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Wastewater treatment in the Danube region: opportunities and challenges

Lessons learnt from a "synthesis centres" exercise

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Contents

Abstract

Wastewater treatment is necessary but requires investments, and the countries more in need of improvements are often those with lower capacity of investment, also related to the affordability of the service for the poor. The JRC has commissioned two feasibility studies concerning the setup of "synthesis centres", to address one feasibility study relative to small decentralized wastewater treatment solutions in a rural area of Slovenia, and another feasibility study relative to a centralized wastewater treatment solution for two municipalities in Serbia.

A "Synthesis centre" is meant in this report as the ad hoc gathering of stakeholders, service operators, government and the local community around the problem to be solved. The wastewater treatment solutions designed and discussed in these two feasibility studies have been further tested in a set of additional cases in all countries of the Lower Danube.

The outcomes suggest that there is considerable scope for the development of decentralized wastewater treatment through constructed wetlands in rural areas and small agglomerations, throughout the Lower Danube. This type of solution offers significantly higher cost-effectiveness than more "technological" and centralized solutions, particularly because it limits the costly investments of sewage collection and the energy and labour requirements of activated sludge or similar processes.

In cases where a centralized plant is justified, this can become the pivot of an "industrial ecological" district where the energy and materials conveyed by wastewater can be conveniently recovered. For energy the benefits are more apparent, while the recovery of fertilizers and water may be limited by lack of a market for these secondary resources, the still relatively high costs, and cultural and legislative barriers hampering their marketability. At the same time, often the sludge line of wastewater treatment plants may be synergetic with the treatment of the organic fraction of municipal, industrial and agricultural waste. When this is the case, expanding the boundaries of the system of waste flows considered in the design of the plant may result in significant economies of scale and revenues offsetting parts of the costs of waste and wastewater treatment.

The study highlights that wastewater tariffs may be relatively low even by standards of middle income countries; however, the large variation of income within countries may give rise to affordability issues. The strategies analysed here may improve the financial sustainability and affordability of the service.

Generally speaking, the involvement of stakeholders in a "synthesis centre" may stimulate the invention of more integrative solutions for affordable and cost-effective wastewater treatment, and can be recommended in order to unleash this potential.

Foreword

By Adam Kovacs, International Commission for the Protection of the Danube River (ICPDR)

As one of the most international river basins in the world, the Danube River Basin (DRB) is of transboundary significance and transnational cooperation plays a crucial role in the management of its water resources. The 19 countries in the basin are very heterogeneous, yet they share a common European aspiration and a joint commitment to sustainably manage and develop the region. In the DRB, water quality and environmental protection, including the treatment of wastewater, are a natural opportunity for regional cooperation.

The ambitious requirements of the European Union (EU)'s water policy, particularly those of the Water Framework Directive (WFD) and the Urban Wastewater treatment directive (UWWTD) oblige member states to construct adequate wastewater collecting and treatment facilities, to maintain their technical performance and to ensure cost-recovery. These obligations require member states to make substantial investments in the wastewater sector, to ensure sufficient management and operational capacity and to introduce appropriate prices for the wastewater services. Some 90 million Population Equivalents (PE) in the DRB generate more than 10 million m^3 of wastewater each day. This significant amount of wastewater needs to be appropriately collected and treated before being discharged into the recipient water bodies to minimise soil and water pollution and health risk. The basin-wide ultimate water management objective set by the Danube countries is to achieve zero discharge of untreated wastewater into the waters of the DRB. On the other hand, wastewater represents significant resources of energy, water and nutrients that could be at least partly exploited at local scale so that the linear energy and material flows are gradually transferred to circular towards a sustainable resource management.

In the last twelve years, the Danube countries have invested more than € 22 billion in wastewater infrastructure[1]. Since 2006, almost 5,000 municipalities and almost 40 million PE have had collecting and treatment facilities constructed or upgraded, with over 2,200 more planned or currently in progress to improve the services for 25 million PE. During the same time period, the percentage of communities and industrial facilities (bigger than 2,000 PE) connected to a sewer system and wastewater treatment plant also increased substantially, demonstrating a remarkable improvement in both the technological response to the problem and improving water quality across the region. The majority of this wastewater is collected by public sewers or handled by adequate local technologies (80%) and treated in centralized treatment plants (73%). The proportion of people connected to nutrient removal in mid-sized and big settlements has also increased by a remarkable 25% and reached 75%. Moreover, since 2006 dozens of urban wastewater treatment plants have added specific technologies to remove hazardous pollutants from wastewater.

