions and the likelihood that they will be successful.

Capacity building (education, high-quality on-the-job training, systematic human resources management) is an essential part of promoting any sector. In the development of WSS projects, capacity building has been an important issue for decades, and there are several examples of successful results. To understand the requirements of a green economy, appropriate education is a necessity. Enabling legislation and other policy instruments are commonly in use in most countries; however, implementing

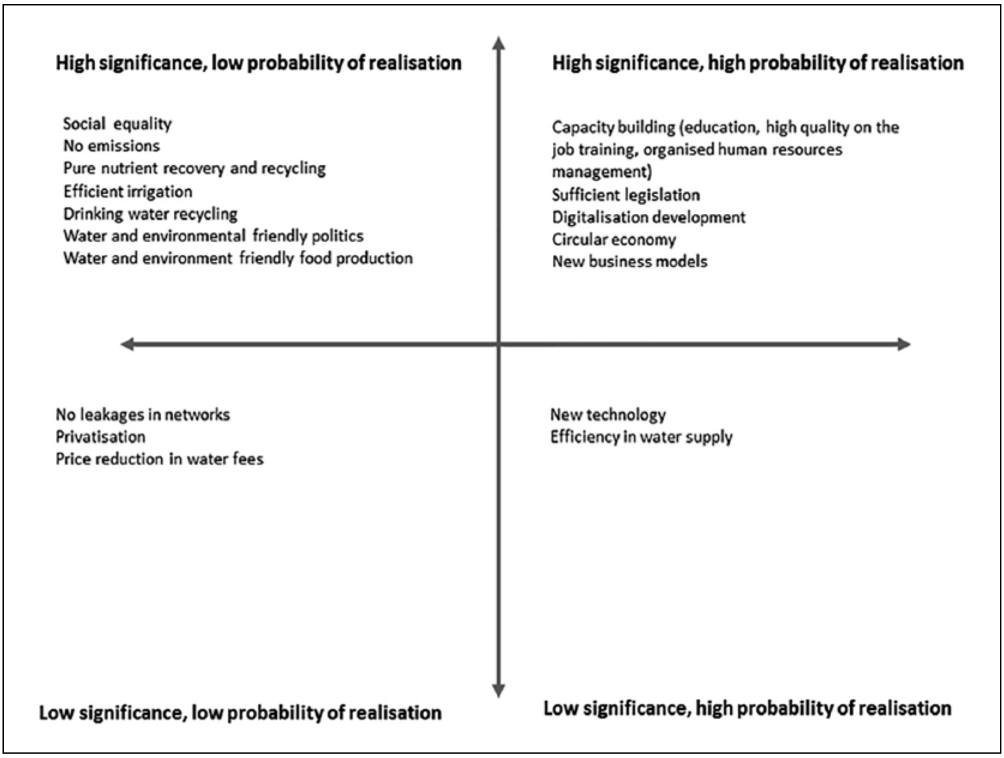

Figure 2. Key classification regarding the water supply and sanitation in the context of a green economy.

them fully still requires additional effort. Digitalization, a circular economy, and new business models are new approaches in the developed countries and significant attention and resources are focused on these issues (Figure 2, upper right corner).

It is unfortunate that the achievement of social equality is far from complete, particularly in developed economies. To that end, social equality between races, genders, and other classes is a main issue in a green economy and it is noteworthy that WSS is a crucial factor for how a green economy should be fulfilled. In the case of Finland, this is not a remarkable issue, so this might be a priority candidate for Finland's export of water management knowledge. The ultimate goal for water management in a green economy would, of course, to be free from emissions, and all nutrients and other products in side streams would be recovered and reused. Technological development, knowledge, and awareness have made progress toward this goal during the last decades (Figure 2, upper left corner).

Total water recycling would be a solution in areas with water scarcity, but so far, the direct production of potable domestic water from wastewater is not generally acceptable. Water and environment-friendly politics is also a popular consideration within political parties and politicians, but unfortunately, it has not been fully implemented in any society so far. Food production is recognized as one of the most important actions related to a green economy and the water sector. However, providing sufficient supplies of safe water and environment-friendly food production is a difficult issue and is not yet resolved.

Technology has improved remarkably over the past few decades and it provides a basis for the provision of adequate water supply and sanitation in the future. In developing countries, the adoption of new technologies is ongoing, and it will increase the quality of services in turn. The efficiency of water supply is dependent on technology, policy instruments, and human resources, and continued improvement will benefit water services in developing countries—services that are already at a high level in developed economies (Figure 2, lower right corner).

This study has attempted to build on the international context of the green economy to address the research gap presented in the beginning of this article. Concerning the ways to benefit from running WSS according to the principles of a green economy, the key findings (capacity building, sufficient legislation, digitalization development, circular economy, and new business models) occur in the upper right corner in Figure 2. These are the issues where available resources would give the best results on national and also international challenges. When the goal is to provide more people with safe and adequate water services without having additional water resources, a green economy solution would be to increase knowledge, skills, and awareness as well as to decrease water loss and inefficient uses of water.

