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Quaternary treatment according to the proposal for a recast of the EU Urban Wastewater Treatment Directive and its monetary implications for candidate countries (e.g. Serbia)

A Master's Thesis submitted for the degree of
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Affidavit

I, **ANA BADHOFER, BSC.**, hereby declare

1. that I am the sole author of the present Master's Thesis, "QUATERNARY TREATMENT ACCORDING TO THE PROPOSAL FOR A RECAST OF THE EU URBAN WASTEWATER TREATMENT DIRECTIVE AND ITS MONETARY IMPLICATIONS FOR CANDIDATE COUNTRIES (E.G. SERBIA)", 69 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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Abstract

After 30 years the Council Directive concerning urban wastewater treatment from 1991 has been evaluated and an Impact Assessment led to a Proposal for revised regulations. Therein included are new policy options serving the purpose of addressing prevailing deficits after an overall satisfactory implementation of the Directive in EU member states. One new policy is addressing the removal of micropollutants which are of emerging concern given the fast growth of anthropogenic pollution with pharmaceuticals, microplastics and cosmetics entering natural waterbodies despite conventional (secondary & tertiary) wastewater treatment. As a solution, an additional fourth treatment stage is suggested following tertiary treatment which has so far primarily achieved nutrient removal. This leads to renewed challenges for EU member states, but even more so, for EU candidate countries, where the state of infrastructure development has yet to achieve compliance with the existent requirements according to the EU Urban Wastewater Treatment Directive. The road to EU integration for a representative EU candidate country such as Serbia is depending on the alignment to EU legislation and has faced institutional, demographic, and monetary challenges ever since its initiation. Furthermore, most of the EU candidate countries, and so does Serbia, lie within the Danube River Basin, a catchment area partially covered by EU member states, and therefore partly subject to strict environmental protection regulations. Compliance of other countries in the basin would therefore be very effective, yet costly. At the example of Serbia, the minimum capital expenditures for the implementation of the prevailing legislation according to the EU Urban Wastewater Treatment Directive would amount to a minimum 5.5 billion Euro. Depending on which method is chosen for quaternary treatment (ozonation, powdered, or activated carbon), additional investment costs are estimated to amount to 65 million Euro at the moment. Two approaches were taken to calculate the total annualized costs: the cost function form the Impact Assessment of the European Commission and an evaluation of Feasibility Studies from German wastewater treatment plants. Findings of this Master Thesis show that annual capital expenditures, however, only make up 35% of the total costs of quaternary treatment over its lifetime, and annual operational expenditures play a bigger role on the long run.

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List of Abbreviations

ASP	Activated Sludge Process
DRBMP	Danube River Basin Management Plan
DSIP	Directive Specific Implementation Plan
FS	Feasibility Studies
MBR	Membrane Bioreactor
PD	Proposal for a Directive concerning the urban wastewater treatment
PPP	Purchasing Power Parity
UWWTD	Urban Wastewater Treatment Directive
WWTP	Wastewater Treatment Plant
WWT	Wastewater Treatment

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1. Introduction

It was on the 21st of May 1991, that the Council Directive concerning urban wastewater treatment (UWWTD) has been ratified and has become binding EU legislation for all member state countries thereafter. Now, thirty years later an Impact Assessment of the Council Directive has provided an EU wide evaluation of the wastewater sector and led to a Proposal of revised regulations for the wastewater sector. This Proposal for a Directive of the European Parliament and of the Council concerning urban wastewater treatment has been published on the 26th of October 2022.

However, not included in the evaluation were EU candidate countries, which – as of August 2023 – are the following eight: Albania, Bosnia and Herzegovina, Moldova, Montenegro, North Macedonia, Turkey, Ukraine, and Serbia (Eurpean Union, n.d.). Despite not being part of the impact assessment, a revised regulation would affect these countries just as much, if not even more than EU member states given their current level of wastewater infrastructure development and financial capabilities. The implementation of the UWWTD has been and still is a challenge for these countries on their way to enforce EU legislation for EU integration. With even stricter and far-reaching requirements according to the status of the Proposal, member and candidate states are set to face renewed challenges. The topicality of the Proposal among European countries will remain for the near future until the revision of the UWWTD is complete.

Yet, the relevance of this Proposal exceeds EU member states, and the foundation it builds for EU accession negotiations. The situation of anthropogenic environmental pollution is ever more pressing and increases pressures to rivers and other water bodies. Pharmaceuticals, care products, and microplastics are adding to the bill of increased water pollution beyond nitrogen and phosphorus contamination (Bofill, 2023). Specifically, the Danube Region, with respect to the Black Sea, has been identified as a sensitive area following the criteria of the UWWTD which affects all the above-mentioned EU candidate countries laying at least partially in the basin. This categorization has been undertaken based on nitrogen and phosphorus pollution due to the negative effect of eutrophication of the receiving water bodies. (ICPDR, 2021a) The ongoing evaluation will, in addition, define Areas at Risk of pollutants which are of emerging concern, namely the above-mentioned pharmaceuticals, and cosmetics. (European Commission, 2022b)

The proposal accompanied by the Impact Assessment evaluating the monetary implications for EU member states used a cost-benefit analysis for the new policy options under revision. Among the policy options two are identified as particularly costly: the connection of very small villages to wastewater management systems, and the removal of micropollutants. While the data situation only allows limited cost estimations for the connection of very small villages, this Master Thesis elaborates on the costs for quaternary treatment in detail.

A fourth treatment stage demands further wastewater treatment than is currently conducted under the advanced treatment method required by the applicable legislation, the UWWTD. Such additional treatment necessary to tackle micropollutants constitutes a fourth treatment stage in wastewater treatment plants and comes along with further capital investment needs. Given the current data basis the estimation of such capital expenditures can be made based on EU models from the Impact Assessment, as well as pioneering Feasibility Studies from Germany.

On the other side, the connection of very small villages with collection and treatment systems for wastewater demands insight, and data beyond the scope of this Master Thesis.

The objective, therefore, is to assess the status quo of wastewater treatment system development in EU candidate countries in order to calculate the additional monetary implications of a fourth treatment stage according to the Proposal for a revised UWWTD. For feasibility reasons, one country is picked as a representative candidate country. Serbia serves the purpose in terms of its country size and population number, given that a comparison with an EU country in the same river basin of the Danube, namely Austria, adds reference to the analysis.

Consequently, this master thesis aims to answer the following three research questions:

1. Where does Serbia, a candidate country to the EU, stand regarding the implementation of the UWWTD from 1991, and what are the challenges?
2. What are the new policy options according to the EU Proposal from October 2022, especially regarding a 4th treatment stage for urban wastewater?
3. Which monetary implications does a 4th treatment stage have on an EU candidate country, such as Serbia?

2. Terminology and Definitions

2.1 Wastewater parameters and their impact on water quality

Relevant for the exploration of the UWWTD and further elaborations in this context is the definition of agglomeration sizes and population equivalents to build EU wide, and internationally, comparable categories for pollution discharges from villages to mega-cities. Agglomeration "*means an area where the population and/or economic activities are sufficiently concentrated for urban wastewater to be collected and conducted to an urban wastewater treatment plant or to a final discharge point.*" (Council Directive 91/271/EEC)

Furthermore, it is crucial how much wastewater an agglomeration produces in addition to wastewater related to the number of inhabitants. Discharge loads per agglomeration with the same population inhabited in it may vary, as not only domestic wastewater but also local industrial discharges are included in the collection and treatment system of the respective agglomeration. Therefore, population equivalents are introduced as a way of comparing discharges e.g., from gastronomy, laundry stores, steel and iron production or fossil-fuel power stations and alike with the per capita domestic pollution concentrations. Simply put, the population bears the total pollution caused in their agglomeration and not only the individually personally caused domestic wastewater discharged into the collection and treatment system of the same agglomeration. The population equivalent represents the amount of the pollution load generated by industrial facilities and services per day related to the pollution load produced by one person's household sewage during the same time. This way a population equivalent for urban wastewater discharge has been established as the load typically stemming from one person: One population equivalent (p.e.) "*means the organic biodegradable load having a five-day biochemical oxygen demand (BOD_5) of 60 g of oxygen per day.*" (Council Directive 91/271/EEC) In this way the total yearly wastewater load of an agglomeration in g/d can be transformed into a wastewater load in population equivalent, which includes the population equivalents from domestic wastewater from permanent residentials (corresponding to the number of inhabitants) plus the population equivalents from industries and trade.

For example, a small hotel standing alone on top of a mountain with 16 bedrooms and 70 seats in the dining room has a population equivalent of 40. (Langergraber, 2021) As one population equivalent is attributed 60 g of BOD_5 per day, the hotel will discharge an estimated load of 2 400 g (40 x 60 g) of BOD_5 per day.

BOD_5 serves as a measure of how much oxygen is needed to degrade (oxidise) the biodegradable carbon present in wastewater and serves as a point of reference for measuring the polluting potential of an agglomeration, or for instance of one specific industry sector or one production facility. A standard period of 5 days is assumed since bacteria need this amount of time at 20°C to oxidise organic carbon to CO_2. (Zessner-Spitzenberg, 2022)

The removal of BOD_5 from wastewater is elementary to avoid oxygen depletion in surface waters, as a pollution load with high biochemical oxygen demand will cause high bacterial oxygen consumption for degradation of the pollution with a consequence of a low concentration of dissolved oxygen in the receiving water body harming the aquatic ecosystem. Nutrients (nitrogen (N) and phosphorus (P)) are the second main group of pollutants in wastewater, mainly stemming from human excreta, or in some places (in case of P) still from phosphorus rich detergents. N and P as nutrients are essential for growth of autotrophic organisms, more precisely algae in the water, who need them to perform photosynthesis during the day. With sunlight as energy source and chlorophyll (green colour of plants) as a catalyst this process transforms CO_2 into algae mass, which is a transformation of inorganic carbon (low in energy content) to organic carbon (high energy content), making the algae grow and storing the energy received from sun in a chemical form. For aquatic systems the oversupply of nutrients (also called eutrophication) is a problem because the consequence is excessive algae growth. Oversaturation of oxygen might occur during the day when algae produce oxygen via photosynthesis. During the night and absence of light, algae switch from photosynthesis to respiration (gaining energy from transformation of organic carbon to CO_2 under consumption of oxygen) which leads to oxygen depletion and together with degradation of dead algae by bacteria at the bottom of rivers and seas making macrobenthos and other aquatic organism suffer which as a consequence poses a relevant impact on the overall aquatic biocenosis. (Zessner-Spitzenberg, 2022)

2.2 Three established treatment stages

According to Kroiss (2022) operation of a WWTP takes place in three stages described below following the structure of the UWWTD.

Primary treatment is mechanical and consists of screens, grit chambers and primary settling. Its goal is the removal of solids, from bigger objects and gravel to sand and coarse particles. The contribution to protecting the receiving water body is not big (less than 30% BOD_5 reduction) yet it prevents the machinery and tanks of the following treatment steps from erosion and clogging, as well as reduces the energy required followingly. While it is not much, it still does already remove about one third of the organic pollution ensuring a well-functioning of the secondary biological treatment. Primary treatment is a process solely adhering to the laws of physics by screening and sieving, as well as relying on density and surface differences for settling and floating separation techniques. Hydraulics also play a big role in these processes. The design is supposed to be based on the maximum wet weather flow[1] (m^3/h), as even at stormy or rainy weather the sand must be removed from the wastewater which still contains most of the organic pollution and nutrients, then entering the second treatment stage. The end waste products either go to incineration together with the municipal waste, to sludge treatment or sometimes sand is reused after being treated of organics contained. Primary treatment can be chemically enhanced to a) further reduce BOD_5 and/or to b) create primary phosphorus removal and even recovery of phosphorus from primary sludge. Alternatives are limited, but there are different techniques concerning mechanically driven sieves, or cloth filters. (Kroiss, 2022)

Secondary treatment is biological and makes use of bacteria which eliminate organic pollution (BOD_5-removal) by using it as nutrition for their growth. Its goal is the enhanced reduction of excessive oxygen consumption in receiving water bodies caused by organic pollution. The total organic carbon (TOC) is reduced, or rather almost removed entirely in this process. Other pollutants, such as some of the heavy metals, are also absorbed in the process. Additionally, endocrine disrupters[2] and pathogenic bacteria are reduced. The sole purpose of the second treatment stage is therefore to provide enough space

[1] While during dry weather conditions only sanitary wastewater from households and the industry is a constituent of the influent at the WWTPs, storm water also brings surface runoff from streets, roofs, and other surfaces to the sewer and consequently WWTP, being called wet weather flow.
[2] "*Endocrine-disrupting chemicals (EDCs) are substances in the environment (air, soil, or water supply), food sources, personal care products, and manufactured products that interfere with the normal function of your body's endocrine system.*" (Ruiz & Patisaul, 2022)

and the adequate environmental conditions for this natural process: Microorganisms (e.g., bacteria, or fungi) can be used in tanks or attached on a support material like stones or clay. In tanks microorganisms are living in sludge as free-floating flocs separated from the treated wastewater by membranes or sedimentation, the latter being the most widely used method, the so-called Activated Sludge Process (ASP). Using this method, the sludge containing the microorganisms sinks down in the tank taking with it the organic carbon from the water as food, while the cleaned effluent can escape the top via an overflow technique. Moreover, ASPs most prominent feature is that excess sludge created in the process can be reused to keep a constant high sludge concentration full of microorganisms in the system. However, it is a partially energy intensive treatment stage, given that the microorganisms must be provided with oxygen at a constant level in aeration tanks. Excess sludge can be used for energy production in the form of biogas production. In case of using membranes instead of a secondary (sedimentation) clarifier, as in the ASP method, the reuse of the water for bathing, or even direct reuse up to recycling it to drinking water is possible since pathogen removal and ultra filtration enhance the effluent quality. This method is called Membrane Bioreactor (MBR) and it is difficult to implement it on a large scale, and to extend the lifetime of the membranes which are heavily cost intensive. (Kroiss, 2022)

The requirements for BOD_5 removal are outlined in Annex I of the UWWTD and can be looked at in Figure 1 in this Master Thesis.

Tertiary treatment is called advanced wastewater treatment in the Urban Wastewater Treatment Directive and similarly to the secondary classified stage constitutes of a biological process. Its purpose is the elevated environmental protection of aquatic ecosystems, and it helps meeting higher environmental quality standards, securing drinking water resources, and upholding hygienic standards. This process tackles a higher level of nutrient removal in densely populated areas, given the contamination of modern wastewater with diverse chemical substances like not only nitrogen, but also phosphorus. Hence, specialized methods are essential. It is important to mention that nutrient removal (of N and P) is often taking place in the same tanks used for secondary treatment. (Kroiss, 2022)

For instance, phosphate contaminated water is initially introduced into a flocculation tank coming from the secondary clarifier. Simultaneously, a chemical solution is injected into the wastewater from a dosing station, achieving thorough mixing. This chemical agent reacts with the phosphates, resulting in the formation of a water-insoluble compound. The remaining impurities coagulate and are put to settle as sludge back in the secondary clarifier, subsequently being thickened and directed to the digestion tower. Among other chemical products, digested gases such as methane (CH_4) form in the digested sludge, which is captured because of its strong greenhouse potential. The captured gas can be utilised for energy production. The treated water, now purified, can be safely discharged into a natural water body. (Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz, 2014)

The requirements for N and P removal are also lined out in the UWWTD in Annex I and can be observed in Figure 2. Advanced treatment according to the UWWTD is only required in areas identified as sensitive. According to Annex II, there are three instances to designate an area as sensitive: the area is discharging to surface freshwaters for the abstraction of drinking water, to natural freshwaters which are or might become eutrophic, or where Directive requirements cannot be achieved without tertiary treatment. (Council Directive 91/271/EEC)

Generally, the primary sludge from the primary sedimentation and the excess sludge from the secondary and tertiary treatment stages are collected in the sludge thickeners in order to reduce its initial water content of 98% - 99.5% down to 92% - 96% through gravity or through mechanical thickening. Roughly summarized, it can then be reused for agricultural landscaping after composting or drying it or for biogas production in the digestion towers and subsequent incineration. Mono-incineration with fluidised bed incinerators have another advantage of recovering phosphorus as well. Leftovers are oftentimes just landfilled, rarely it is used for industrial utilisation. (Kroiss, 2022) This part of the treatment process is not essential for the explorations of this Master Thesis, but with respect to a circular economy is one of the main policy options of the Proposal to revise the regulations of the UWWTD. (European Commission, 2022a)

Regarding the implementation of these three treatments stages the European Commission concluded that "*…[l]oads of biochemical oxygen demand, nitrogen and phosphorus in treated wastewater fell across the EU by 61%, 32% and 44% respectively between 1990 and 2014. This has clearly improved the quality of EU water bodies*." (European Commission, 2022b)

2.3 A fourth treatment stage and potential methods

The ever-increasing pollution stemming from the ever-growing metropolitan areas and the condensation of the population in denser agglomerations cause an increase in the number of pollutants in the wastewater. Anthropogenic micropollutants are organic pollutants such as human pharmaceuticals, industrial chemicals, personal care products, detergent ingredients, food additives, additives in wastewater and sewage sludge treatment, veterinary pharmaceuticals, plant treatment and pest control agents, and feed additives. Most of these hazardous substances are not eliminated in conventional wastewater treatment but discharged in the receiving water bodies. (Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V.)