The improvements in urban wastewater management have significantly decreased organic nutrient and hazardous substances pollution of the water bodies of the DRB, resulting in much cleaner and healthier waters for the environment and for people to enjoy. Thanks to the substantial development of the wastewater infrastructure in the last decade, organic matter, nitrogen and phosphorus emissions via wastewater discharges have been reduced by almost 50%, 20% and 40%, respectively[2].

Despite the huge investments already made in the wastewater infrastructure, additional measures should be taken in the future. About 25% of the total PE in the DRB need basic infrastructural development aiming to achieve connection to public sewer systems and at least biological treatment. Settlements above 10,000 PE (representing about 70 million PE

[1] ICPDR: 2018 Interim Report on the Implementation of the Joint Programme of Measures in the Danube River Basin (http://www.icpdr.org/main/2018-interim-report-implementation-joint-programme-measures-danube-river-basin)

[2] ICPDR: Danube River Basin District Management Plan - Update 2015 (http://www.icpdr.org/main/activities-projects/river-basin-management-plan-update-2015)

in total) are mainly equipped with nutrient removal technologies (75%), but there is still room for improvement.

Further efforts should be made to foster the development of investment projects in the wastewater sector. Whilst some of the EU Member States (MS) have already fulfilled these requirements in the past decades, others (mainly new MS) are still struggling with the implementation due to lack of funds and management capacity. This is particularly challenging for the associate and candidate countries where substantial investments and significant capacity strengthening are needed in the wastewater sector to comply with the EU water legislation. Supporting new and non-EU MS to find appropriate financial sources and to achieve progress is still a challenge in the DRB and should be further facilitated. For other EU Member States, investment needs are shifted to proper maintenance and rehabilitation of the existing infrastructure.

Until about twenty years ago, in many DRB countries water supply and sanitation services, more specifically wastewater collection and treatment facilities were state-owned and state-run by a few large, regional companies. Since the fall of the iron curtain and the political changes that came along, the ownership and management structure of the wastewater infrastructure have been fragmented. Many of the facilities are owned by local governments/authorities and operated by municipality or private companies usually in the form of concession. Yet, these often lack appropriate management skills and the financial means to construct, operate and maintain a good wastewater infrastructure. To operate the newly built infrastructure in a sustainable manner, a sufficient tariff, sufficient incentives and accountability needs to be in place to ensure compliance with wastewater collection, treatment and discharge standards.

Particularly in the new EU Member States, and in those approaching EU accession, affordability of modernised wastewater services is of high concern. Whilst operational costs of high-level wastewater services are similar in the DRB countries, the average incomes are significantly lower in the new EU MS and non-EU MS in comparison to those in the old EU MS. Operating and maintaining enhanced infrastructure would require to substantially increasing water prices to a level that is hardly affordable for citizens with low income.

In addition to the challenges of constructing, operating and maintaining the conventional wastewater infrastructure (sewer systems and centralised treatment plants), other emerging aspects need to be taken account. At small agglomerations (e.g. below 2,000 PE) and in areas, where construction of sewer systems is not advantageous therefore appropriate individual systems can be reasonably applied, wastewater management may be managed by small scale, decentralised treatment facilities to make the infrastructure technically and economically feasible. Thanks to the rapid development of the chemical industry sector, a large number of chemicals are released from households, industrial facilities and urban areas with wastewater that cannot be sufficiently treated by conventional treatment technologies but need to be handled by more enhanced measures. There is a great potential to significantly improve the energy and mass balance of the treatment plants by energy production and optimisation as well as wastewater and sludge reuse.

In light of the multidimensional problem of wastewater management, three main fields associated with challenges can be identified where further efforts are needed in order to strengthen capacity:

- investment and financing,
- management and operation,
- and innovation and technology.

The activities addressing these challenges should target all relevant sectors involved, i.e. national/regional authorities, local authorities and utilities.

In terms of financing, understanding the financial issues behind both the construction/upgrading/extension of wastewater collecting system and/or treatment plants and the operation of the facilities is crucial for improving and maintaining the wastewater infrastructure. Identifying funding sources and ways of adsorbing funds, prioritising investment needs according to cost-efficiency and cost-benefit analysis, ensuring maintenance costs, setting fair water prices and ensuring affordability and social subsidies are the most critical issues to be addressed.