Conclusion

Based on the literature review and the findings from the workshop, responses to the research questions posed earlier have been developed and are presented in Table 1. These findings are currently in various stages of implementation and can serve as the basis for the Finnish WSS industry to move toward fuller realization of the principles of a green and circular economy.

Adequate water supply and sanitation services are critical to sustainable development, and the availability and function of both services are basic elements of an operational green economy. Investments in the water sector are especially needed in developing countries to achieve the health, environment, economic, and social benefits of a green economy. Although the supply of safe drinking water is often the first issue in the water sector, it is intrinsically linked to proper wastewater management—decent sanitation is a definite prerequisite for well-being and a good quality of life. Hence, urban and rural land-use planning greatly help in obtaining the objectives of a green economy as defined by UNEP (2011).

Due to aging infrastructure, full cost recovery will become an increasingly important principle for sustainable water services. This focus will require both supportive legislation and improved financial supervision of water utilities. Water fees should be designed to cover costs over the entire life cycle of water service systems and infrastructure.

Inadequate water supply and poor sanitation cause millions of deaths and cases of illness annually. Fortunately, in Finland, this is only an occasional problem. The reason for this is that the Finnish WSS industry has improved water management in terms

Table 1. Principal findings to the research questions

Research question	Principal finding
(1) What are appropriate and sustainable urban water supply and sanitation policies for a society that is adopting the basic principles of a green economy?	WSS policies that are needed to fulfill the principles of a green economy are appropriate legislation; social equity in services; good technological, economic, and ecological knowledge; and good governance. To implement this policy, good education and training is needed as well as the right attitude for collective good.
(2) What should be the role of water supply and sanitation in a green and circular economy and what are the current challenges to meeting this objective?	The role of WSS in a green and circular economy depends on the area; in Finland, it is mainly sustainable use of water, recycling of nutrients, and management of the infrastructure.
(3) What actions are needed in the Finnish WSS sector to effectively meet the requirements of a green and circular economy?	The main actions for Finland to meet the requirements of a green and circular economy are to enhance management of the infrastructure as well as sludge management and recycling.

Note. WSS = water and sanitation services.

of water saving processes, water recycling, and material efficiency. The main challenges in Finland are asset management and the implementation of the principles of TWM in achieving sustainability. WSS is only one part of the functions of a society, but when considering the principles of a green economy, it is clear that these principles cannot be successfully realized without ongoing and sustainable water management.

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PUBLICATION
IV

RESILIENT WATER SERVICES FOR THE 21ST CENTURY SOCIETY – STAKEHOLDER SURVEY IN FINLAND

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Article

Resilient Urban Water Services for the 21th Century Society—Stakeholder Survey in Finland

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Abstract: Resilience has become a vital theme in the discussion concerning urban water services. Resilience in this context can be defined as both keeping up a good level of services, as well as rapid and fluent recovery from failures caused by natural disasters, unsound infrastructure or incorrect management. Although adequate water services resilience can be considered as sustainable, resilience is a wider concept than sustainability. In order to call water services resilient, all sections from policy and management to technical operation should be clear and coherent, and their operation in challenging situations also must be guaranteed. This study seeks a resilient approach to water services through a literature review, and a questionnaire to stakeholders; mainly water supply and sanitation experts. The results show that sufficient technology and good water quality are not sufficient for achieving resilient water services, but also education and institutional management are essential issues. These are accomplished by a methodical education system, capacity building, and good governance.

Keywords: good governance; sanitation; sustainability; water supply

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1. Introduction

Water services—water supply and sanitation in this context—are essential services for human welfare. Yet, these services are not always organized and operated in an adequately planned and controlled mode of operation, even in many developed countries. Especially in urban areas, systems are vulnerable to internal or external disturbance, which might cause severe health, environmental and economic challenges for communities. These kinds of disturbance can include, for example, technical and economic problems (internal) or changes in environment or policy (external). Climate change is one example in external disturbances affecting raw water resources and wastewater management.

To maintain continuous and acceptable water services, decision makers, public servants, and experts have to be aware of the requirements of the community for adequate operation of the water systems utility. The requirements concern not only water utilities, but the whole process that affects the urban water cycle. Special challenges are faced due to disasters and climate change impacts. To prepare for recovering from these situations as soon as possible, and for providing uninterrupted water services, the water utility must become more resilient. There are several different issues and sectors that must be robust as prerequisites for considering a community's comprehensive water services resilient. Resilience in water services is in this study considered to include (a) ability to operate continuously and resist disturbances and (b) ability to recover after failures.