“*Moreover, the scientific community, policy makers and the general public see the growing evidence of contaminants of emerging concern, including micro-pollutants such as pharmaceuticals and micro-plastics in water bodies, as an increasingly important issue*.” (European Commission, 2022b)

To improve the performance of wastewater treatment plants, various processes are available that are currently still subject of research. Nevertheless, first plants have been implemented on an industrial scale already. According to the Impact Assessment of the European Union, the advanced treatment methods that can be used as quaternary treatment for removal of trace substances encompass ozonation, activated carbon utilization, or a fusion of both, implemented through various process applications. It is important that alternative configurations of ozonation and activated carbon are anticipated to exhibit substantial comparability in terms of overall reduction in toxicity. (European Commission, 2022a)

The treatment of wastewater by means of ozonation is an oxidative process that takes place on a chemical level. On the one hand, there is a direct reaction with ozone molecules and on the other hand an indirect reaction involving hydroxyl radicals. The aim of using ozone in wastewater treatment is to oxidise the chemical compounds of the trace substances. This should transform the trace substances into less harmful compounds. However, this process still leads to the formation of transformation products, which can also react further with ozone, but do not necessarily do so. In the best-case scenario, the reaction proceeds to complete mineralisation. In most cases, however, feasibility studies have included post-treatment stages, as transformation products can also be very harmful to the environment. Therefore, ozonation is often combined with activated carbon methods. Furthermore, interaction occurs with other components in the wastewater, such as dissolved organic carbon (DOC) or nitrite. Nitrite consumes ozone and, at high concentrations, can significantly increase the demand for ozone and thus the energy required for the process. In addition, it is important that the influent to the ozone treatment is largely free of solids. The Proposal for a revised UWWTD makes it mandatory that treatment is carried out up to the third stage before a fourth stage can be implemented. (Brückner, et al., 2018)

To be more precise, to keep the demand for ozone as low as possible, ozone treatment at wastewater treatment plants is usually carried out after the comprehensive biological treatment following the secondary sedimentation. Efficient performance of the biological treatment as well as effective separation in the secondary sedimentation are important to keep the general load of organic substances and even inorganic compounds such as nitrite in the wastewater at a low level. In this way, the required ozone consumption can be minimised. Since the use of chemical oxidants results in shorter, more easily degradable substances – from previously long, difficult-to-degrade substances – before they are brought to complete mineralisation by additional oxidants, post-treatment in the form of biological active filtration or an activated carbon filter is required following ozonation. By means of a biological active post-treatment, such as sand filtration or fluidised bed reactors, most transformation products can be effectively removed. However, this does not apply to the N-oxides formed from tertiary amines, for the removal of which further treatment with activated carbon is required, e.g., GAC-filters. In addition, bromide present in wastewater can be converted to bromate by reacting with ozone. This bromate is subject to strict regulations according to the Drinking Water Directive. Ozone must be generated on site in an ozone generator and is then introduced into the wastewater in gaseous form. The carrier gas is usually oxygen, which is supplied in liquid form and stored in a tank. It is also possible to produce ozone from ambient air. The wastewater to be treated is fed into an ozone reactor. Ozone can be introduced either via ceramic aerators installed at the bottom of the reactor or via an injector system that injects the ozone into the wastewater. The ozone reactor must be sufficiently large so that the ozone can react with the wastewater constituents for a sufficiently long time. (Ehlers, 2020)

Methods for removing trace substances using activated carbon are based on the principle of adsorption. Activated carbon can be used in the form of powder or granules. Activated carbon is characterised by its porous structure and high specific surface area.

Factors such as starting materials, manufacturing processes and applications, including the recovery of granulated activated carbon, significantly influence the properties of activated carbon. This also influences its effectiveness in removing trace substances from wastewater. (Brückner, et al., 2018)

In detail, carbon, as a material is predominantly derived from sources such as stone or wood charcoal, coconut shells, or peat. The production of activated carbon hinges on the fundamental principle of activation through exposure to elevated temperatures, often reaching up to 1000°C, in the presence of water vapor. This controlled process results in the selective breakdown of specific components of the carbon structure, leading to the formation of pores, cracks, and fissures that significantly enhance the surface area per unit of mass. Notably, commercially available activated carbon grades boast an internal surface area ranging from 400 to 1 500 m^2/g. Activated carbon is found in two main forms, namely granulated, and powdered. Granulated activated carbon (GAC), is characterized by particle sizes that can reach up to four millimetres. In wastewater treatment scenarios, the wastewater flows through dedicated filter systems containing GAC for efficient treatment. Commonly deployed after the secondary sedimentation, GAC applications often involve fixed-bed filters facilitating top-to-bottom flow. However, the presence of concentrated solid or suspended matter can swiftly clog activated carbon pores, compromising its functionality. Powdered activated carbon (PAC), on the other hand, is very fine, porous mass, rich in carbon. Compared to GAC, powdered activated carbon has much smaller particle sizes and a larger active surface. The powdered activated carbon can be mixed into a wastewater stream (stirred reactor), for example. In wastewater treatment plants, it is blended it into the wastewater stream, initiating a subsequent contact phase where micro-pollutants adhere to the activated carbon. The loaded activated carbon must then be separated from the wastewater stream. However, it is crucial to note that the regeneration of loaded powdered activated carbon is unfeasible, necessitating its proper disposal. Its application involves direct dosing into or after the biological stage, often after secondary sedimentation within a contact basin or a filter's flocculation chamber. (Ehlers, 2020)

In conclusion, most of the time a combination of the methods described above is applied in wastewater treatment plants or examined in Feasibility Studies on the implementation of a fourth treatment stage. However, one method is the main one, being assisted by another and therefore the three categories of treatment methods are ozonation (O_3), PAC, and GAC. Given the Proposals suggestion, and as it does not appear in the Feasibility Studies, a method using a membrane is not explored due to exceeding costs.

3. The EU UWWTD

3.1 Overview

Two important legislative regulations for water quality, sanitation and consequently protection in the EU are the Water Framework Directive (WFD) from 2000 and the Urban Wastewater Treatment Directive (UWWTD) from 1991. The WFD 2000 was initiated to secure water quality on an EU wide level including all aquatic systems and the aim to achieve good status for all of them. As a framework it puts an obligation in place to cooperate, plan and implement in terms of river basins (as opposed to national levels) and for this purpose foresees a combined approach of emission controls and quality objectives. It also installed cost recovery for water-related services, comprehensive public consultation, and participation into the water sector at EU level. Most importantly, it integrated emission control directives (UWWTD, Nitrates Directive, IEC-IPPC) into plans and programmes. (Directive 2000/60/EC)

The UWWTD came into force earlier and public information and participation was not included in its development. The Directive has its focus on the details of numerical emission controls, staged deadlines for collection and treatment of wastewater, depending on size of 'agglomeration' and affected waters, plus it banned sewage sludge dumping into all surface waters, including marine waters. (Council Directive 91/271/EEC)

Michel Sponar, Deputy Head at the European Commission's Directorate-General for Environment, held a detailed presentation for the European Water Association, which was recorded and is available online. He provided information on the wastewater sector in the EU, as well as the Proposal to revise the UWWDT. The EU wastewater sector is characterized by a combination of public and private involvement, with wastewater management being primarily the responsibility of public authorities. While private utilities are at work too, the overall responsibility lies with the public sector. The sector operates in what can be described as a captive market, meaning that there is no choice for consumers to opt among a variety of wastewater treatment providers. It is not affected by supply and demand, but primarily reactive to legal requirements set forth by the EU Directive and Commission. One of the notable features of the EU wastewater sector is the high concentration of treated wastewater load in a relatively small number of facilities. Within the EU-27, approximately 81% of the pollution comes from agglomerations (clusters of population centres) with more than 10,000 inhabitants, or rather almost half, 46%, comes from larger agglomerations with more than 100,000 inhabitants. This concentration of pollution sources in big cities presents both challenges and opportunities for the sector. For instance, one major challenge faced by the wastewater sector is how to reduce administrative burden and streamline processes while still achieving tangible results on the ground. Regarding financing, the costs associated with wastewater management are primarily covered by water tariffs paid by users, which account for around 70% of the overall costs for wastewater management in the EU-27. This means that users bear a substantial portion of the cost of sanitation. Additionally, public budgets contribute to covering the remaining 30% of costs which may include financial support from the European Union as well. Having water tariffs is mandated by the EU WFD, ensuring that there is a financial mechanism in place to support wastewater treatment and sanitation initiatives. However, it's essential to note that the financial burden placed on users through water tariffs can vary significantly among EU member states. Different economic conditions, population densities, and infrastructural setups can lead to varying tariff structures and rates across countries. (EWA Online, 2023)

The obligations of the Council Directive of 21 May 1991 concerning Urban Wastewater Treatment for the first time had foreseen a comprehensive collection and treatment of wastewater discharged from urban areas within the EU. It was a decision demanding action at community level with the goal of protecting the environment. Obligations not only include primary, secondary, and / or tertiary treatment according to the sensitivity of the area, but also monitoring and reporting to the Commission. Articles 3, 4, and 5 of the Directive therefore represent real milestones in the improvement of anthropogenic pollution discharges into the environment. According to the size of agglomeration measured in p.e., a collecting system was foreseen to be installed in all bigger cities and villages until the end of year 2000, or respectively for smaller ones until the end of year 2005 as lined out in detail in Article 3. Followingly it was obliged to treat the collected wastewater according to Article 4 at a secondary stage given the same deadlines as in Article 3, only a little bit more nuanced according to small, medium, and big agglomeration sizes. For both Articles less stringent measures can be applied under specific circumstances outlined in the respective paragraphs. Moreover, it is important to mention Article 5 according to which sensitive areas are to be defined where even more stringent and therefore a third treatment stage is to be applied. For example, big metropolitan agglomerations (above 100.000 p.e.) are often considered sensitive areas, making sure the urban polluting discharges from big cities are subject to a higher form of treatment under certain circumstances following the provisions in the UWWTD, Annex II. Areas defined as sensitive had to fulfil the indicated obligations within seven years. Under specific circumstances, which mainly include very small agglomerations, areas where construction is difficult (e.g., mountainous regions), or discharge points into water bodies with high dilution rates, either less stringent measures or individual / appropriate systems can be applied. The level of treatment and its expected pollution reduction in concentrations have been laid out in Annex I of the UWWTD in Table 1 and 2, to be seen here below in Figure 1 & 2. (Council Directive 91/271/EEC)

Table 1: Requirements for discharges from urban waste water treatment plants subject to Articles 4 and 5 of the Directive. The values for concentration or for the percentage of reduction shall apply.

Parameters	Concentration	Minimum percentage of reduction (1)	Reference method of measurement
Biochemical oxygen demand (BOD5 at 20 °C) without nitrification (2)	25 mg/l O_2	70-90 40 under Article 4 (2)	Homogenized, unfiltered, undecanted sample. Determination of dissolved oxygen before and after five-day incubation at 20 °C ± 1 °C, in complete darkness. Addition of a nitrification inhibitor
Chemical oxygen demand (COD)	125 mg/l O_2	75	Homogenized, unfiltered, undecanted sample Potassium dichromate
Total suspended solids	35 mg/l (3) 35 under Article 4 (2) (more than 10 000 p.e.) 60 under Article 4 (2) (2 000-10 000 p.e.)	90 (3) 90 under Article 4 (2) (more than 10 000 p.e.) 70 under Article 4 (2) (2 000-10 000 p.e.)	— Filtering of a representative sample through a 0,45 µm filter membrane. Drying at 105 °C and weighing — Centrifuging of a representative sample (for at least five mins with mean acceleration of 2 800 to 3 200 g), drying at 105 °C and weighing

(1) Reduction in relation to the load of the influent.
(2) The parameter can be replaced by another parameter: total organic carbon (TOC) or total oxygen demand (TOD) if a relationship can be established between BOD5 and the substitute parameter.
(3) This requirement is optional.

Analyses concerning discharges from lagooning shall be carried out on filtered samples; however, the concentration of total suspended solids in unfiltered water samples shall not exceed 150 mg/l.

Figure 1: Requirements for discharges according to UWWTD 1991 Art. 4 & 5

Table 2: Requirements for discharges from urban waste water treatment plants to sensitive areas which are subject to eutrophication as identified in Annex II.A (a). One or both parameters may be applied depending on the local situation. The values for concentration or for the percentage of reduction shall apply.

Parameters	Concentration	Minimum percentage of reduction (1)	Reference method of measurement
Total phosphorus	2 mg/l P (10 000 - 100 000 p. e.) 1 mg/l P (more than 100 000 p. e.)	80	Molecular absorption spectrophotometry
Total nitrogen (2)	15 mg/l N (10 000 - 100 000 p. e.) 10 mg/l N (more than 100 000 p. e.) (3)	70-80	Molecular absorption spectrophotometry

(1) Reduction in relation to the load of the influent.
(2) Total nitrogen means: the sum of total Kjeldahl-nitrogen (organic N + NH_3), nitrate (NO_3)-nitrogen and nitrite (NO_2)-nitrogen.
(3) Alternatively, the daily average must not exceed 20 mg/l N. This requirement refers to a water temperature of 12° C or more during the operation of the biological reactor of the waste water treatment plant. As a substitute for the condition concerning the temperature, it is possible to apply a limited time of operation, which takes into account the regional climatic conditions. This alternative applies if it can be shown that paragraph 1 of Annex I.D is fulfilled.