Regarding management, the administration level (either national/regional or local administration) is facing a high demand for better institutional capacity and qualified experts dealing with project development and implementation in the wastewater sector. In order to submit bankable project proposals, people with proper organizational and strategic skills at the central and local administration are crucial. Moreover, at the level of water authorities, regulation and control of the respective policy implementation are important aspects. Utilities often lack sufficiently trained technical experts. Well-developed trainings targeting the operation and maintenance of wastewater infrastructure are crucial to ensure not only a qualified workforce, but also efficient and sustainable wastewater treatment.

With regard to innovation, technological progress and the rise of environmental awareness in the water management sector have led to advanced solutions supporting the objectives of the circular economy and resource efficiency and addressing emerging challenges. Examples are nutrient recovery from sludge, wastewater reuse, biogas utilisation, energy optimisation, nature based and decentralised treatment technologies, treatment of organic micro-pollutants (e.g. activated carbon filters, UV-treatment) that allow using resources in a technically and environmentally sound manner.

Several initiatives are already in place at regional level to assist the Danube countries in achieving sustainable wastewater management. The International Commission for the Protection of the Danube River, in cooperation with its partner organisations, intends to support national and local administrations in enhancing their skills needed to develop and implement wastewater projects and properly finance and manage wastewater infrastructure in order to protect the DRB surface water resources and to ensure adequate services for the population. The Danube Water Program (jointly managed by the International Association of Water Supply Companies in the Danube Catchment Area and the World Bank) is extending the scope of its capacity building program called D-LeaP (Danube Learning Partnership) to the wastewater utilities in order to establish a nationally developed but regionally coordinated wastewater management curriculum, and to provide support and training programs for utility operators.

This report highlights the outcomes of the two feasibility studies (in Slovenia and Serbia) initiated by the Joint Research Centre of the European Commission for integrated wastewater treatment solutions that is able to recover energy and materials from wastewater/sludge, valorise them on the market, and allow henceforth a reduction of water treatment tariffs. The novelty of the proposed approach is to setup so-called synthesis centres that would integrate authorities, local communities and stakeholders relevant for the wastewater management to jointly elaborate management solutions. The report makes a business case of these types of solutions, and discusses their potential to be generalized for sustainable wastewater management in the lower Danube region. In this respect, the report contribute may be a useful contribution in the context of the above-mentioned regional initiatives.

Acknowledgements

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Mr Karoly Kovacs, past president of the European Water Association and President of the Hungarian Water Association, is gratefully acknowledged for his constructive critical comments and suggestions, which have helped improve this work.

The drawing reproduced on the cover was made by Anna Mak, from School 37, Chernivtsi, Ukraine. The script can be translated as: "*Don't waste water! Who are we without it?*". It was selected in a contest organised by the Water Utility in Chernivtsi "Чернівціводоканал" (Chernivtsi Voda Canal, www.vodokanal.cv.ua). More details from the Awards ceremony of the contest at: https://vodokanal.cv.ua/news/vidbulasya-urochysta-tseremoniya-nagorodzhennya-peremozhtsiv-konkurs-dytyachyh-malyunkiv-ekonomiya-vody-zberezhennya-resursiv.html. Ms.Nadija Velichko, from Chernivtsi Voda Canal, is gratefully acknowledged for providing the picture.

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Feasibility study 2 was developed by a team led by Jovana Husemann and including Heidrun Steinmetz, Aleksandar Maksimovic and Craig Hempfling. The authors of the two feasibility studies have provided the information contained in Section 4 of this report.

The test cases in the lower Danube region were developed by Cveta Dimitrova (Bulgaria), Pavel Panus (Moldova and Ukraine), Elena Presura (Romania), Doru Popa (Romania), Alenka Mubi Zalaznik (Bosnia & Herzegovina, Croatia and Montenegro). Additional contributions to the test cases were provided by Ana Timus (Moldova), Tsvetomira Komitova (Bulgaria), Anja Potokar (Slovenia) and Gregor Plestenjak (Slovenia) under the coordination of Ciprian Nanu.

All experts above have contributed to the preparation of this report. The opinions expressed on the feasibility studies and test cases presented here are those of the experts involved, and do not represent the position of the European Commission.

Executive summary

Policy context

Wastewater treatment is a fundamental issue in the Danube river basin, with some countries still lagging behind in implementing the Urban Wastewater Treatment Directive (91/271/EEC) or other applicable standards. The Danube River Basin Management Plan aims at achieving adequate treatment of wastewater throughout the Danube. In the case of larger agglomerations, wastewater treatment may be hampered by lack of financial as well as technical capacity of the plant operators. In the case of smaller agglomerations and rural areas, often corresponding also to the poorer and older part of the population, centralised technical solutions may entail costs exceeding the users' ability to pay.