Applying integrated water resources management (IWRM) Koop and Leeuwen (2015) analyzed 45 municipalities in 27 countries using the improved city blueprint framework (CBF) [1]. They categorized five different levels of sustainability of urban IWRM, (1) cities lacking basic water services, (2) wasteful cities, (3) water-efficient cities, (4) resource-efficient and adaptive cities, and (5) water-wise cities. They emphasized the importance of effective governance, environmental awareness and community involvement for sustainable IWRM.

Closely related to IWRM and very much applicable when studying sustainability and resilience of urban water services is the concept of integrated urban water management (IUWM) [2]. In this approach drinking water, sanitation and storm water management are not developed, planned and implemented separately, their cross-scale interdependences must be acknowledged. This is a growing aspect especially in large urban centers.

Urban water services include water intake, treatment and distribution, wastewater collection, treatment and discharge back to natural waters. Storm water management also affects urban water services and that cannot be neglected, especially when considering impacts of climate change on urban water management [2]. The abovementioned issues are the main issues of urban water management globally, but their importance is different depending of the meteorological, hydrological, political, environmental and economic conditions of the country and the area [3].

Some areas may have severe problems because of water scarcity, while other areas have enough water sources, but not adequate water policy. In recent years there have been alarming news about water crisis in large urban areas all over the world [4]. Some studies have been carried out to compare resilience of urban water services in developed and developing economies [5], and impact of population and lifestyle changes [6]. The results show that there are parallels between water, human rights and reproductive justice crises in communities, and that e.g., UK may face a supply-demand gap by the 2080s [6]. In the UK, the Water Services Regulation Authority (Ofwat) has prepared a document, which gives proposals on water regulation in future [7]. The US Environmental Protection Agency has defined systems measures of water distribution system resilience for securing drinking water services in future [8]. One remarkable issue is that, when improving resilience, it is most effective when implemented at a local level [9].

The objective of this study was to determine what kind of institutional aspects should be developed to strengthen the resilience and sustainability of Finnish water services. This study concentrated on Finnish urban water services and their resilience by surveying stakeholders' points of view regarding the value and best practices of community water services. This survey was carried out via a questionnaire to find answers to the following research questions:

1. What is resilience in urban water management?
2. What are crucial aspects for securing adequate water services?

Sustainability and resilience in water services have been studied and applying these principles has been attempted in several countries, e.g., [7,8]. The studies often concentrate on some special subjects or themes, like urban water technology and infrastructure [10], operational management [11], governance [12], or they try to define a method for analyzing the system [13]. The research gap addressed by this study is to develop a wider perspective in technical, institutional and socioeconomic aspects of water resilience. Water resilience and water governance is still poorly understood, especially institutional and governance dimensions of building water resilience [14]. More research should be directed to factors, practices and governance principles that help increase the resilience of people, communities or the environment to water-related risks [15].

2. Materials and Methods

This study was carried out via a literature survey and a questionnaire sent to experts representing key water services stakeholders. Within the stakeholders, 67 individuals were selected from universities, ministries and institutions. In addition, the questionnaire was sent to 338 water utilities, in which there were 403 individual recipients. These 338 water utilities provide drinking water to more than 80.0% of Finland's population. Of these 470 recipients, 99 replied with response rate of 21%. This kind of scope of study concerning Finnish water services has been applied also in studies carried out in 2010 and 2011 by Technical University of Tampere [16,17]. The questionnaire is presented as an attachment in Supplementary Material S1.

The results of the questionnaire can be interpreted for forming a reasonably good and representative view of sustainable and resilient water services in Finland. The main stakeholders in Finland are ministries (responsible of legislation), regional authorities (one organization responsible of permitting and another of monitoring), municipalities (responsible of organizing water services) and water utilities (operation and maintenance). Other stakeholders to whom the questionnaire was sent were research organizations, universities, consultants, equipment and service providers, as well as some NGOs. The coverage of respondents was as follows: water utilities (44%), other water companies (19%), governmental organizations (14%), private companies (7%), municipalities (6%), universities (4%), and other miscellaneous bodies (6%). The questions are formulated especially to experts of urban water services. Normally the questionnaire was sent to the managing director of a water utility, or respective leaders in other sector bodies. It would be interesting to implement a survey also to customers; institutions and citizens, but then the questions should be different and sampling considerably larger.

The geographical distribution of the replies covered the whole country, largely representing the distribution of settlements: 23% of respondents were from the capital area or other big cities, 27% from Southern Finland (other than the capital area), 20% from Eastern Finland, 19% from Western Finland, and 11% from Northern Finland. This corresponds well to the distribution of the population. Of all respondents, 74% were men and 26% women, while 64% represented management positions and 22% experts.

The questions were formulated to gain an understanding of experts' and stakeholders' points of view regarding the following major aspects. The answers supported the results and conclusions when searching for answers to the research questions formulated in Introduction of this article.

i. Significance of water services failures and their significance in urban water services.
ii. Policy instruments and impact methods for ensuring continuous service in water supply and sanitation: a. pricing policy b. institutional strengthening c. service reliability, d. development planning.