Figure 2: Requirements for discharges according to UWWTD 1991 Art. 5 (sensitive areas)

Article 5 points out three alternatives for compliance regarding advanced treatment according to the designation of sensitive areas. Paragraph 3 requires advanced treatment in all WWTP covering more than 10 000 p.e., while paragraph 4 allows individual plants to not fulfil the requirements if a certain level of pollution reduction is met within the sensitive area. Figure 3 is a visual recreation from a World Bank Workshop held in 2017 by Helmut Blöch, “International Workshop on Wastewater Management in the Danube River Basin”, to better understand the requirements of the UWWTD Article 5 paragraph 3 and 4. Furthermore, Article 5 (8) reads: “*A Member State does not have to identify sensitive areas for the purpose of this Directive if it implements the treatment established under paragraphs 2, 3 and 4 over all its territory.*” (Council Directive 91/271/EEC)

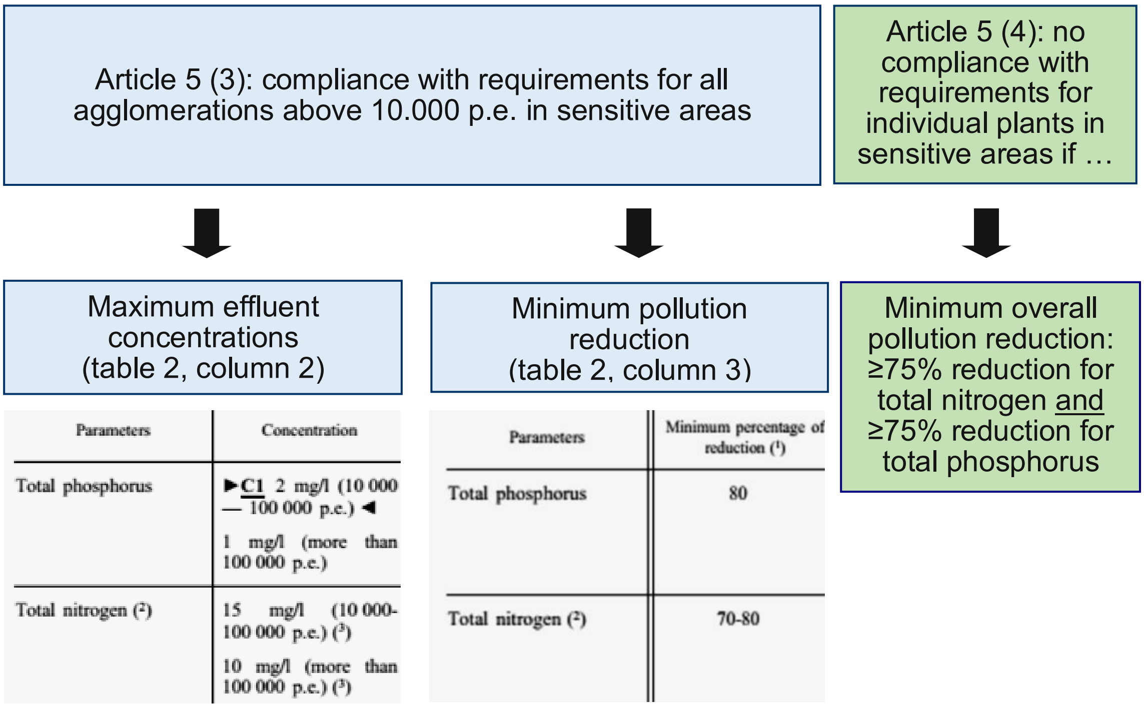

Figure 3: Displaying Article 5 (3, 4) graphically for better understanding (Blöch, 2017)

As outlined above, the obligations defined in the UWWTD from 1991 had foreseen to collect and treat wastewater, while at a second instance it was stipulated to monitor and report results to the Commission, see mainly Article 15 & 16. Recovering sludge from wastewater for reuse has already been enshrined in Article 14 in the UWWTD in 1991 as a favourable action leading to a phase out of its disposal, while the recycling of phosphorus was not addressed yet. The monitoring of the composition and amount of sludge was also made statutory alongside the monitoring of discharges from UWWTPs as well as of receiving water bodies. Every two years the member states should report back to the Commission. (Council Directive 91/271/EEC)

According to Michel Sponar, Deputy Head at the European Commission's Directorate-General for Environment, the idea of the Council Directive of 21 May 1991 was supposed to be easy to follow and to implement due to clear and feasible obligations. He speaks of fast movers and follower countries, and that not all member states have to and also now should not have to follow the speed of the slowest ones, as already at the time big discrepancies regarding the level of wastewater collection and treatment among member states were observed. Also, countries who joined the EU at a later point than when the Council Directive was adopted were granted their own individually determined implementation periods as defined in the respective accession treaties and accompanying documents. (EWA Online, 2023)

3.2 Implementation status in the EU

The UWWTD has played a significant role in improving water quality and wastewater management across member states. Followingly, the successful aspects of UWWTD implementation, acknowledging the achievements that have led to an impressive implementation status, are explored. However, also areas that require improvement to address remaining challenges and ensure sustained progress towards environmental preservation and sustainable development are highlighted.

M. Sponar, 2023, states that the EU's member states have demonstrated commitment to implementing the UWWTD, with over 90% compliance achieved. This accomplishment highlights the directive's effectiveness and its role as a driving force in the sector. In countries that joined the EU later fast and visible progress was made which is attributed to the directive's simple and targeted instruments. The carrot and stick approach employed in enforcing the UWWTD has proven successful. Infringement cases, symbolised by the stick, in some countries have acted as drivers to accelerate investments in wastewater infrastructure to ensure compliance with the directive's standards. The carrot aspect, involving regional funds from the EU, has been instrumental in supporting and facilitating necessary investments, particularly evident during the entry of Spain and Portugal into the EU. Despite significant costs associated with infrastructure construction, the benefits of UWWTD implementation have outweighed these expenses. Improved water quality and enhanced wastewater treatment justify the financial investments made by member states. (EWA Online, 2023)

However, there remain areas for improvement. Addressing pollution sources from cities remains a critical challenge. Identifying and mitigating urban pollutants, such as pharmaceuticals, microplastics, and chemicals, requires innovative and tailored solutions to protect aquatic ecosystems effectively. In some regions, eutrophication continues to pose a problem. While the UWWTD considered water quality, energy aspects were not fully incorporated into its framework. Integrating energy considerations could lead to more sustainable and energy-efficient wastewater treatment practices. The wastewater sector's energy use remains relatively high, accounting for around 1% of the EU's energy consumption. Encouraging and incentivizing energy-efficient technologies and practices within the sector could lead to substantial energy savings, if not even energy production. Furthermore, the directive has not adequately addressed greenhouse gas (GHG) emissions and sludge management, leaving room for improvement. Integrating measures to reduce GHG emissions and promote environmentally responsible sludge handling can significantly enhance the directive's environmental impact. All in all, the performance of wastewater treatment operators varies across member states. Transparency regarding wastewater treatment data varies significantly among member states, ranging from full access to limited or no data accessibility. Ensuring consistent and open access to data can foster accountability and facilitate best practices sharing among member states. Last but not least, since 1991, several new legislations have been introduced, but some might not be entirely coherent with the UWWTD or the Water Framework Directive (WFD). (EWA Online, 2023)

Despite the significant progress achieved through the Urban Wastewater Treatment Directive implementation, certain challenges persist, particularly regarding the remaining pollution stemming from cities. Addressing these challenges requires a targeted approach to combat the various pollution sources effectively. From the Explanatory Memorandum of the Proposal for a revised Directive three remaining sources can be identified.

One of the primary sources of pollution stems from certain countries that are still facing difficulties in fully implementing the existing UWWTD. Inadequate infrastructure, limited financial resources, and institutional constraints have hindered the complete realization of the directive's objectives in these regions. This includes pollution originating from existing WWTPs that do not meet modern technological standards. These outdated facilities are a critical source, particularly concerning nitrogen and phosphorus removal, contribute to nutrient pollution, leading to eutrophication in water bodies. Upgrading these WWTPs to meet current standards is essential to reduce their environmental impact. (European Commission, 2022b)

The second most significant source of pollution arises from rainwater and sewerage storm overflows, which are expected to increase in frequency and intensity with the impacts of climate change. These overflows can carry pollutants, such as debris, oils, and other contaminants, directly into water bodies, leading to further degradation of water quality. (European Commission, 2022b)

Finally, an additional source of pollution contributing to the challenges in urban wastewater treatment is smaller cities with populations below 2000 p.e. and decentralized facilities. These decentralized facilities often include individual appropriate systems (IAS) that cater to smaller communities and are permitted under the UWWTD. However, these facilities must adhere to the same treatment standards as centralized wastewater treatment plants. Smaller cities, or rather villages (below 2000 p.e.) did not have to be connected the collection networks at all under the UWWTD and, if no IAS are in place, their wastewater discharge goes straight to the (aquatic) environment. (European Commission, 2022b)

3.3 Proposal for a Revised EU UWWTD

In response to the identified areas for improvement by the European Commission regarding the UWWTD and the evolving challenges in wastewater management, the European Parliament together with the Council has initiated a process to propose a revised Urban Wastewater Treatment Directive. Central to this process is a thorough Impact Assessment of the Proposal, which involves a comprehensive evaluation of costs and benefits associated with potential revisions before selecting a preferred option.

The Impact Assessment begins with a large-scale consultation process involving stakeholders from various sectors, including environmental experts, industry representatives, and the public. Best practice options are then explored and analysed to identify effective and feasible solutions. Each option undergoes a rigorous cost-effectiveness analysis to determine its potential economic impact while maintaining a balance between financial considerations and environmental objectives. To align with the EU's commitment to the Green Deal, each option's contribution to sustainability and environmental goals is assessed. Additionally, the enforceability and administrative burden of the proposed options are carefully evaluated to ensure that they can be adequately monitored, measured, and enforced without undue complexity. Following the Impact Assessment, the preferred option is identified based on its alignment with the Green Deal objectives, cost-effectiveness, enforceability, and simplicity of implementation. The selected option then serves as the basis for the legal Proposal for the revised Urban Wastewater Treatment Directive. (European Commission, 2022a)

The Impact Assessment identified the following three sets of problems, along with their drivers:

1. Remaining pollution from urban sources
2. Alignment with Green Deal and new societal challenges
3. Modernisation and governance

The drivers of remaining pollution from urban sources have been described in chapter 3.2 in greater detail already, yet can be summarized as non-compliant agglomerations, agglomerations smaller then 2 000 p.e., and pollutants of emerging concern. Given the Green Deal focus on circular economy, the main drivers are greenhouse gas emissions, as well as lacking energy production, not enough sludge, water, and phosphorus recovery. Finally, uneven application of the polluter pays principle, and of the monitoring and reporting activities, partial absence of transparency and of data access are the drivers for modernisation and governmental problems. (European Commission, 2022a)

In response to each problem set highlighted in the evaluation of the Impact Assessment, potential policy options were formulated based on the implementation of best practices within Member States and through thorough consultations with stakeholders. Options that lacked stakeholder support or were deemed excessively intricate were eliminated in the initial stages. Various levels of strategic intent were devised, encompassing a spectrum from conservative measures applied exclusively to larger facilities (low ambition) to identical measures extended to smaller facilities as well (high ambition), with an intermediate level of ambition devised using a risk-oriented strategy. This intermediate approach involves the implementation of measures exclusively in cases where there is a discernible risk to the environment or public health. The latter demands a new method of assessing new areas at risk in addition to the existent sensitive areas already enshrined in the UWWTD. (European Commission, 2022b)

The twelve policy options listed in the Impact Assessment are the following:

1. Storm water overflows and urban runoff
2. Smaller agglomerations than 2 000 p.e.
3. Individual appropriate systems (IAS)
4. Remaining nitrogen and phosphorus pollution leading to eutrophication
5. Micro-pollutants
6. Non-domestic emissions
7. Energy use and production
8. Sludge and water re-use
9. Health issues
10. Transparency and governance
11. Monitoring and reporting
12. Access to sanitation

From the policy options mentioned, two are introducing completely new aspects which have not been tackled before, at least not legally under the EU UWWTD. Up till now, agglomerations below 2 000 p.e. were not addressed for neither collection nor treatment of wastewater discharges. Over and above that, removing micropollutants and pollution of emerging concern for the first time demands a legal basis for a quaternary treatment stage. Given the novelty, promising degree of effectiveness and the extent of necessary infrastructure development of these two policy options, the monetary implications are of specific interest. As this Master Thesis investigates on the financial effects of a fourth treatment stage, the respective policy option is explained below. Regarding the inclusion of smaller agglomerations, new obligations are incorporated namely in the revised former Articles 3, 4 and 5. While Article 3 will remain to be about collecting systems, Article 6 will cover secondary treatment in the future and Article 7 will cover tertiary treatment.

The preferred option for the removal of micro-pollutants is the second one lined out in Figure 4, which proved to be the most cost-effective one. It implies the upgrade of WWTP catering all agglomerations above 100 000 p.e. and of all agglomerations between 10 000 and 100 000 p.e. in an area at risk with a deadline set at the end of 2040. „…, *it was assumed that 70% of facilities between 10.000 and 100.000 p.e. with a dilution rate of 10 or less would be considered as at risk*" (European Commission, 2022a)

Options	Costs (Million €/year)	Toxic load avoided (p.e.)	Avoided toxic load in areas at risk (p.e.)	Additional GHG (Million t CO2e/year)
1. Low ambition - all plants > 100 k p.e.	841	59.236	32.875	0 to 4,33
2. All plants >100 k p.e. + plants 10 k to 100 k in areas at 'risk' [34]	1.185,51	68,198	41.836	0 to 4,97
3. High ambition - all plants > 10k p.e.	2.651,82	103,431	41.836	0 to 7,58

Figure 4: Impacts by 2040 of measures to reduce micro-pollutants (European Commission, 2022a)

Stakeholders were emphasizing the significance of enacting measures at the source and advocating for a more comprehensive application of the 'polluter pays' principle, thereby holding producers financially accountable for the costs associated with the additional treatment required to address micro-pollutants. The extended producer responsibility (EPR) framework garnered widespread support, although notable exceptions were observed from the pharmaceutical and chemical industries, which expressed reservations towards such principles in the past already globally. Their reservations were primarily grounded in the argument that the financial burden should either be shared across all participants along the chain (ranging from industry to consumers) or should be assumed by public authorities. Regardless, the adoption of such a system would inherently lead to a distributed financial responsibility anyway since a fraction of the costs would be borne by consumers through tariffs. (European Commission, 2022a)

Quaternary treatment, according to the Proposal, shall become Article 8 in the revised version of the UWWTD, and currently encompasses 6 paragraphs, to be found on page 45-46 of the Proposal. (European Commission, 2022b) "*With the preferred option, the toxicity of the released waters would be reduced by 44% against the current situation, of which more than 60% would happen in areas at risk.*" (European Commission, 2022a)

4. Materials and Methods

4.1 Materials and Data Collection

The research for this Master Thesis involved meetings with experts in the sector working both in Austria, as well as generally in and for the Danube Region. Therefore, the data collection method, was conducted on a very time intensive and interpersonal level. The main aim was to evaluate the current status which experts in the field are working with at the moment. Applying their baseline situation regarding data concerning a 4th treatment stage in a representative EU country, such as Austria, as well as in a comparable EU candidate country, such as Serbia, guarantees state of the art research material. Meetings were held with the following experts:

- Raimund Mair & Stjepan Gabric, World Bank, Danube Water Program
- Katerina Schilling, International Association of Water Service Companies in the Danube Catchment Area, Danube Water Program
- Adam Kovacs, International Commission for the Protection of the Danube River
- Predrag Bogdanovic, Udruženje za tehnologiju vode i sanitarno inženjerstvo SRB
- Heidemarie Schaar, Senior Lecturer at TU Wien
- Katharina Lenz, Environmental Agency Austria

The result of the expert discussions is that Austrian stakeholders are in the process of evaluating the implications of the Proposal for a revised Directive, but that no information is gathered yet on neither capital nor operation expenditures of a 4th treatment stage in Austria. K. Lenz has provided the preliminary factsheets on "*Austrian data, facts and figures on selected policy options*" (Kretschmer, et al., 2021) regarding the Proposal elaborated by the Environmental Agency Austria in collaboration with TU Wien. The factsheet indicates a graph and formula for application in Austria from Rizzo, et al., 2019, on specific annual costs (capital costs and operating costs) for the 3 different treatment methods (Ozonation, GAC & PAC) which come into question for a 4th treatment stage according to WWTP sizes. A very similar graph and formula are given by Pistocchi, et al., 2022, which are used in the Impact Assessment accompanying the Proposal. With the help of S. Gabric, it was possible to obtain the Directive Specific Implementation Plan for Serbia elaborated in 2017/2018 from P. Bogdanovic to assess the Wastewater Sector and investment needs in Serbia in order to achieve compliance with the EU UWWTD. It includes an Annex on the capital expenditures needed for full compliance. A. Kovacs extracted and sent the number of agglomerations per size category of population equivalents from the data used for the Danube River Basin Management Plan 2021. H. Schaar provided a set of Feasibility Studies from Germany, which is used for the assessment of investment costs for a 4th treatment stage in this Master Thesis. Furthermore, R. Mair, and K. Schilling provided deep insights into the sector, additional documents on the status quo of Serbia, and the Danube River Basin.

4.2 Cost Calculation

Austria, as an EU member state was taken into consideration for the Impact Assessment accompanying the Proposal (European Commission, 2022a), and has therefore been evaluated alongside all other member states. Serbia on the other side, like all other EU candidate countries, was not part of the assessment and has no respective evaluations of costs regarding a potential impact of the Proposal on the country. Austria and Serbia are two countries in the Danube River Basin, which are of similar size and population number (see Table 1).