The majority of the 15 questions were formulated, 10 dealt with substance and five with the background of the respondent. In three questions the respondents were asked to assess statements or arguments using a scale from 1 to 5, one question was completely open-ended. The majority of the questions included several alternative means or proposals for improving the current situation out of which from 1 to 3 were selected and ranked. In this way, it was possible to get a balanced overview on how the experts in water services prioritize the selected questions related to resilient water services in Finnish conditions.

This method was considered to suit well for finding answers in this kind of study and to the stated research questions [18]. Before sending the web-based questionnaire, it was pre-tested by five experts. In the beginning of the survey, a short description of all the questions was presented for giving an overview to the respondents before they replied to specific questions. The answers were compiled and analyzed in order to get a good impression and response to research questions that were set in the beginning of the study.

3. Results

3.1. Resilience in Urban Water Services—Literature Survey

Resilience in water services has no definite definitions in literature. The term has been increasingly used, especially during the last few years. However, it can be defined in several ways. Johannessen and Wansler (2017) stated that the resilience concept is generally not operationalized, and they investigated in their study how the resilience concept can be systematized, operationalized and applied better in urban water management [19]. United Nations International Strategy for Disaster Risk (UNISDR) defined the term resilience as follows: "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner" [20]. According to a thorough study by Folke (2016), resilience thinking is an integrative approach for dealing with the sustainability challenge [21]. It can be viewed as a subset of sustainability science with a focus on social-ecological systems of people, communities, economies, societies and cultures.

A major challenge is to make the now largely invisible infrastructure of water services more visible to decision-makers and citizens. From a historical context, water services are not only necessary but invaluable, and they are a key component of the national security of water supply. Only if water services fail, do they seem to get recognized. Resilient water services and systems are the foundation of well-being, and resiliency is the key for sustainable water services [22]. In considering urban water resilience, it is good to assess various scales in urban water systems depending on users (households, communities, cities), institutions (service providers and regulators), technologies and ecosystems [22]. According to Johannessen and Wansler (2017) [19] resilience in urban water services and defined three levels of disturbances as follows:

i. Socioeconomic disturbance, which is not associated with external hazards but within the urban water service infrastructure and the entities that manage and govern them.
ii. Hazard disturbance, i.e., external hazard, disaster, and crises-related disturbances that are outside the urban water service infrastructure.
iii. Long-term disturbances such as unsustainable resource extraction by the urban water services on the broader social-ecological system and vice versa.

Resilience has also been studied in other environment and infrastructure-related ensembles, such as housing. Miller (2015) concluded that sustainability, environmental performance and resilience are inter-related, and she used technical, social and economic approaches in her study [23]. This paper emphasizes the importance of cooperation and collaborative approach, which can be seen quite clearly also in resilience of water services. Bocchini et al. (2014) compared the terms 'sustainability' and 'resilience' in civil infrastructure and concluded that the proposed perspective and assessment technique is applicable to various types of civil infrastructure systems, although their case concentrated on transportation networks and bridge systems [24].

Linkov et al. (2013) formulated a resilience matrix for measuring overall system resilience, not only fragmented resilience in separate disciplines [25]. They defined four functions with respect to adverse events: (i) planning and preparation, (ii) adsorption, (iii) recovery and (iv) adaptation. In their resilience matrix these events are mapped to four functions:

(i) Physical: sensors, facilities, equipment, system states and capabilities
(ii) Information: creation, manipulation and storage of data
(iii) Cognitive: understanding, mental models, preconceptions, biases and values
(iv) Social: interaction, collaboration and self-synchronization between individuals and entities

This matrix was defined for supporting the decision-making process for perceiving the overall picture of possible disaster management.

It is challenging to combine different stakeholders' views in the same calculations or assessments. One way to navigate this problem is to visualize water supply systems graphically so that different views are illustrated. Using this scheme, Lehrman (2018) used so-called Sankey diagrams for engaging water policy makers on issues of social and environmental justice, ecological water use, sustainability, recreational access and urban/rural issues [26].

Cities generate more than 80% of the gross world product (GWP), so resilience of cities is important to maintain [27]. GWP is the combined gross national product (GNP) of all countries in the world including the total domestic and foreign output claimed by residents of a country. For this, sustainable water services are crucial and in the transition towards smarter cities, water issues play a significant role. Urban water security is strongly related to resilience [11]. Four issues can be pointed: welfare, equity, sustainability and water-related risks. While public administrations and political scientists are looking for mechanisms of good governance, they underestimate the quality and effectiveness of policy outcomes. Good governance is essential, but it does not guarantee outcomes that are effective in terms of solving the problems at hand. For the level of organizations, the Finnish Technical Research Centre VTT recommended the principle of "flexibility for change" for supporting organizational resilience [28].

In benchmarking water utilities, a wide variety of indicators are used [29,30]. It is important that, in addition to indicators for the performance of the physical infrastructure, there are also indicators illustrating management and financial performance [11]. These indicators point out that "We need to better understand the full potential of water-sensitive design, rainwater harvesting, recycling, reuse, pollution prevention and other innovative urban water approaches" [11].

Hordijk et al. (2014) explored water governance systems in four cities and assessed adaptation practices at three levels: resilience, transition and transformation [31]. They concluded that "the crucial question for the transformation of water governance systems in all cases will be whether, in the long run, participation and deliberative decision-making are extended to decisions about hard infrastructure and the provision of local water and sanitation services, and whether local powers are indeed empowered to hold the approach of water as an economic good to account". This complex problem can also be seen when comparing the combination of centralized and decentralized water systems approaches. In Melbourne, Australia, it was discovered that this kind of hybrid water system both reduced potable water demand and altered wastewater flow and contaminant concentration [32]. This improved the resilience of the water system to variable climate conditions.

In many countries, where water supply and sewer networks in cities are aging, resilience of urban water services is subject to risk of malfunction of deteriorated networks. Krueger et al. (2017) studied how to enhance water and sewer network resilience to external and internal threats [10]. They compared the functional topology of planned urban infrastructure networks to natural river networks draining natural landscapes. As implications, they emphasized the relevance of efficient planning of networks and observation of expected topological features.

Water supply and sewer networks are technically and financially remarkable parts of sustainability and resilience in water services, however these are not the only aspects of water and sewer network management. Sustainable water demand management (SWDM), was defined by Arfanuzzaman and Rahman (2017) in their research in Dhaka city, Bangladesh [33]. In their analyses, they covered the present condition of water demand, supply, system loss, pricing strategy, groundwater level and per capita water consumption. The main idea was to reduce the water footprint and pollution. To achieve SWDM political, financial, technical and legal control, a variety of methods are needed, e.g., 100% coverage of metering, pricing policy on water withdrawal, development of surface water sources and penalty or discount according to meeting the consumption goals.

Schifman et al. (2017) introduced a Framework for Adaptive Socio-Hydrology (FrASH) for planning of using green infrastructure in storm water management [34]. This approach requires cooperation between community organizations and increases stakeholder involvement. Thus, integrated urban water resources management can be a step towards sustainable city development. The authors see also that this concept can be applied to other environmental management plans and projects, and it can be considered suitable for planning sustainable urban water services. One important aspect in IUWM concept is separation of wastewater systems from rainwater drain systems. This was concluded in the Netherlands in a study of three case cities, namely Amsterdam, Rotterdam, and Utrecht [12].

The paradigms of sustainability and resilience in the built environment were the subject matter of research by Lizarralde et al. [35]. They found that there are different interpretations of these terms. This might explain tensions that occur when the paradigms of sustainability and resilience are translated into policy instruments. They name sustainability 'green' and resilience 'blue' and conclude that both academics and practitioners need more refined tools and conceptual frameworks to successfully achieve a turquoise agenda in the built environment.

3.2. Results of the Survey

In our survey, the respondents considered water services the most important part of municipal engineering. However, it must be stated that they represent particularly stakeholders of water services, like water utilities, consultants, researchers and authorities. In water use, water as a source of water supply was considered extremely important (see Figure 1). The exact question was "What is the most important use of water resources?" The respondents were given a scale from one to five, one meaning not important at all and five extremely important. So, the scale from all 99 answers ranges from 99 to 495. The same scale is used in Figure 2.

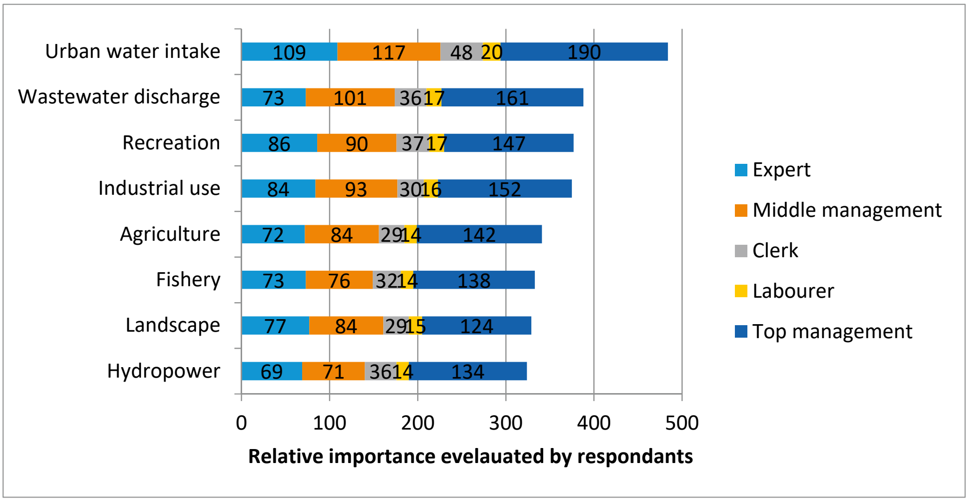

Figure 1. Ranking of water use priorities, illustrated by occupational groups.