Table 1: Comparison of EU and non-EU countries in the Danube River Basin

	Serbia	Austria
Size	77 474 km² excluding Kosovo (BBC, 2023)	83 883 km² (Statistik Austria, 2023)
Population	6 664 449 (Republički zavod za statistiku, 2023)	9 104 772 (Statistik Austria, 2023)

Consequently, a comparative analysis of these two countries was initially chosen for the evaluation of costs for Serbia. However, as research showed, no detailed cost evaluation for Austria is available yet apart from the total sum of expenditures estimated for the advanced treatment of micro-pollutants (4th treatment stage): 37 634 807 Euro/a. This sum describes the specific annualized costs (CAPEX + OPEX), given an investment lifetime of 30 years, a interest rate of 2.5%, and including the potential cost of upgrading existent WWTP to tertiary treatment, which were not required to do so yet, but need it now as a precondition for further advanced treatment. The formula used is provided later in this chapter. (European Commission, 2022a)

It is to be expected that the highest additional financial burden would stem from two new requirements from the Proposal:

1. Small Agglomerations: The preferred option according to the Impact Assessment would be to reduce the threshold of 2 000 p.e. down to 1 000 p.e., leading to the connection of even smaller villages (agglomerations with an emission load of 1000 to 2 000 p.e.) to treatment systems, and the construction of a respective infrastructure. (European Commission, 2022a)
2. Micropollutants: The new Proposal addresses the reduction of micropollutants for all agglomerations above 100 000 p.e., which requires investments in the new or extensive construction of treatment plants. Considerations of the most cost-intensive measures included the identification of Areas at Risk of micro-pollution for agglomerations of 10 000 p.e. to 100 000 p.e., as it would lead to an obligatory instalment of a 4th treatment stage in case of agglomerations of that size laying in an area at risk. (European Commission, 2022a)

The amount of sewer systems to be built for the connection of small towns below 2 000 p.e. for Serbia could not be determined. However, it can be stated that in Austria for the calculation of the investment costs a range of 100 Euro/running metre to 300 Euro/running metre is necessary. The operating costs of wastewater collection systems are calculated depending on the sewer network, special structures and actual maintenance and inspection efforts. They are given between 1.1 Euro/running metre and 3.23 Euro/running metre. (Lindtner, 2007)

Meanwhile, the Directive Specific Implementation Plan for Serbia calculated the total investment costs for wastewater collection according to the UWWTD from 1991. For achieving Directive compliance 10 269 km of new sewerage was calculated to be needed at a total price of 2.3 billion Euro, resulting in CAPEX of 220 Euro/running metre by the end of 2017. (Directive Specific Implementation Plan, 2018) This cost figure does not include the cost of sewerage renovation. Given the inflation rates above it would equal to 2.8 billion Euro in 2022.

In this Master Thesis the costs of tackling the reduction of micropollutant is elaborated in greater detail. As described in the Proposal it is foreseen to implement a 4th treatment step for the purpose in all WWTP catering to an agglomeration of more than 100 000 p.e.. Furthermore, a range of additional potential costs is estimated considering the identification of Areas at Risk in Serbia. Three scenarios given in % of total agglomerations with 10 000 – 100 000 p.e. set the corner stones of the estimation:

1. 0% - no risk assessment has been yet conducted; therefore, no agglomerations are to be considered in an area at risk
2. 70% - setting the level of agglomerations into an area at risk which is assumed by the EU (European Commission, 2022a)
3. 100% - following the precautionary principle all agglomerations could fall into an area at risk

For small (2 000 – 10 000 p.e.) and very small (2 000 – 1 000) agglomerations the assessment of costs for a 4th treatment stage is not necessary.

As a result of the lack of detailed data for Austria, the comparative analysis is discarded, but Austrian results remain a point of reference. Followingly two different approaches are chosen to calculate the sum of further investment and operational costs for a 4th treatment step in Serbia. Primarily, as the first approach is to use the cost function from the EU Impact Assessment, a comparison with the total Austrian expenditures per year is of high interest. An investment lifetime of 30 years and an interest rate of 2.5 % are anticipated in this formula.

$$\boldsymbol{C_{adv}} = \mathbf{1000}\, \boldsymbol{p.e.}^{\mathbf{-0{,}45}} \text{ (European Commission, 2022a)}$$

The second approach includes 16 Feasibility Studies from German Wastewater Treatment Plants. They are listed here below:

1. FS (2014): WWTP Emmerich, 195 000 p.e.
2. FS (2020): WWTP Wachtberg-Züllighoven, 4 900 p.e.
3. FS (2021): WWTP Wegberg, 47 000 p.e.
4. FS (2020): WWTP Honnef-Aegidienberg, 10 000 p.e.
5. FS (2018): WWTP Eilendorf, 87 000 p.e.
6. FS (2020): WWTP Niederkassel, 64 000 p.e.
7. FS (2020): WWTP Krefeld, 1 200 000 p.e.
8. FS (2019): WWTP Nordwalde, 14 000 p.e.
9. FS (2019): WWTP Borken, 140 000 p.e.
10. FS (2020): WWTP Blankenheim und Freilingen, 3 300 p.e.

11. FS (2022): WWTP Erkelenz-Mitte, 48 000 p.e.
12. FS (2019): WWTP Püsselbüren, 121 300 p.e.
13. FS (2018): WWTP Münster-Hiltrup, 30 000 p.e.
14. FS (2018): WWTP Horstmar, 11 000 p.e.
15. FS (2019): WWTP Frechen, 56 100 p.e.
16. FS (2014): WWTP Altenberge, 11 800 p.e.

As mentioned, H. Schaar provided 16 Feasibility Studies of WWTPs in Germany, where the CAPEX, OPEX and partially the annualized costs have been assessed. In the process of the analysis for this Master Thesis all 16 FS are examined and the indicated treatment methods and costs are listed in an excel-sheet. Followingly the costs per p.e. of each WTTP are calculated and their mean value is used to calculate the estimated costs per category of agglomeration size.

The purchasing power parities from Austria and Germany, as well as Serbia are relevant for comparison of economies within and outside the EU. I sought to consider the cost of the implementation of quaternary treatment in the Serbian economy in relative terms against the cost estimations based on the EU economies, Austria and Germany. In order to do this, I use the purchasing power parity figures (PPP) of each economy. The PPP ratios used are based the national currency units per USD. The ratio is taken from the OECD. The German PPP is 0.7. The Serbian PPP is 43.9. (OECD, 2023) This means that $1 in Austria and Germany can purchase 0.7 Euro of goods and services, and that, $1 in Serbia can purchase 43.9 dinars of goods and services. This concludes that 0,7 Euros is equivalent to 43.9 Dinar in terms of purchasing power. Thus 1 Euro is equivalent to 62.715 Dinar in terms of purchasing power.

Using the exchange rate from OANDA, on 26 August 2023, of 1 dinar = 0.0854 Euro and 1 EURO = 117.1 dinar, allowing for the following calculation:

1 Euro = 62.715 Dinar (in PPP ratios)

62.715 Dinar x 0.00854 (exchange rate) = 0.52572 Euro

1 Euro (in Austria/Germany) ~ 0.52572 Euro (in Serbia)

This ratio will then be applied to the EU-based cost calculation to determine an estimated cost in Serbia taking into account the relative purchasing powers.

As this Master Thesis will elaborate on the costs of a 4th treatment stage, it will look at two indicators to do so. Firstly, the capital costs, or investment costs, short CAPEX, describe the initial sum of construction, machinery and instrumentations and control engineering (ICE) technologies. Incidental building costs are added with 20% of the net investment amount, as well as 20% VAT, equally applicable in the EU, as well as in EU candidate countries, represented by Serbia. Secondly, to operational/operating costs, short OPEX, are majorly the annual costs for (electrical) energy, sludge disposal, staff, granulated or powdered activated carbon, flocculation aids, as well as maintenance and servicing. To receive an estimation of total costs of ownership, operation, and management of a WWTP over its entire useful life, the annual costs are calculated as well. (Werger, et al., 2014)

it's essential to recognize that different components of a WWTP have varying lifespans. According to Werger et al. (2014), they attributed 40 years of useful life to construction assets, 20 years to machinery, and 10 years to Instrumentation, Control, and Electrical (ICE) systems, with an assumed interest rate of 3%. However, Trumm et al. (2022) proposed updated lifespans, attributing 30 years to construction assets, 15 years to machinery, and maintaining the 10-year lifespan for ICE systems. These adjustments reflect a more accurate assessment of equipment longevity based on contemporary data and technological advancements.

The calculation of annualized costs hinges on the selected lifespans and interest rates. Assuming a 30-year lifespan for construction assets, as adopted in Feasibility Study NO. 12 listed in chapter 4.2, allows for the annualization of the initial capital investment costs (CAPEX). This means that the substantial upfront costs are spread over the assets expected life. When combined with the annual operating costs (OPEX), this approach provides a comprehensive view of the WWTP's annual financial requirements.

However, this simplified approach overlooks the varying lifespans of machinery and ICE systems. A more detailed analysis, as suggested by Werger et al. (2014) and applied in other FS as well, would necessitate factoring in the replacement or reinvestment costs associated with machinery and ICE systems during the WWTP's operational lifetime. For instance, machinery may need to be replaced at least once or twice during a 30-year period to ensure optimal performance. These additional costs are essential to accurately estimate the total annualized costs.

In order to convert initial investments sums provided by FS on individual WWTPs in Germany into annualized costs, the following economic formula is used:

$$C_{ann.CAPEX} = \frac{CAPEX \times i}{(1-(1+i)^{-n})}$$

The results are annualized CAPEX which are adjusted according to inflation rates over the lifespan of assets. The current interest rate in Serbia is 6.5% (National Bank of Serbia, 2023) Furthermore, "…[i]*n the long-term, the Serbia Interest Rate is projected to trend around 5.00 percent in 2024 and 3.50 percent in 2025*" (Trading Economics, 2023) according to econometric forecast models. All following years, starting with 2026, are assumed to even out at 3% after the pandemic, the war in Ukraine, and the subsequent economic crisis. However, for comparability, the rate should also come close to the assumed interest rate of 2.5% used in the cost function and the interest rate of 3% used in most Feasibility Studies. Therefore, a steady interest rate of 3% The assumed lifetime of 30 years according to the European Commission, 2022a, and Pistocchi et al., 2022, and the FS is used.

4.3 Limitations

Through the course of the research for this Master Thesis it became evident that the topicality of the Proposal concerning a revised UWWTD was limiting the existent material to work with, especially those publicly available. While no methodologically qualitative interviews have been conducted, expert consultations in the sector were elementary to obtain a proper insight into the status quo. Not only for the impact of the proposal on a candidate country, such as Serbia, but even for an EU country, such as Austria, these expert meetings have allowed to obtain the necessary information and materials.

The first and foremost impactful limitation was posed by the insufficient data situation of detailed investment and operation costs for a fourth treatment stage in Austria, as a comparative analysis of the two countries was hindered. The Impact Assessment of the European Union provided the sum of expected total annual costs. Within the competent bodies of Austria, the evaluation of national costs is currently underway, and about to be evaluated. As a solution, a new methodology had to be adopted. Instead of deriving the costs for Serbia on the example of a statement of costs from Austria, two approaches were chosen to establish benchmarks. These benchmarks serve as a first point of reference for future calculations and cost estimations in the context of EU accession procedures.

The calculation of annualized costs in the context of WWTPs is a critical step in assessing the financial feasibility and sustainability of these facilities. It involves spreading out the initial capital investment costs over the asset's expected lifespan, accounting for annual operating expenses, and considering the replacement or reinvestment costs for components with shorter lifespans. The accuracy of these calculations is vital for making informed decisions, securing funding, and ensuring the long-term viability of wastewater treatment infrastructure. As more new data emerges, it is essential to continually refine these calculations to reflect the most up-to-date and accurate cost projections.

The first approach entailed the cost function used in the Impact Assessment for EU member countries and thereby completes the gap of not assessing it upon EU candidate countries. A limitation was posed by the clear definitions of numbers of agglomerations per size category. Even though the previous costs for the implementation of the UWWTD were based on the classification in the DSIP, it could not be used for the cost function, as the size categories in the DSIP are not congruent with the defined size categories in EU documents. Furthermore, in the more detailed annex, agglomerations were not listed in p.e., but in terms of population, or rather per capita. Consequently, the agglomeration count according to the Danube River Basin Management Plan from the International Commission for the Protection of the Danube River served as a basis for the application of the cost function. This approach therefore lacks an identical conformance with the exact number of agglomerations as the sum according to the DSIP is 56 more agglomerations than according to the DRBMP. Namely, 25 very small agglomerations below 2 000 p.e. are included in the DSIP, and of the remaining 31 agglomeration, 22 must fall into the size category of 2 000 – 10 000 p.e.. In the future, a clear set of agglomeration data must be defined, best according to the newest census conducted by Serbia in 2022. (Statistical Office of the Republic of Serbia, 2023)

The second approach evaluated feasibility studies from Germany of WWTPs already planning the implementation of the fourth treatment stage, providing numbers close to reality but with a small sample of 16 FS. The limitation of a small sample number has become particularly visible in the small agglomeration size category where only 2 FS were available, each one very specific for their respective WWTP evaluating either activated carbon or ozonation, resulting in one FS for each method in that size category. It hindered concluding a mean value representative of small agglomerations which in any case has no big impact given the regulation to implement a fourth treatment stage to only apply for agglomerations above 10 000 p.e.. Furthermore, a few negligible amount of cost numbers are missing in 3 FS in the size category 10 000 – 100 000 p.e., as they were originally not included. A more relevant limitation is the fact that the FS have been conducted for the very specific circumstances and varying preconditions at each WWTP. Here again, a mere benchmark can be drawn, and must be adjusted to the price level in Serbia (see chapter 4).

Another relevant limitation is that technically PPP portraits the economy from a consumer point of view, not specifically looking at the construction sector on the producer side. Nevertheless, it is still a reliable ratio to use, because it gives a general overview of the relative relationship of weight of money in the respective representative countries of EU and non-EU states, as suggested by the World Bank. (World Bank, 2018) Therefore, based on publicly available ratios this is the closest to show the real cost estimate relative to the appropriate economy.

Finally, the fourth treatment stage is only one out twelve new policy options likely to be adopted during the revision of the UWWTD from 1991, and specifically the connection of very small agglomerations with sewer networks implies a substantial cost centre not yet calculated for candidate countries, as sewer network extensions and maintenance is the main origin of wastewater infrastructure costs. (Zessner, et al., 2010) It will be crucial to evaluate the true and all-encompassing monetary implications of the whole Proposal on candidate countries.

5. UWWTD implementation in Serbia

5.1 Overview

Serbia, with a current (2022) GDP of 9 400 $ per year (World Bank, 2023), which is about 8 500 Euro annually, has one of the lowest implementations of wastewater collection and treatment in the Danube Basin. Figure 5 shows the status of development of wastewater collection and treatment systems in all countries of the Danube River Catchment Area, among them seven out of the eight EU candidate countries: Albania, Bosnia and Herzegovina, Moldova, Montenegro, North Macedonia, Ukraine, and Serbia. Albania is not included in the graph of Figure 5 given its very small share in of the Danube River Basin with 0.02%. (ICPDR, 2021a)

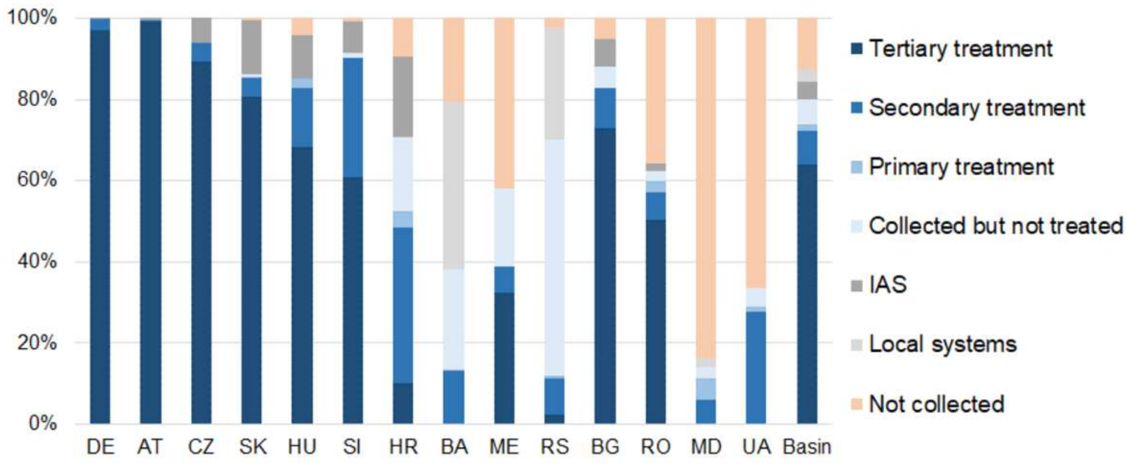

Figure 5: Share in population equivalents connected to collection and treatment systems bigger then 2.000 p.e. (ICPDR, 2021a)

Upstream and EU countries are clearly more advanced than downstream and EU candidate countries. The Danube River Basin Management Plan (DRBMP) highlights the role of specifically Serbia, being one of the least developed countries with the greatest potential to reduce pollution, among some of its neighbouring countries.

> Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Romania and Bulgaria still have great potential to reduce organic pollution of their national surface water bodies by introducing at least biological treatment technology. In particular, Serbia, Bosnia and Herzegovina and Croatia can significantly cut organic pollution via wastewater since their PE-specific emissions are still high. Serbia and Romania have the highest absolute discharges indicating that further improvement in the wastewater sector in these countries would substantially reduce the basin-wide emissions. (ICPDR, 2021a)

Annex 3 of the DRBMP, shows the BOD, COD, nitrogen, and phosphorus discharges of centralized systems according to the level of treatment in tons per year. Table 2 summarizes all 4 indicators for Serbia. For comparison, Austria fulfils the requirements of the UWWTD with a BOD discharge of 4 254.3 t/a, a COD discharge of 29 522.1 t/a, a Nitrogen discharge of 8 819.7 t/a, and a Phosphorus discharge of 570.1 t/a.

Table 2: BOD, COD, N, and P discharges in Serbia according to level of treatment (ICPDR, 2021a)

Level of treatment	BOD (t/a)	COD (t/a)	Nitrogen, N (t/a)	Phosphorus, P (t/a)
Tertiary	256.2	469.6	83.1	7.9
Secondary	3 693.4	6 694.0	1 070.3	254.8
Primary	597.9	1 096.2	114.7	25.2
Collected but not treated	63 763.0	116 898.8	9 351.9	1 912.9
Total	**68 310.5**	**125 158.7**	**10 620.0**	**2 200.7**

In 2017, a comprehensive report has been composed, funded by the European Union and with the aim to support EU aquis implementation planning capacities within the Ministry of Environmental Protection of Serbia. The report, called “The Directive specific Implementation Plan for the Council Directive of 21 May 1991 concerning urban wastewater treatment (91/271/EEC)” (DSIP), was finalized in April 2018, including an assessment of the current implantation level and a monetary evaluation of measures to reach full compliance. The framework guiding the formulation of sustainable water policies is the Water Management Strategy designed for the jurisdiction of the Republic of Serbia until 2034, which was endorsed in December 2016. This strategy establishes a comprehensive outline encompassing legal, structural, fiscal, technological, and scientific dimensions pertinent to water management endeavours, all within the prevailing socio-economic context. (Directive Specific Implementation Plan, 2018)

The DSIP addresses all requirements form the UWWTD and holds detailed information about the designation of sensitive areas, the delineation of agglomerations, service coverage and wastewater balances, wastewater infrastructure development, and technical compliance gaps. In 2018, Serbia has not yet defined its sensitive areas, as required in Article 5 of the UWWTD (see Figure 3). (Directive Specific Implementation Plan, 2018)

In 2007, when Romania had joined the EU, it declared the Black Sea a sensitive area, as it was heavily burdened by eutrophication. As the Danube is discharging into the Black Sea as one of the main contributories, all upstream EU countries in the Danube River Basin had to adapt to more stringent technologies. Consequently, the same approach is expected from EU member state countries lying within the Danube River Catchment Area, which for Serbia is 98% of its territory excluding Kosovo. (ICPDR, 2021a)

It is, therefore, proposed that Serbia too, will have to apply more stringent treatment technology, or rather advanced treatment beyond a secondary treatment stage. (Directive Specific Implementation Plan, 2018)

According to the DSIP 3.9 million inhabitants in Serbia are connected to sewer systems totalling to 14 800 km of sewerage channels, which is about 55% of the population, coinciding with Figure 5. Though, the average age of sewers is 35 to 40 years, and therefore at the end of their useful life. In 2016, 210 million m^3/year of wastewater from households was collected and directly discharged without treatment. Respectively, 34 million m^3/year industrial wastewater and 39 million m^3/year institutional and other wastewater was collected and directly discharged. 47 million m^3/year of the collected wastewater is treated to some stage, creating a total flow of 283 million m^3/year of collected wastewater minus 47 million m^3/year of treated wastewater, resulting in a point source pollution directly from the sewer of 236 million m^3/year. The majority of treated wastewater (36 million m^3/year) went through secondary treatment as highest stage. (Directive Specific Implementation Plan, 2018)

As Figure 5 indicates, by 2020 almost all wastewater was at least subject to some sort of sanitation. A clear bulk is collected, yet only a small fraction is undergoing treatment. Of the total wastewater treated the highest fraction is going through the secondary stage (71%), and only a very small part is treated more advanced (19%) according to the DSIP. In 2018, 39 urban wastewater treatment plants were counted, some of which were not in operation, having an estimated capacity of 1.3 million p.e., given the information from the DSIP. "*Existing wastewater treatment capacities of roughly 1.3 million p.e. are utilised only up to 0.80 million p.e. (around 60%)* […]" (Directive Specific Implementation Plan, 2018). This leads to a total wastewater load of approximately 780 000[3] p.e..

In terms of inhabitants a compliance gap for wastewater treatment of 1.7 million inhabitants not connected was evaluated. The collection rate and compliance gap with Article 3 of the UWWTD for Serbia can be summarised as follows:

- Population connected to sewers: 3.9 million
    - Load collected: 4.8 million p.e.
- Population that should be connected to sewers according to Art. 3: 5.6 million
    - Eligible load: 6.9 million p.e.
- Population gap for compliance: 1.7 million
    - Load gap for compliance: 2.2 million p.e.

[3] 60% of 1.3 million p.e. equal 780 000 p.e., yet the numbers in the DSIP suggest a load of 720 000 p.e. given the estimation "*by cross-checking the available operational treatment* […] *facilities* […]". (Directive Specific Implementation Plan, 2018)

Table 3: Summary of compliance gap analysis expressed in p.e. (Directive Specific Implementation Plan, 2018)

	Article 3	Article 4	Article 5
Total generated load	8.6 million p.e.	8.6 million p.e.	8.6 million p.e.
Load to be covered according to UWWTD	6.9 million p.e.	6.9 million p.e.	5.6 million p.e.
Load currently covered	4.8 million p.e.	670 thousand p.e.	120 thousand p.e.
Compliance with total load	55.6%	7.8%	1.4%
Compliance with load to be covered according to UWWTD	69.8%	9.8%	2.1%

Table 3 summarizes the compliance gap for all three Articles of the UWWTD concerning a) wastewater collection according to Article 3, b) wastewater treatment at a biological treatment level according to Article 4, and c) wastewater treatment according to sensitive areas with nutrient removal according to Article 5.

Regarding efforts to close these technical compliance gaps, the DSIP calculated the amount of sewer networks to be renovated, the amount of new sewer network extensions and the respective infrastructure construction at existent WWTPs, as well as new WWTPs, whereas "*…* [w]*herever the existing treatment facility is to be substantially rehabilitated and/or upgraded in order to meet the Directive and national requirements, it is considered as "new" treatment facility.*" (Directive Specific Implementation Plan, 2018)

Pursuant to Article 3, 10 400 km of additional sewers are necessary, to reach 2 million more inhabitants (additional 2.1 p.e. given Table 3). The DSIP points out "*that all new wastewater collection networks are constructed as separate (foul only) systems*". (Directive Specific Implementation Plan, 2018) Pursuant to Article 4, additional WWTP capacities for 6.2 million p.e. (from Table 3: 6 900 000-120 000), and pursuant to Article 5, advanced treatment capacities for 5.5 million p.e. (from Table 3: 5 600 000-120 000) should be newly installed and constructed. The plan proposes the renovation or construction of 360 WWTPs and accompanying sludge management capacities and facilities. (Directive Specific Implementation Plan, 2018)

The financial burden coming along with this plan has been calculated for infrastructure investments for every agglomeration. Therefore, in 2018, the results showed the need for 2.5 billion Euro for collection network rehabilitation and extension, and 1.3 billion Euro to upgrade wastewater treatment in the whole of Serbia to be compliant with the

UWWTD. The costs for project preparation, construction supervision, and contingencies were estimated to be about 0.5 billion Euro, leading to a grand total of 4.3 billion Euro[4] of total estimated investment costs. (Directive Specific Implementation Plan, 2018)

5.2 Institutional responsibilities and financing

The Directive Specific Implementation Plan for the UWWTD completed in April 2018 for Serbia provides a deep insight not only on the current status of wastewater infrastructure development and its investment needs in the future but also an overview of the administrative organisation of institutions and their responsibilities for the wastewater sector:

> *The Ministry of Agriculture, Forestry and Water Management through its Republic Directorate for Water and the Ministry of Environmental Protection are competent authorities (no single line ministry) for managing water and the water management system and is thus responsible for the implementation of the requirements set forth in the UWWTD (inc. ensuring integration of international and EU obligations)[5].*
>
> *The Ministry of Construction, Transport and Infrastructure is the parent ministry of water utility companies. It has no specific directorate in charge of water utilities but does have a department for inspection supervision.*
>
> *The Ministry of Public Administration and Local Self-government, via its Department for Local Self-government, supervises local self-governments, which manage water utility companies.*
>
> *The Ministry of Finance is responsible for final control of tariff revision, which is proposed by water utility companies and accepted by local self-governments, in accordance with the general price policy.*
>
> *The public water management companies of Waters of Serbia (Srbijavode) and Waters of Vojvodina (Vode Vojvodine) are companies with responsibility for flood protection and for issuing opinions on legislation on water, and for maintenance of the water information system in their territory. They are under the umbrella of the Government of Serbia and the Government of Vojvodina, respectively (state-owned/city-owned), and from time to time they participate in maintenance and reconstruction of regional water facilities.* (Directive Specific Implementation Plan, 2018)

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[4] According to the provided Annex in the DSIP, the detailed cost estimation shows a grand total of 4,48 billion Euro, which are later used in this Master Thesis for the basis of the calculations of inflation up till 2022.

[5] *The Ministry of Agriculture, Forestry and Water Management, Republic Directorate for Water, is responsible for identification of sensitive areas, assessment of the quality of water in sensitive areas and setting more stringent treatment appropriate for the local situation. Republic Directorate is also responsible for preparation and implementation of developing programme (Water Management Strategy for the territory of the Republic of Serbia, River Basin Management Plan for the Danube River, Water Pollution Protection Plan (government/ministry), implementation plans etc. with support of other competent authorities, primarily: Ministry of Environmental Protection.* (Directive Specific Implementation Plan, 2018)

Local and regional self-government institutions have established approximately 150 public utility companies (PUC) to manage the services for water supply and wastewater collection and treatment. Serbia's water sector's structure is concentrated, with seven PUCs serving a number of municipalities making up around 30% of the population. One prominent example is Belgrade waterworks which alone covers around 20% of the population[6]. The remaining 143 municipal public utilities cater to around 45% of the population. About 25% of the population in rural areas rely on self-provision for water supply and sanitation services. In addition, these PUCs have diverse functions beyond water and wastewater services. Many of them also engage in other utility-related activities, such as gas supply, municipal waste disposal, retail markets, and more, even non-related services. Some companies even report being involved in around 50 different activities. PUCs in Serbia are, for this reason, specific legal entities operating as either multisector operators or water-only operators. While municipalities manage and oversee these entities, asset ownership still rests at the state level. The Constitution of the Republic of Serbia, introduced in 2006, began the process of transferring property rights to municipalities. However, this transfer is still ongoing, and utility assets remain under state ownership. (Directive Specific Implementation Plan, 2018)

The competences of the relatively high amount of responsible institutions and organizations are visually presented in Figure 6. In the green box "Srbijavode" stands for the Public Water Company "Serbia Waters", "Vode Vojvodine" stands for the Public Water Company "Water of Vojvodina", and "Beogradvode" stands for the Public Water Company "Belgrade Waters".

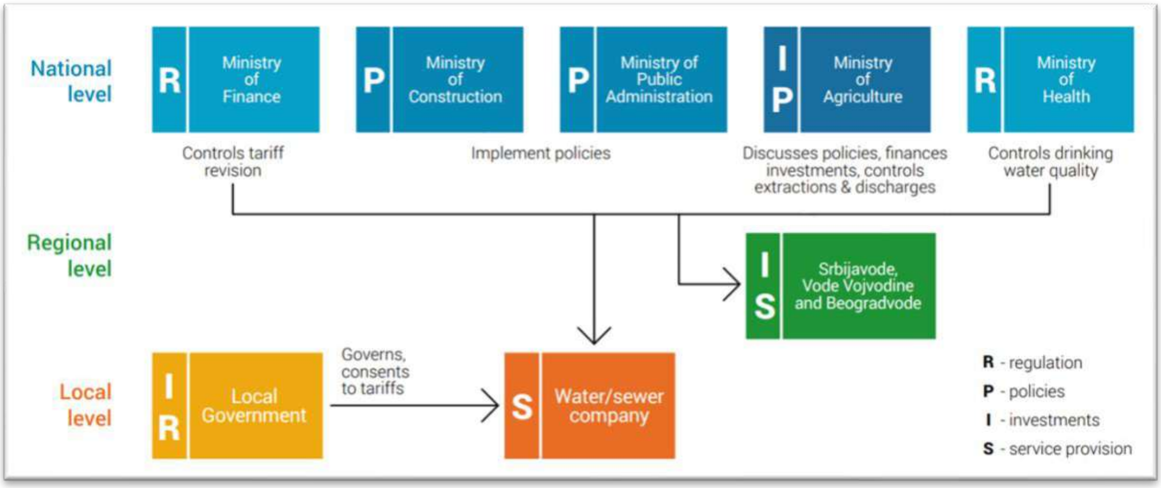

Figure 6: Graphic depiction of Institutions and Division of Responsibilities in Serbia (Salvetti, 2015)

[6] Post-socialist Serbia experienced an extraordinary suburbanization of its metropole, Belgrade, ever since the 90ies. (Hirt & Petrovic, 2011)

Compared to Austria, the wastewater sector in the EU country of the Danube River catchment area is also a public domain, yet more aggregated with four different options of legal entities: cooperative or natural persons, community sewage treatment plants, association sewage treatment plants, or municipal enterprises (Assmann, et al., 2020). Funding from the Federal Ministry of Agriculture, Forestry, Regions, and Water Management for urban water management ensures the construction and rehabilitation of the necessary infrastructure for orderly wastewater disposal and adequate drinking water supply (Bundesminister für Land- und Forstwirtschaft, Regionen und Wasserwirtschaft, 2022).

According to the Country Note developed by the World Bank on Austria "*a clear distinction between responsibilities borne by each level, and no overlap*" (Michau, 2015) among stakeholders is observed. The organigram for Austria (Figure 7) depicts the duties and responsibilities according to the respective ministries. It includes three ministries and regional governements.