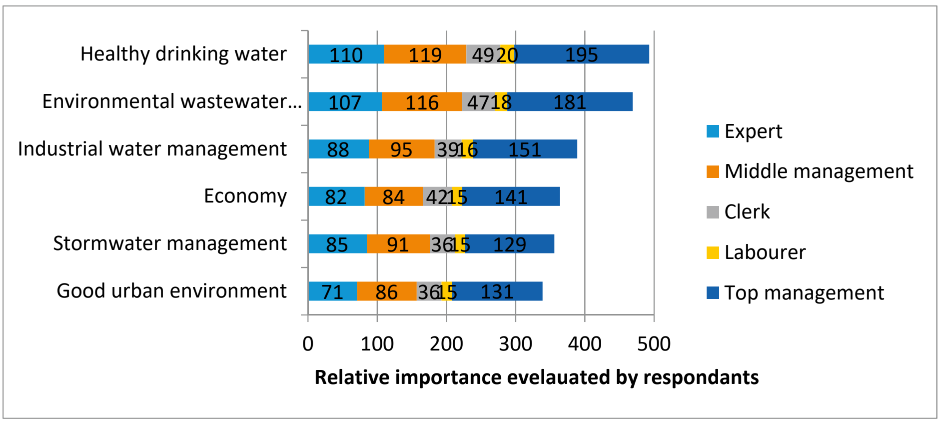

Figure 2. Relative importance of water services according to respondents, illustrated by occupational groups.

In the relative importance of water services, the most important aspect was healthy and secure water supply (scale from 99 to 495) followed by wastewater management that is secure for the environment (Figure 2). Participants responded to the statement 'Importance of functional water services'.

Pricing policy and institutional aspects were explored for getting views on policy instruments. Six statements were given, and respondents were asked to pick the most important one:

- Water fee must be decreased so that everybody can afford water services
- Water fee must be increased so that services can be improved
- Water fee is reasonable, services can be improved by more-efficient operational management
- Payments for owners of water utilities (usually municipalities) must be decreased
- Water supply network leakages should be decreased
- Sewer network leakages should be decreased

Most remarkable is that no-one thought that the water fee should be decreased and 31% thought that it should be increased for improving water services (Figure 3).

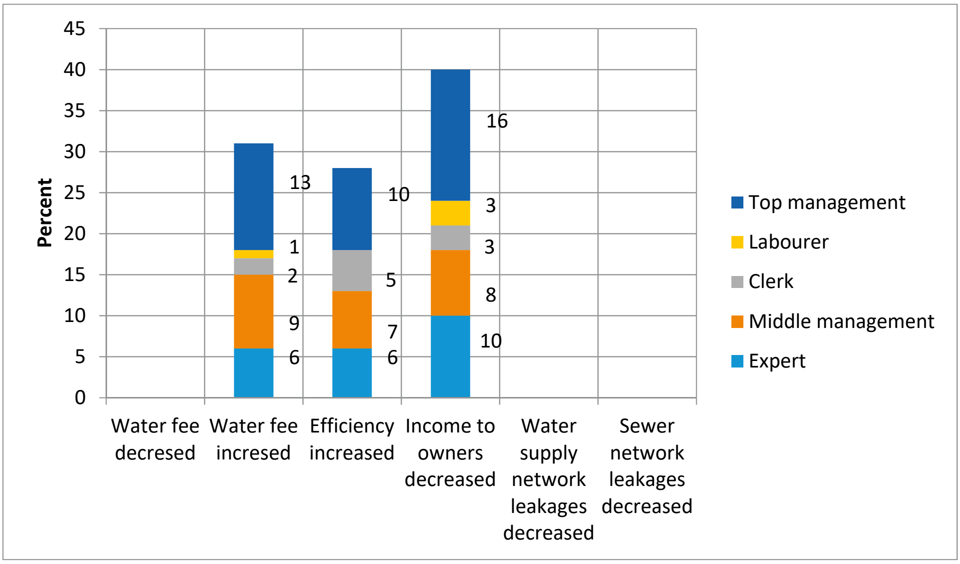

Figure 3. Policy instruments and pricing policy, illustrated by occupational groups.

Municipalities transfer part of water utilities' profits as income for other municipal costs (so-called reasonable rate of return). This might be a considerably large part of funds that could be used for development and renovation investments. Altogether, 41% of respondents had the view that the current rate of return is too high (this is too large a part of the water utilities budget) and it should be reduced.