> *The Ministry of Agriculture, Forestry, Environment and Water Management, which is the line ministry responsible for the definition of environmental policy, including technical and subsidizing regulations for water supply and sanitation*.
>
> *The Ministry of Finance, which is responsible for subsidising the water sector via the Kommunalkredit Austria AG* […].
>
> *The Ministry of Health, which is responsible for setting tap water quality standards and for monitoring drinking water quality compliance* […].
>
> *The nine state governments, which are in charge of implementing and enforcing national regulations via their administrative districts* […]. (Michau, 2015)

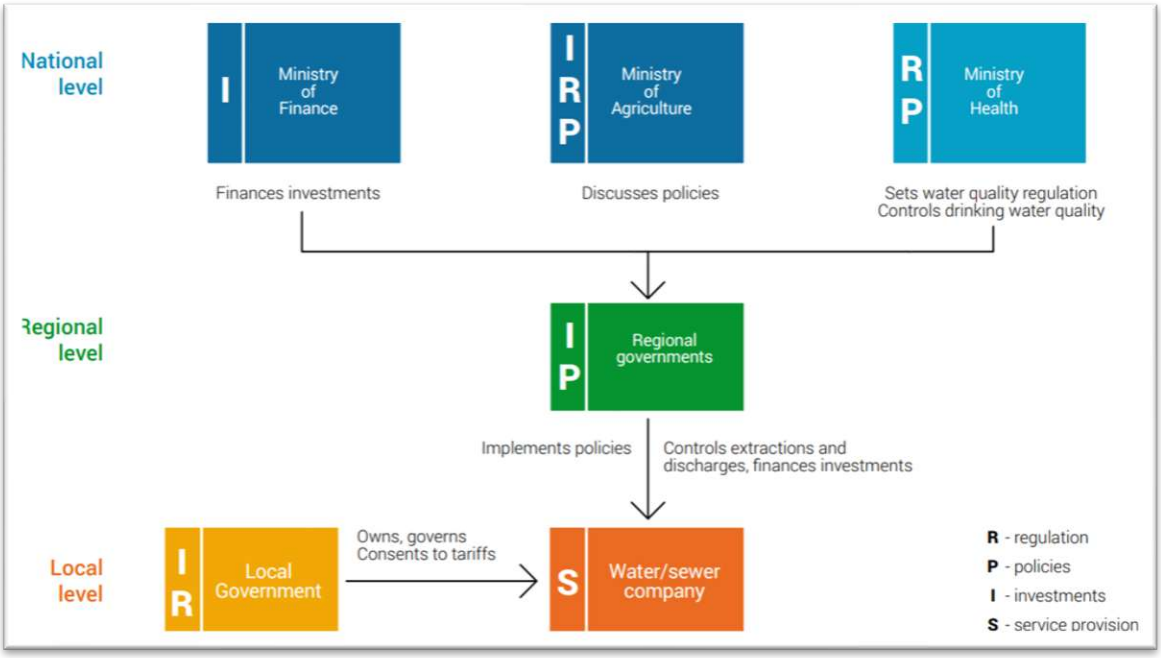

Figure 7: Graphic depiction of Institutions and Division of Responsibilities in Austria (Michau, 2015)

The water sector in Serbia follows a tariff-setting approach based on targeted inflation. Tariffs undergo annual revisions and require approval from the municipal assembly before implementation. Since 2004, the Ministry of Finance has imposed a tariff increase ceiling, driven by political and social considerations rather than addressing the operational and investment needs of public utility companies, as they can no longer determine a price above the fixed inflation rate. Overall financing in the water sector faces challenges as tariffs only cover a small portion of operation and maintenance costs, comprising 86% of total sector expenditure. Subsidies from the national budget are necessary to cover both operational costs and investments, which represent less than 15% of sector costs, proving insufficient to adequately maintain and expand services and infrastructure. Although the latter had received international grants too. (Salvetti, 2015)

In the pursuit of full cost recovery, it is crucial that revenues encompass not only operational and maintenance costs but also development investments, interests, depreciation, and loans. However, attaining full cost recovery solely through tariffs is unfeasible for any nation within the Western Balkans[7]. This challenge is evident in Serbia, where numerous utilities face the inability to cover their operating costs from their generated revenues. An analysis of sector financing data from *A State of the Sector,*

[7] The Western Balkans consists of Albania, Bosnia and Herzegovina, North Macedonia, Montenegro, Kosovo, and Serbia. (European Commission, 2023)

2015, Serbia Country Note reveals that utilities predominantly rely on tariffs, constituting a share of 82% of their revenue sources. The low price of water, set at 0.48 Euro/m^3, constitutes 1.2% of the average household budget. Expectations are for tariffs to continue increasing as Serbia strives to meet the EU environmental standards, demanding significant investments and subsequent operating costs. (Salvetti, 2015)

Nevertheless, to cover their comprehensive expenses for operations and maintenance, as well as investments, interest, and depreciation, these utilities also depend on financial support in the form of transfers and taxes from the state level. This multifaceted approach to financing is necessitated by the limitations of revenue generation through tariffs alone. (Rücker, 2020) Figure 8 shows the overall utility sector financing in Serbia.

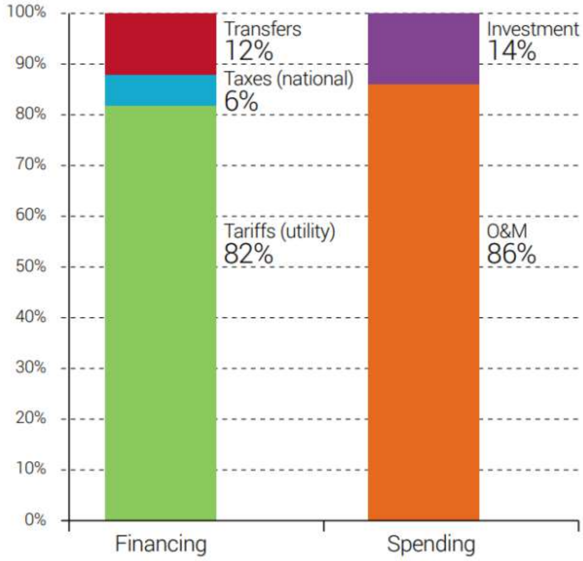

Figure 8: Share of financing resources and spendings (Salvetti, 2015)

Despite an increase in the rate of investment in Serbia's water sector, the current level remains critically insufficient. In 2012, investments were extremely low, amounting to only 4 Euro per inhabitant per year, constituting a mere 0.04% of the nominal GDP. This starkly contrasts with the OECD-recommended investment range of 1.2% to 6% for low-income countries. Although there has been a threefold increase in investment since 2007, a substantial portion of water and wastewater investments still heavily relies on subsidies from the central state budget, as well as loans from international financial institutions and EU supporting funds, signifying the sector's vulnerability. (Salvetti, 2015)

Getzner et al. (2018) further shed light on the concerning state of investment in Serbia, particularly in the sewerage and wastewater disposal domain. When compared to central European countries, Serbia's investment per cubic meter of wastewater treated annually is distressingly below 1 Cent. For example, Austria invests approximately 66 Cents for each cubic meter of wastewater treated annually, accentuating the disparity between Serbia's investment and that of its most similar EU counterpart in terms of size and inhabitants as well as location in the same river basin. (Getzner, et al., 2018)

The financing of construction and rehabilitation projects in the field of public sewage systems and municipal wastewater treatment plants in Austria is carried out through cooperation between the national government, the individual provinces, and the municipalities. Approximately 30% of wastewater infrastructure projects have been financed with the help of federal subsidies since the implementation of the law governing Environmental Subsidies in 1993 (ÖWAV, 2020). This financial support was granted and not to be refunded. It has played a significant role in achieving and maintaining the current level of development of wastewater infrastructure. Altogether, a sum of 22 billion Euro has been invested over a timespan of almost 20 years from 1993 to 2020. Important to mention is that, nevertheless, 37% of this sum has been financed through bank loans after all. (Müller-Rechberger, et al., 2022)

The variations of wastewater charges within Austria show regional differences and on average show lower amounts in urban areas than in their rural counterparts. In 2018, the average wastewater charge per person per year was 161 Euro, which corresponds to about 3.2 Euro/m^3 of wastewater. As further explained later in the Master Thesis, the economy of scale principle applies to the wastewater treatment sector, implying higher costs where less households are connected to a WWTP. Austria tackles this financial unbalance by allowing financial grants. These subsidies are granted to the municipalities by the national government, but under the condition that the wastewater fees are not less than 2 Euro/m^3, including taxes. (Müller-Rechberger, et al., 2022)

5.3 Costs for full UWWTD implementation

As the baseline scenario for Austria is 100% compliance with the UWWTD, the monetary evaluation of full compliance of Serbia assessed in 2017/18 is described in this chapter. It serves as an initial sum of capital expenditures on which inflation until 2022 was added (see Figure 9). The International Monetary Fund indicates in its International Financial Statistics and data files an inflation rate in Serbia from 2017 to 2022 as given in Table 4 and Figure 9 below. The initial sum was 4 477 974 495 Euro by the end of 2017, and for reading flow purposes is rounded to 4.48 billion Euro.

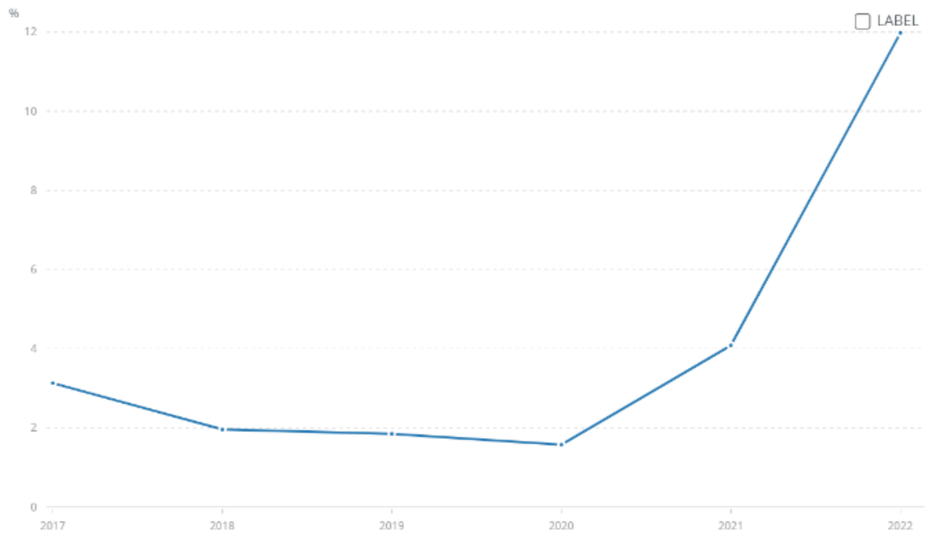

Figure 9: Inflation in Serbia (World Bank, 2023)

After adding the inflation of the subsequent 5 years, the amount of capital expenditures to be invested in network rehabilitation, network extension and wastewater treatment plants according to Article 4 and 5 of the UWWTD would amount to roughly 5.5 billion Euro.

Table 4: Inflation calculated for the CAPEX elaborated in 2018 for full compliance with the UWWTD

Year	Inflation rate	investments in € by the end of each year
2022	12%	5.51 billion
2021	4.1%	4.92 billion
2020	1.6%	4.72 billion
2019	1.8%	4.65 billion
2018	2%	4.57 billion

5.4 Additional costs for quaternary treatment

5.4.1 Cost Function Approach

The cost function used in the Impact Assessment for quaternary treatment in EU member state countries such as Austria, according to Pistocchi, et al., 2022, is the following:

$$C_{adv} = 1000\, p.e.^{-0,45}$$ (European Commission, 2022a)

As mentioned above an investment lifetime of 30 years and an interest rate of 2.5 % are anticipated in this formula.

With regard to the Danube River Basin Management Plan, 2021, Annex 3, Table 1, there are 342 agglomerations according to collection and treatment systems in Serbia (ICPDR, 2021a). The number of Serbian agglomerations in the respective categories defined above are in Table 5 following:

Table 5: Serbian agglomerations according to size categories of small, medium and big agglomerations

Agglomeration Size	Sum of p.e.	N° of Agglomerations
> 100 000 p.e.	2 305 917	5
10 000 - 100 000 p.e.	2 700 037	81
2 000 - 10 000 p.e.	1 090 976	256

The smallest agglomeration in the data set has ~ 2 020 p.e. and the biggest constitutes an outlier with 1.4 million p.e., whereas the second biggest follows with ~ 340 000 p.e..

For the consideration of Areas at Risk yet to be defined which will affect agglomerations the size of 10 000 – 100 000 p.e. the 81 indicated agglomerations represent 100% of this agglomeration size category. Consequently, 70% are rounded to 57 agglomerations falling in an area at risk with respect to the estimation made in the Impact Assessment. This would be equivalent to ~ 1.9 million p.e. instead of the 2.7 million p.e. in Table 5.

Inserting the number of p.e. in each of the 342 agglomerations in the cost function, the following total annualized costs (CAPEX + OPEX) for Serbia are observed (Figure 10).

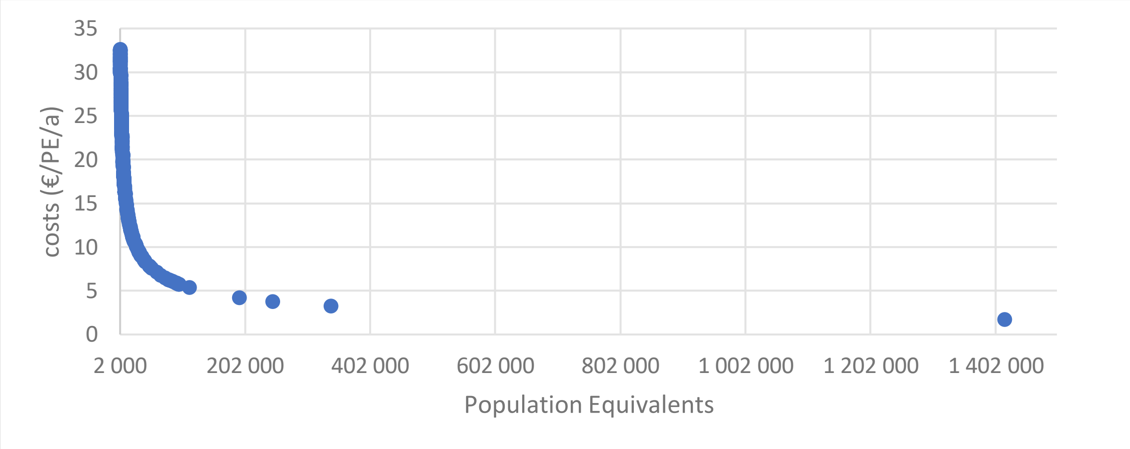

Figure 10: Annualized Costs (€/p.e./a) for Serbia according to agglomeration size for 2 000 - 1 500 000 p.e

As the costs for small agglomerations (2 000 – 10 000 p.e.) are not relevant given no obligation for a 4th treatment step at this size, Figure 11 shows the costs in Euro per p.e. and per year for 10 000 – 350 000 p.e., excluding the outlier at 1.4 Million p.e., where treatment would cost 1.71 Euro per p.e. per year, for better visualization.

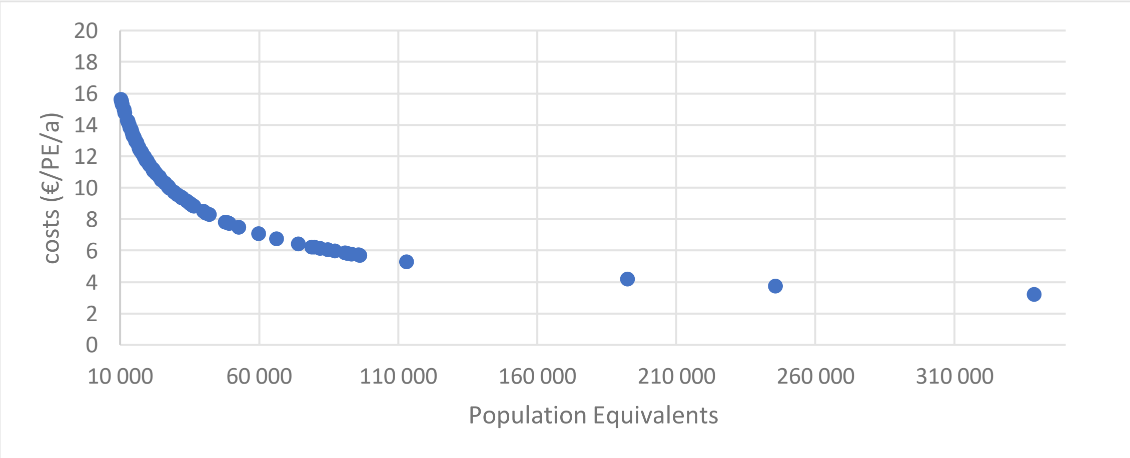

Figure 11: Annualized Costs (€/p.e./a) for Serbia according to agglomeration size for 10 000 - 350 000 p.e.