One remarkable issue in Finnish water services for the time being is renovation of water pipe and sewer networks. Major parts of networks were constructed in the 1950–1960s and now it is time for major investments for maintaining a safe and acceptable level of water services. Considering the most important measures to ensure good water services, 64% of respondents thought that renovation of water pipe networks should be increased and 57% thought that renovation of sewer networks should be increased. Only 5% thought that the quality of drinking water should be improved, which indicates that the quality is good enough in most of Finnish communities.

The measures for ensuring continuous acceptable levels of water services, good data and information management, were considered the most important issues. Other issues identified as important were detailed planning for renovations and modelling as a tool for leakage monitoring. In ensuring the reliability of water services, skillful and sufficient personnel is important. Hence, national-level capacity building should be ensured. Network rehabilitation financing was also considered important for ensuring good-quality water services (see Figure 4).

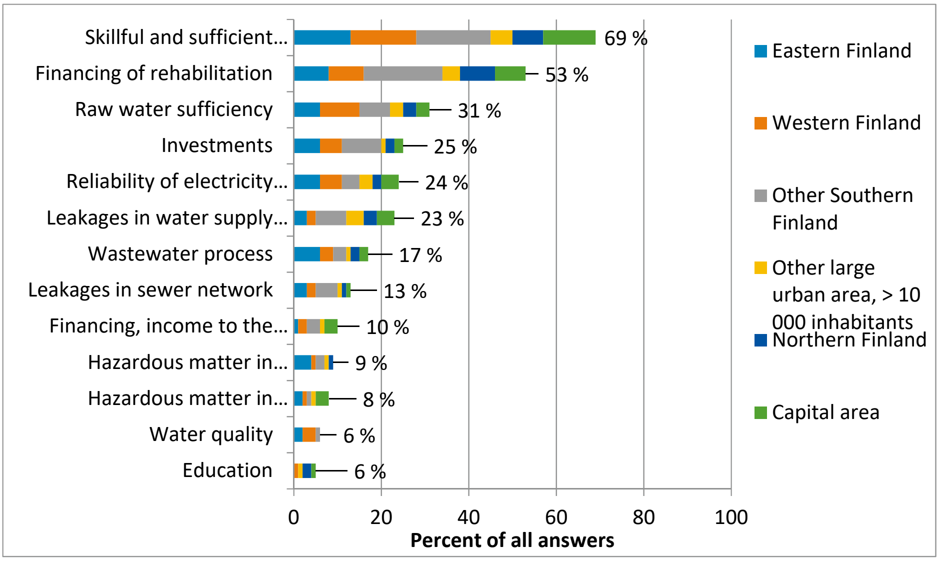

Figure 4. Topics for ensuring sufficient water services, illustrated by regions (in % of all answers).

The questionnaire included one open question: "What is the significance of adequate water services for your organization?" The 102 answers from 63 respondents were divided to seven groups; Operation of community, Health, Environment, Industry, Convenience, Economy, and Image of water services. Altogether, 29 (28%) of the answers emphasized operation of community, 24 (23%) the economy, and 19 (19%) the environment. This indicates that Finnish water experts consider water services as an eminent part of socioeconomic civil services.

The Finnish Act for Water Services says that the municipalities are in charge of water services, but they can outsource operation and purchase services from private or public organizations. This course of action is considered highly functional (89% of respondents) and flexible cooperation between public and private operators is important (70%). Only 1% thought that also private companies could be owners of a water utility.

4. Discussion and Conclusions

This study was carried out via a literature review and a questionnaire to professionals in water services. The coverage of the respondents was quite good when proportioned to the size of the country and the previous studies. This study dealt only with urban water services and its resilience. Issues in rural areas are different and the results could have been different if the questions had concerned also rural water supply and sanitation. In such a case, it would have been more difficult to find specific conclusions to the formulated research questions.

The first two questions in the questionnaire concerned the importance of water services in the field of other critical municipal services and water issues. These sectors are strongly connected, and as public services they must be planned and developed integrated. For example, very often the rehabilitation of water and sewer networks is sensible to implement together with street rehabilitation. Storm water management is also connected with water services, and especially due to climate change impacts, it must be taken into consideration together with water supply and sanitation as well as construction of streets and green infrastructure.

4.1. Results Reflected in the Survey

In the literature survey, the articles can be divided according to how they approached the concerned theme, or the subject they emphasized. According to the subject, most of them deal with water infrastructure and disturbances in service. In terms of approach, the most common concerns are water scarcity and sufficiency as well as water-smart cities. According to this study, the importance of these subjects can be confirmed, but there are also several other issues that cannot be neglected. The most important point of views in addition to subjects mentioned above are education and skilled personnel, good governance, institutional arrangement and financing. As a conclusion this literature survey gives an idea what resilience means in water services and how it can be reflected to the case of Finland.

Countries can learn from each other and by taking the different circumstances into account, they can improve the weaknesses of their own systems. Water scarcity is not a big problem in Finland, which can be seen also through the responses to our questionnaire survey. However, the methods to approach the strategy can be applied in Finnish water management.