Given the annualized costs for one p.e. the following total costs per agglomeration size category are calculated for the three scenarios regarding the respective definition of Areas at Risk for medium agglomerations (Table 6, Figure 12) To be more precise, as the costs per p.e. at WWTPs covering a load of one agglomeration with more than 1 million p.e. are significantly lower than the costs of other WWTPs above 100 000 p.e., the total annual costs were calculated separately for that one agglomeration, but still counts to the category of "> 100 000 p.e.".

Table 6: Scenario No. 2 - 70% of medium agglomerations (10 000 - 100 000 p.e.) fall into an Area at Risk

Categories	Sum of PE	No. of AGG	average costs (€/PE/a)	costs (€/a)
> 100 000	1 416 572	1	1,71	2 400 000
	889 345	4	4,13	3 700 000
10 000-100 000	1 890 026	57	10,59	20 000 000
Total	2 779 371	61		26 000 000

If Scenario No. 1 is applied, where 0% of medium agglomerations fall into an Area at Risk, as is currently the case with regard to definitions of Areas at Risk not being determined yet, then only the total costs of big agglomerations are to be taken into account amounting to ~ 6 million Euro, as can be seen in Table 6 (2.4 + 3.7 million Euro). Figure 12 visually depicts the increase in costs according to the three scenarios with Scenario No. 2 being the most likely one. In the following only Scenario No. 2 is considered.

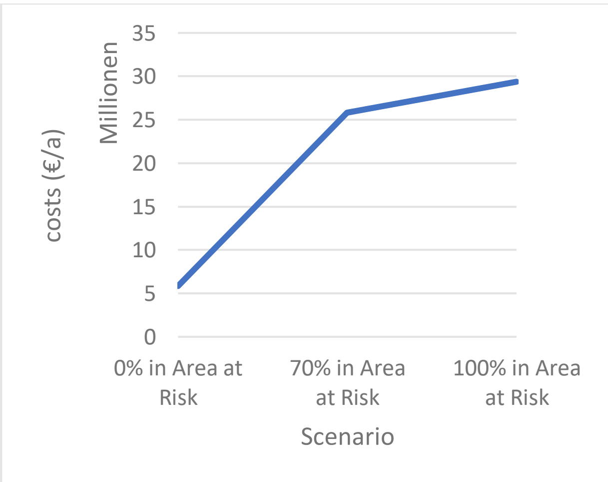

Figure 12: Costs (€/a) per Scenario of Area at Risk Definition

Adjusted for PPP, Scenario No. 2 would imply annualized CAPEX of 13.9 million Euro per year.

5.4.2 Feasibility Study Approach

Each one of the Feasibility Studies has been very individually conducted for its respective WWTP in Germany and the preconditions given on location. The description of various treatment method options according to the existent asset investments to date is to be found in chapter 2.3 on a fourth treatment stage. The 16 FS follow a very similar structure:

1. Description of the existing wastewater treatment plant and the currently planned upgrading measures
2. Micropollutants /trace substances found in the (local) water cycle
3. Method options for the elimination of micropollutants / trace substances
4. Cost & sensitivity analysis
5. Evaluation

Almost all FS cover the three principal treatment methods, apart from the three smallest WWTP (No. 4, 2 & 10 in Figure 13), which only partially evaluated costs for one or two of the methods. This is negligible due to the fact that WWTP catering to agglomerations smaller than 10 000 are not to be equipped with a 4th treatment stage. Almost all FS calculated the annualized costs too with the exception of three (No. 5, 3 & 2 in Figure 13) using varying interest rates and life spans over the years from when they were conducted. Only one FS did not include operating costs (No. 15 in Figure 13).

When FS evaluated different forms of application of one treatment method (Ozonation, PAC, or GAC) then the cost deviation was very small, and the average cost was taken into consideration. For example, FS No. 9 evaluated three different forms of application for GAC, and two different forms of applications for PAC and Ozonation, each. In this case, the average cost for each of the three treatment methods was calculated and used in Figure 13. This is also possible due to the anticipation of alternative configurations of ozonation and activated carbon to exhibit substantial comparability in terms of overall reduction in toxicity. This is true for all but one of the FS, which is N°7, where four different forms of application for the PAC method have been examined. While, as usually, three out of the four application techniques included adding the PAC into the existent filter system or (aeration) tanks, the fourth application included using a membrane which alone accounts for 13 million Euro out of the total 27 million Euro for this form of the PAC method. This fact has significantly altered the average costs for PAC at WWTP No. 7, and therefore the median was used instead.

Agglo Size Category	Wastewater Treatment Plants Feasibility Study N°	P.E.	Investment Costs (CAPEX) in € Ozon	PAC	GAC	Operation Costs (OPEX) in €/a Ozon	PAC	GAC
> 100000	Feasibility Study 7	1 200 000	4 121 000	1 699 000	7 919 000	488 000	1 249 000	1 714 000
	Feasibility Study 1	195 000	4 398 000	4 229 000	3 032 000	285 000	268 000	442 000
	Feasibility Study 9	140 000	9 734 000	9 227 000	9 281 000	632 000	728 000	719 000
	Feasibility Study 12	121 300	4 600 000	2 930 000	2 880 000	360 000	375 000	250 000
10 000 - 100 000	Feasibility Study 5	87 000	4 279 000	5 376 000	2 010 000	171 000	288 000	483 000
	Feasibility Study 6	64 000	3 060 000	3 060 000	3 037 000	239 000	254 000	212 000
	Feasibility Study 15	56 100	11 220 000	5 540 000	4 430 000	-	-	-
	Feasibility Study 11	48 000	7 717 000	6 133 000	6 006 000	516 000	374 000	490 000
	Feasibility Study 3	47 000	2 900 000	1 256 000	7 755 000	276 000	214 000	198 000
	Feasibility Study 13	30 000	1 942 000	3 369 000	3 176 000	140 000	162 000	174 000
	Feasibility Study 8	14 000	1 967 000	1 748 000	1 332 000	92 000	98 000	109 000
	Feasibility Study 16	11 800	1 850 000	1 496 000	1 803 000	98 000	92 000	115 000
	Feasibility Study 14	11 000	2 312 000	1 981 000	1 982 000	52 460	56 000	95 000
	Feasibility Study 4	10 000	1 090 000	-	1 029 000	80 000	-	88 000
2 000 - 10 000	Feasibility Study 2	4 900	1 380 000	-	-	78 000	-	-
	Feasibility Study 10	3 300	-	1 084 000	1 080 000	-	78 000	89 000

Figure 13: Summary of Feasibility Studies including CAPEX, OPEX & Annualized Costs where available

As a next step, the total investment costs listed in Figure 13 were annualized to result in CAPEX per year by using an interest rate of 3% and a lifetime of 30 years. The annualized CAPEX were then calculated per p.e. (see Figure 14).

Agglo Size Category	Wastewater Treatment Plants Feasibility Study N°	P.E.	annualized CAPEX in €/a Ozon	PAC	GAC	annualized CAPEX in €/p.e./a Ozon	PAC	GAC	Mean
> 100000	Feasibility Study 7	1 200 000	210 250	86 682	404 022	0,18	0,07	0,34	0,19
	Feasibility Study 1	195 000	224 383	215 760	154 690	1,15	1,11	0,79	1,02
	Feasibility Study 9	140 000	496 621	470 755	473 510	3,55	3,36	3,38	3,43
	Feasibility Study 1	121 300	234 689	149 486	146 935	1,93	1,23	1,21	1,46
0 000 - 100 00	Feasibility Study 5	87 000	218 311	274 280	102 549	2,51	3,15	1,18	2,28
	Feasibility Study 6	64 000	156 119	156 119	154 945	2,44	2,44	2,42	2,43
	Feasibility Study 1	56 100	572 436	282 647	226 015	10,20	5,04	4,03	6,42
	Feasibility Study 1	48 000	393 716	312 901	306 422	8,20	6,52	6,38	7,03
	Feasibility Study 3	47 000	147 956	64 080	395 654	3,15	1,36	8,42	4,31
	Feasibility Study 1	30 000	99 079	171 884	162 037	3,30	5,73	5,40	4,81
	Feasibility Study 8	14 000	100 355	89 182	67 958	7,17	6,37	4,85	6,13
	Feasibility Study 1	11 800	94 386	76 325	91 988	8,00	6,47	7,80	7,42
	Feasibility Study 1	11 000	117 957	101 069	101 120	10,72	9,19	9,19	9,70
	Feasibility Study 4	10 000	55 611	-	52 499	5,56	-	5,25	3,60

Figure 14: annualized CAPEX and in €/p.e./a

Calculating the annualized costs using the CAPEX and OPEX per p.e. the cost structure can be visualized. Figure 15 shows the annualized costs per p.e. and per year from each Feasibility Study showing the size of each WWTP in p.e. connected to it. Table 7 show the data used for the graph.

Table 7: annualized CAPEX, OPEX and total costs per p.e. per year

p.e.	OPEX in €/p.e./a	CAPEX in €/p.e./a	Total annualized costs in €/p.e./a	Average/ category
10000	5,60	3,60	9,20	
11000	6,17	9,70	15,87	
11800	8,62	7,42	16,04	
14000	7,12	6,13	13,25	
30000	5,29	4,81	10,10	10,87
47000	4,88	4,31	9,19	
48000	9,58	7,03	16,62	
56100	0,00	6,42	6,42	
64000	3,67	2,43	6,11	
87000	3,61	2,28	5,89	
121300	2,71	1,46	4,17	
140000	4,95	3,43	8,38	5,09
195000	1,70	1,02	2,72	
1200000	0,96	0,19	1,15	1,15

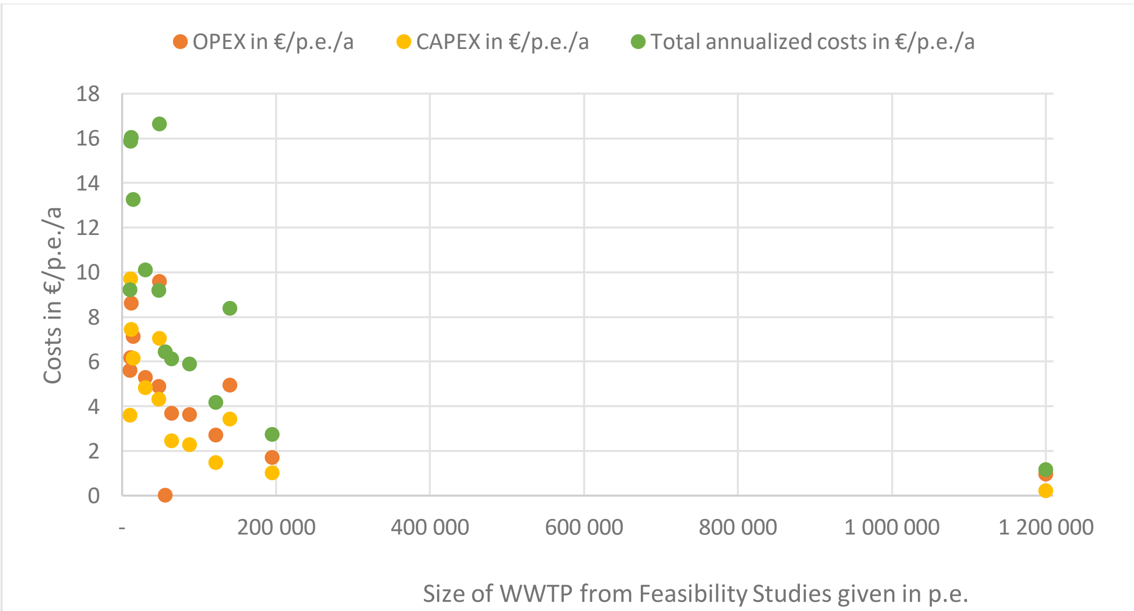

Figure 15: Annualized costs per p.e. from each FS from 10 000 – 1 210 000 p.e.

Given the lack of sufficient FS from WWTPs within a connection rate of 200 000 to more than 1 million p.e., Figure 16 also shows a closeup of the distribution of costs from 10 000 to 200 000 p.e. WWTPs.

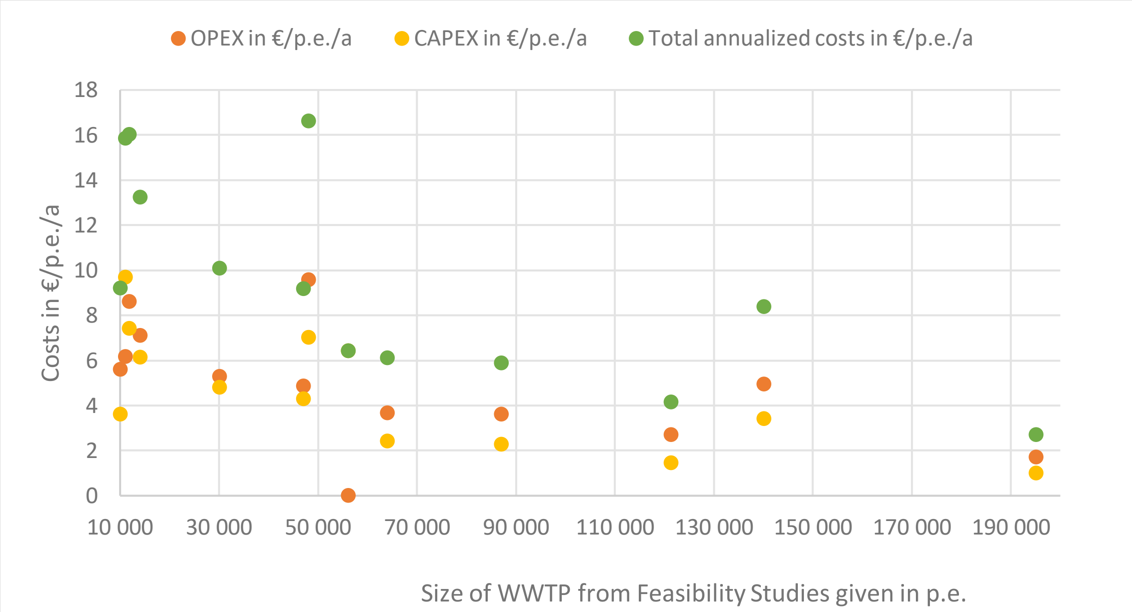

Figure 16: Annualized costs per p.e. from each FS from 10 000 – 200 000 p.e.

The total annualized costs per p.e. are calculated with the mean value of the three treatment method options which are averaged per agglomeration size category.

Analogous to the cost function approach, the total annualized costs (including CAPEX and OPEX) per p.e. can be used to evaluate the total annualized costs for Serbia given that Scenario No. 2 is applied (Table 9).

Table 8: Scenario No. 2 – Feasibility Study Approach results

Categories	Sum of PE	No. of AGG	average costs (€/PE/a)	costs (€/a)
>100 000	1 416 572	1	1,15	1 600 000
	889 345	4	5,09	4 500 000
10000-100000	1 890 026	57	10,87	20 500 000
Total	2 779 371	61		26 700 000

Adjusted for PPP, Scenario No. 2 would imply annualized CAPEX of 14.3 million Euro per year.

Additionally, the results of the following calculation of overall capital investments (not annualized) and operational costs for Serbia using the numbers of p.e. from agglomerations in Serbia according to Scenario No. 2 (where 70% of medium sized cities fall into an area at risk) can be seen in Figure 17. The mean value of all 3 treatment methods is drawn. This primarily provides the total sum of CAPEX to be invested for a fourth treatment stage at the moment without considering future interest rates.