One common issue in water services in western countries, reducing resiliency, is the deteriorating water infrastructure, especially water and wastewater networks, and the fact that the knowledge of networks and their real conditions is inadequate. In recent years, it can be seen that water utilities have been able to gain more knowledge and funding for systematic rehabilitation. Also, technical development provides better possibilities to implement thorough surveys regarding the state of networks. The respondents did not consider that water fees are too high in Finland. The average water fee, including drinking water supply and wastewater collection and treatment, is about 5 euros depending on the house type [36]. When average water consumption is about 130 L/person/day, this means that the cost of water services is about 2% of the household’s income, assuming that two persons are working and receiving an average salary.

4.2. Results Reflected in Research Questions

The questionnaire was designed so that when analyzing the answers, the answers to research questions would also be gained. The results show that generally reliable water services were considered a very important part of municipal services. Within water services, safe drinking water was considered the most important issue, while environmentally adequate wastewater management was seen almost as important. Noteworthy is that the price of water was not considered a very important concern. This indicates that in Finland the price of supplied water is reasonable and in developing more sustainable and resilient urban water services, the stakeholders considered that willingness to pay is quite high. Concerning water utilities, the economy was still regarded an important part of their operational management. An open question on major concerns in urban water services revealed that 23% of the answers found the economy as one of the most important issues in practice. This is, however, not a concern of pricing, but of revenue sharing within the utility and its owner.

Aging infrastructure was still considered a big problem in urban water utilities, as discovered by Heino et al. already in 2011 [16]. The other topics that were raised as relevant in developing sustainable and resilient Finnish water services, were skilled personnel, financing of rehabilitation, and raw water sufficiency. The last issue, that is growing in significance in Finland too, is that due to climate change, seasonal water scarcities are expected in some parts of the country.

Good governance is a prerequisite for any society to have sustainable water services. Finland is often considered as one of the best countries in the world concerning low corruption, good public services and public private partnership. These institutional aspects are essential in water management, while continuous development and improvement are needed for avoiding regression. The results indicated that there is a clear commitment to this among water experts, and their knowledge should be integrated into decision-making for the good of society.

4.3. Resilient Finnish Water Services in the Future

Recovering from disaster or adversity requires proper technical and institutional preparedness. According to this study, technical resilience is considered strong in Finland. When water utilities are run in accordance to the full-cost recovery principle, it is easy to keep technical preparedness in good order. Institutional preparedness requires good consensus among water professionals, authorities and decision makers. This necessitates continuous discussion and mutual understanding in development and implementation of water services. This is not only a question of technical service, but a question of wider socio-institutional principles, how health and environment issues are dealt with within the whole society.

In the future, to maintain the current standard of water services and to strengthen resilience, some topics can be listed:

(a) Asset management as an important part in water services
(b) Good governance ensured
(c) Economic aspects as full-cost recovery
(d) Continuous improvement
(e) Institutional framework maintained
(f) Capacity building and human resources policy cannot be neglected.

More research could be done, for example, in comparing water services concerning their resilience in different countries with various institutional frameworks. It would also be interesting to study opinions of the customers by a comprehensive questionnaire targeted to the public. Public private partnership is an essential part in resilient water services, and therefore a thorough review of the institutional framework is needed.

4.4. Conclusions

The main achievements of this study are knowledge about main disturbances, which threaten trouble-free water services, and how to develop or keep sustainability and resilience of a water utility. According to this knowledge, a water utility can prepare its strategy and strengthen its resilience in its future operation. These achievements are explained in following aspects and topics.

The main aspects in resilient and sustainable water services in Finland can be concluded as follows:

(a) Maintaining in high-quality education and training at all levels; high school, college and university
(b) Skilled and motivated personnel is considered very important in water services performance
(c) Integrated knowledge in technical development, institutional aspects and socioeconomic needs
(d) Awareness of effects of external disturbances, e.g., climate change (droughts and floods), political situations and the changing urban environment.

This can be secured by regular training and education needs assessment and development, open discussion and cooperation between all operators and stakeholders, and realistic objectives that can be agreed and accepted among all parties. Need for open cooperation between public and private parties is obvious. Answers showed, however, quite clearly that water services should be owned by a public organization, which can purchase services from private companies. This is organized differently in some European countries, but for keeping this basic and necessary function accessible for all people, Finnish public–private partnership or cooperation with public ownership has worked socio-economically fluently, confidently, and equally. This can be ensured by keeping the core functions strictly controlled by the owner of the utility, and outsourcing only support functions, e.g., repairs, accounting, and cleaning work.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4441/12/1/187/s1, Supplementary Materials S1: Questionnaire used in stakeholder survey.

Author Contributions: J.L. was the correspondent author and the principal researcher of this study. J.K. and J.J.H. gave their contribution in methodology and validation of the results. T.S.K. acted as a co-writer, and a supervisor together with P.J. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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