Agglo Size Category	Sum of PE	Total Investment Costs (CAPEX) in €		
		Ozon	PAC	GAC
>100 000	1 416 572	25 000 000	21 000 000	20 000 000
	889 345	15 000 000	13 000 000	13 000 000
10 000 - 100 000	1 890 026	33 000 000	28 000 000	27 000 000
Total		73 000 000	63 000 000	59 000 000
Mean		65 000 000		

Figure 17: Total Investment Costs in Serbia according to FS before considering interest rates, PPP adjusted

6. Discussion

The overview of the state of the wastewater sector has primarily shown the complexity of competences distributed across numerous institutions. With the help of Figure 6, the administrative organization of institutions and their responsibilities described in the DSIP, could be better understood. The reorganization of the water sector, involving the consolidation of water utility areas and companies, is a pivotal step towards addressing a range of pressing challenges. These include resolving ambiguities or overlaps in institutional responsibilities, enhancing coordination, bridging gaps in administrative and technical proficiencies across all tiers, and bolstering capabilities for maintaining and operating existing local-level infrastructure managed by public companies. (ICPDR, 2021b)

The ICPDR recommendation paper, generally, also suggests that non-EU member states in the Danube region need to take into account navigating demographic shifts like depopulation in rural regions, rectifying outdated standards governing infrastructure elements and treatment technologies, and lastly, addressing the glaring deficiency in adequate collection and treatment facilities for specifically rural areas. (ICPDR, 2021b)

Especially, the phenomenon of suburbanization in metropole areas, in the mostly post-socialist states of the region plays a big role when it comes to the assessment of agglomerations in rural areas. Representative examples are Belgrade and Sofia which are growing in surface area beyond city boarders, causing new challenges to the cities' wastewater infrastructure, while rural areas experience an exodus. (Slaev, et al., 2018) It leaves the question open how to deal with the wastewater collection and treatment connection in what is already being called "*ghost towns*" (Djurica, 2017).

Furthermore, the current economic status reveals the critical need for overcoming funding deficits for the construction and operation of wastewater collection and treatment systems, grappling with issues of affordability and the incongruity of water pricing for improved services, tackling the absence of efficient planning and construction capacities which lead to project delays, and streamlining ineffective public procurement procedures. (ICPDR, 2021b)

Already, in 2015 the Serbia Country Note developed by the World Bank stated an investment need of 5 billion Euro to achieve EU compliance for the entire water supply and sanitation sector, of which 40% should be invested in drinking water coverage, and 60% should be invested in sewerage infrastructure. At the time, this was twice as much as was raised. As a result, it was suggested to apply the cost recovery principle to progress in the development for the EU accession process. (Salvetti, 2015)

> The Cost Recovery Principle forms a cornerstone of EU water policy. As per Article 9 of the WFD, member states should ensure by 2010 that water pricing policies provide adequate incentives for users to use water resources efficiently and thereby contribute to the environmental objectives of the directive. It also introduces the principle that the cost of water services should be recovered from the different water users (households, industry, and agriculture). (WAREG, 2023)

Moreover, the fines for wastewater discharge above authorized limits are considerably low compared to the costs of treatment facilities, leading to inadequate incentives for industrial and domestic sectors to comply with EU regulations. (Salvetti, 2015)

The estimated 5.5 billion Euro of only capital investments in 2022 given the inflation of the past 5 years (see Table 4) are a conservative estimate of the real number to be invested in the near future to fully comply with the UWWTD as it is. This inflated number does not yet include an expected continuation of rising material costs, or at least their stagnation at a high level, along with bottlenecks of recent times, nor the lack of human resources, leading to a necessity of capacity development. "*About 45% of the capital costs are due to salaries and about 55% to construction materials, installations, machinery*." (Zessner, et al., 2010) In recent years, especially since 2019, when the global COVID-19 pandemic, and subsequently the war in Ukraine, hit the construction sector, the costs of construction went up steeply. From 2021 to 2022, it was an increase of 10.3%, and additional statistics show that less construction work was done for more money, being coherent with elevated salaries in the sector. (Euronews Srbija, 2022)

When looking at the economic potential of the wastewater sector in Serbia on the comparison to a comparatively even country in terms of size and population, then Austria generates a total domestic production value of 2.2 million Euro, and a value-added effect of 1.3 million Euro as a result of primary and secondary effects. In addition, the ongoing operation leads to macroeconomic employee compensation effects of 440 million Euro. Including secondary effects, a full-time equivalent of almost 9 000 people is employed in the wastewater sector (Assmann, et al., 2020)

Notwithstanding the above, the cost function approach has delivered potential cost numbers for quaternary treatment according to each of the three scenarios of numbers of agglomerations in areas at risk. Proceeding with the most likely outcome of 26 million Euro (Table 6) of total annual costs (CAPEX and OPEX), given the proclamation in the Impact Assessment of 70% of agglomerations between 10 000 and 100 000 p.e. to fall into an Area at Risk, the number is lower than in Austria (36.6 million €/a). In this context, it is important to mention that in the Impact Assessment, it is assumed that the costs of upgrade are corresponding "*to the difference between costs of new tertiary and secondary plants, plus 50% of the costs of a new secondary plant to account for the potentially significant overhaul*." (European Commission, 2022a) This means that in the 36.6 million Euro per year calculated for Austria potential necessary expenditures on the construction of a secondary and/or tertiary treatment stage are included due to them being a prerequisite for quaternary treatment. However, it is to be expected a small proportion given that Austria is fully compliant with the UWWTD, whereas this number would be much higher for Serbia. In this Master Thesis the costs of reaching the before-mentioned advanced treatment necessary prior to quaternary treatment implementation is mostly entailed in the 5.5 billion Euro for investment already.

The feasibility study approach, based on calculations for WWTPs in Germany is evaluated to have varying results. Annual investment and operating costs amount to 26.7 million Euro, and purchasing power parity adjusted, the costs amount to 6.6 million Euro. As the results are close to the outcome of the cost function, they are reliable. When looking at the results of the feasibility study approach, depending on how many of one treatment method are implemented, one could roughly argue that the average total CAPEX of installing ozonation, either of the activated carbon processes, or a combination of both is to be estimated at 65 million Euro. Added to the baseline of technically full compliance achievement with the UWWTD through capital investment in the amount of 5.5 billion Euro, the total sum for additional quaternary treatment on top would be 5.565 billion Euro, keeping in mind the limitation described in the previous chapter of a low sample number of FS. It leads to a comparably low increase in costs, and is a momentary snapshot for current investment needs, not forecasting potential interest rates developments, nor considering annual operational costs, which actually make up the bigger part of the total costs.

The result for costs of quaternary treatment varies only slightly between both approaches (Table 11). A comparison of the costs according to Scenario No. 2 is made in Table 11. The visual comparison of graphs (Figure 18) suggests that the effect of economy of scale hold true according to appliance to WWTPs in Germany. Taking a closer look at the distribution of CAPEX and OPEX in the FS, a ratio 35% to 65% is established. The results of the Feasibility Study Approach suggest that CAPEX will make up 35% of the total annualized costs and that OPEX will cover the remaining 65% of total annualized costs. Since the fourth treatment stage differs from all previous stages in that - depending on the method - only minor construction measures have to be taken at existing WWTPs, but considerably more ongoing expenditure is incurred (e.g. procurement of ozone and/or activated carbon), this ratio is plausible.

Table 9: Comparison of results from Cost Function and Feasibility Study Approach

Type of Costs (adjusted to PPP and interest rate)	Cost Function Approach	Feasibility Study Approach
Total annual costs	26 million €	26.7 million €
PPP adjusted for Serbia	13.9 million €	14.3 million €

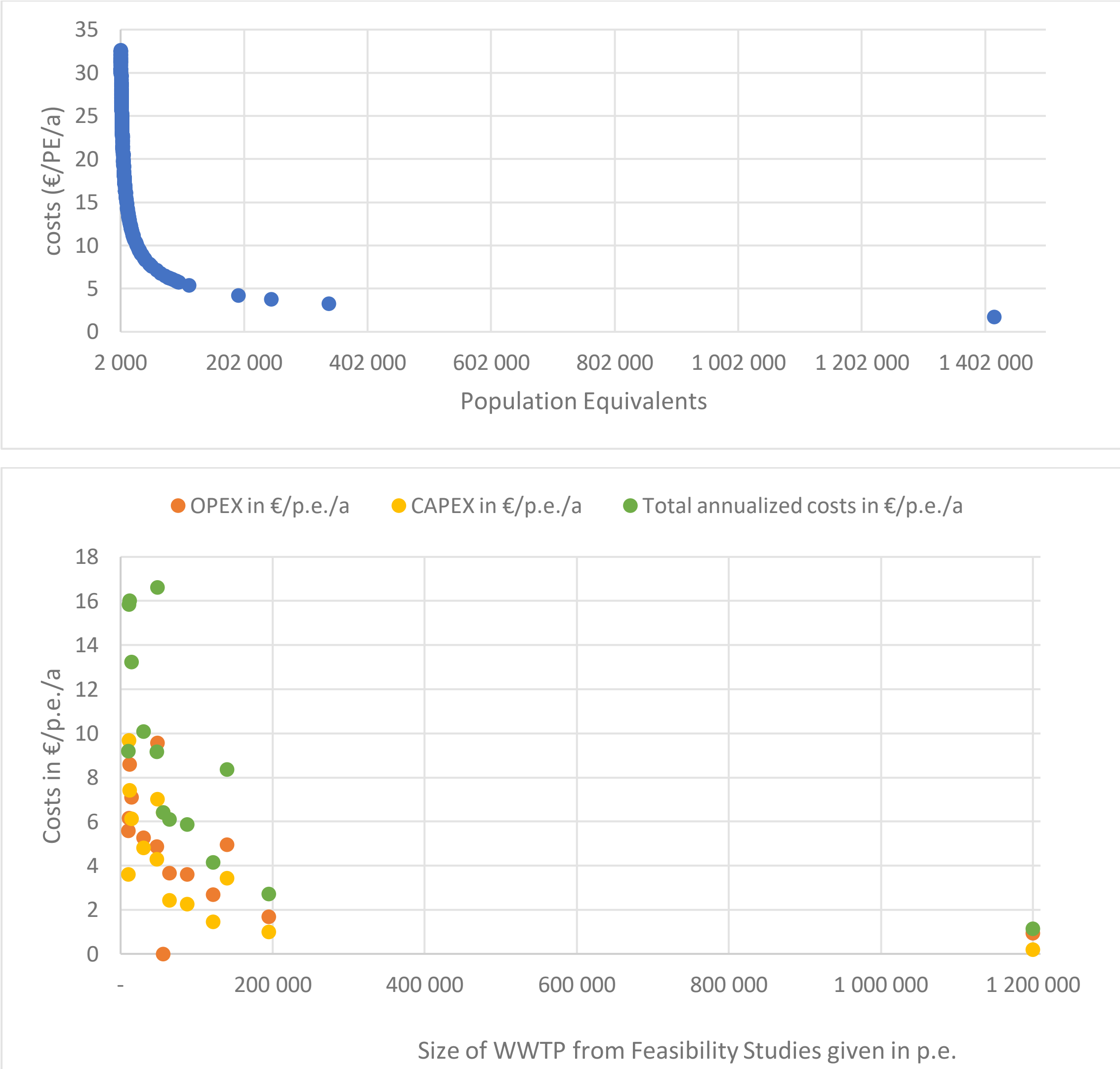

Figure 18: Graphic comparison of Cost Function and Feasibility Study Approach results

Graphs from both approaches (Figure 11 and 15, compiled in Figure 18) show the economy of scale effect, proving that WWTPs with higher loads are more cost-efficient. Moreover, the FS show that in reality this is in not a smooth curve where with every additional p.e. connected to a WWTP the costs sink. There are also exceptions due to individual local circumstances.

For reference, the budget adopted by the Serbian Parliament for 2023 foresees 1,843.4 billion Dinars (15.7 billion Euro) in revenues and 2,107.4 billion Dinars (18 billion Euro) in expenditures. (Čovs & Vujić, 2022) Prime minister, Ana Brnabic, stated that the "*spending plan also envisions allocation of 6.8% of total funds for capital investments, mainly in infrastructure*" (Vasovic, 2022). This would be equivalent to 1.2 billion Euro which are not reserved for water supply and sanitation infrastructure only.

Another finding suggests that the policy option developed in the Proposal concerning the connection of very small agglomerations (< 2 000 p.e.) will make up a much bigger part of the investment funds necessary for implementation of a revised UWWTD. The Austrian example shows that 75% of capital investments flew into the construction of sewerage systems (Assmann, et al., 2020). When it comes to operating and maintenance costs, the share of ongoing investments even lies at 85% for network rehabilitation and renovation works, which is estimated to be equivalent to a sum of 1.6 million Euro from 2021 to 2027 (Müller-Rechberger, et al., 2022).

7. Conclusion

The implementation status of the UWWTD in Serbia is very low, and infrastructure development in this sector is only progressing slowly due to several reasons. As depicted in Figure 5, the biggest part of wastewater in Serbia is collected but not treated, while the fraction of wastewater going to WWTPs for the biggest part only reaches the secondary stage. A high level of pollution (see Table 2) is consequently reaching natural water bodies downstream in the Danube River Basin. Local and/or individual appropriate systems are very present in large parts of the country, mostly in rural areas, which are more and more abandoned due to migration to metropolitan outskirts. Suburbanization can therefore be identified as a major challenge faced by not only Serbia, but also other post-socialist EU candidate countries.

A very complex and dispersed allocation of responsibilities within national institutions stands in the way of reforms to aggregate duties. As the quote from the DSIP on page 4f. reads, four different ministries and at least two public water management companies are currently overseeing diverse sub-aspects and tasks of the wastewater sector, let alone a federal system of about 150 PUCs managing other utility-related activities. This allocation of tasks creates obstacles such as intransparency, and inefficiency caused by overlaps.

Addressing the dearth of investment in Serbia's water sector is imperative to achieve sustainable and resilient water infrastructure and services for the country's population (Getzner, et al., 2018). Specifically, the state of the economic situation is burdened by a lack of investment stemming from not least insufficient tariff setting, as the operating costs of many PUCs cannot even be covered through their own generated revenue. A total sum of investment needs elaborated in the DSIP in 2017/18, shows a demand for at least 5.5 billion Euro adjusted to inflation of 5 years until 2022. This sum which rather constitutes the lower end of the investment span shows that transfers from international and national, as well as taxes from national level still play a key role in achieving sufficient financing, as tariffs alone cannot bear the total spendings still required. Not only affordability in fiscal terms, but also in capacity terms of human resources pose challenges yet to be overcome.

It can be concluded that Serbia still stands at the beginning of the UWWTD implementation and has a long way to go for compliance with the Directive adopted in

1991 at EU level. The before-mentioned institutional, demographic, financial, and capacity challenges could be identified.

Regarding the policy options outlines by the Proposal for a revised UWWTD, two were identified as specifically cost intensive. The total costs of connection of agglomerations below 2 000 p.e. could not be determined, but the price of 1 km of sewerage network extension in Serbia was calculated to be 220 Euro/running meter. As the focus of this Master Thesis was to specifically evaluate at the monetary implications of a fourth treatment stage, the eligible methods according to the EU Impact Assessment and thus Proposal, were elaborated. Ozonation, powdered, or activated carbon, or a combination of using O_3 and AC, can be considered where AC has the advantage of being able to be reused several times before disposal. The Proposal suggests that one of these methods, or their combination, should be applied to all WWTPs catering to agglomerations bigger than 100 000 p.e., and to an expected 70% of agglomerations between 10 000 and 100 000 p.e. due to laying in an Area at Risk of micro-pollution.

Both approaches taken in the Master Thesis led to a similar sum of total costs needed for implementing quaternary treatment. The cost function approach in comparison with the feasibility study approach provided proof of the economy of scale principle being applicable to the wastewater treatment operations showing annualized costs decreasing with an increasing amount of p.e. load per wastewater treatment plant. Total annualized costs, interest rate and purchase power parity adjusted for Serbia, estimate to around 13.9 to 14.3 million Euro.

The Feasibility Study approach suggest that the CAPEX for quaternary treatment will make up the smaller part (35%) of the total estimated costs, given that the capital investment need for additional construction measures at existent WWTP equipped with secondary or tertiary treatment facilities is rather low. Moreover, quaternary treatment methods imply higher total operational costs (65%) than total capital expenditures. The FS approach revealed that treatment methods using primarily ozone are the most expensive, followed by GAC and then PAC in terms of capital costs.

Furthermore, if investments were to be made now (in 2023), at least 5.5 billion Euro are needed for full compliance with the UWWTD, and additionally 65 million Euro of pure investments would need to be added for including the construction of quaternary treatment facilities. This policy measure would consequently not impact the current investment sum significantly.

It will be crucial to estimate the costs of the policy option considering the connection of small villages as a next step, taking into account the challenges already identified.

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