Often wastewater treatment is planned and designed by specialists, with limited involvement of the social and industrial ecosystem. An *ad hoc* gathering of stakeholders, service operators, government and the local community, what in this report we call a "synthesis centre", may be effective at finding site-specific solutions to the wastewater problem that are effective, economically and socially sustainable.

In this context, the JRC has commissioned two feasibility studies concerning the setup of "synthesis centres", in order to address one case relative to small decentralized wastewater treatment solutions in a rural area of Slovenia, and another case relative to a centralized wastewater treatment solution for two municipalities in Serbia. The solutions designed and discussed in these two cases have been then presented, and their applicability has been checked, in a set of test cases in all countries of the Lower Danube (Bulgaria, Romania, Moldova, Ukraine, Montenegro, Bosnia and Herzegovina, Croatia).

Main findings - Key conclusions

The feasibility studies suggest that there is considerable scope for the development of decentralized wastewater treatment through constructed wetlands in rural areas and small agglomerations, throughout the Lower Danube. This type of solution offers significantly higher cost-effectiveness than more "technological" and centralised solutions, particularly because it limits the costly investments of sewage collection and the energy and labour requirements of activated sludge or similar processes.

In the case of larger agglomerations, where a centralized plant is justified, this can become the pivot of an "industrial ecological" district where the energy and materials (fertilizers and water) conveyed by wastewater can be conveniently recovered. For energy the benefits are more apparent, while the recovery of fertilizers and water may be limited by lack of a market for these secondary resources, the still relatively high costs of the recovery process, and cultural and legislative barriers hampering their marketability. At the same time, often the sludge line of wastewater treatment plants may be synergetic with the treatment of the organic fraction of municipal, industrial and agricultural waste. When this is the case, expanding the boundaries of the system of waste flows considered in the design of the plant may result in significant economies of scale and revenues that may offset parts of the costs of waste and wastewater treatment.

The feasibility studies have highlighted that often wastewater tariffs are rather low even by standards of middle income countries; however, the large variation of income within countries and, particularly, between urban and rural areas may give rise to affordability issues. Both the adoption of decentralized, nature-based solutions and the integration of wastewater sludge and organic waste treatment may improve the financial sustainability and affordability of the service.

Generally speaking, the involvement of stakeholders in a "synthesis centre" is expected to bear a potential to stimulate the invention of more integrative solutions for affordable and cost-effective wastewater treatment. While this was achieved only to a limited extent in this study, efforts should be devoted to a broader involvement of stakeholders in the future, in order to unleash this potential.

Related and future JRC work

This study is part of a line of JRC activities in support to the Danube macroregional strategy, under the JRC "Water-Energy-Food-Ecosystems Nexus" project. The Danube river basin is a test bed for transboundary river basin management in Europe, and may provide indications to be transferred to other contexts in the European Union and beyond.

Quick guide

This report is organized as follows:

- Section 1 introduces the context and the issue of wastewater treatment in the Danube.

- Sections 2 and 3 present the Slovenian and the Serbian feasibility study, respectively; in both cases, we quickly describe the context and challenges that the synthesis centre was set up to address.

- Section 4 summarizes the solutions explored in the two feasibility studies, and provides parametric estimations of their costs and effectiveness. These could be used for an appraisal of other similar situations in the Danube.

- Section 5 discusses the respective contexts of Bosnia and Herzegovina, Bulgaria, Croatia, Moldova, Montenegro, Romania and Ukraine in the perspective of applying the proposed solutions in each specific context, based on the test cases analysed therein.

- Section 6 summarizes the findings of the study and take-home messages.

1 Introduction

The Danube River is mighty. It flows across a vast territory in Central and Eastern Europe, connecting several large cities, diverse populations, languages and cultures. About 80 million people make their living in the river basin, and use water as a means of transport, a raw material, a process fluid; they drink it, use it to irrigate, to generate electricity. And yes, they discharge water after use, enriched with nutrients, chemicals and organic matter. The Danube collects used waters and mixes them up with its generous discharge fed by glaciers in the Alps as well as aquifers in the plains. No single discharge of urban wastewater, not even from a whole city, is more than an itching spot on the muscly back of this majestic water body: it is diluted 1000, 10,000 times in the Danube's waters, and quickly forgotten downstream. But when you count them all together, discharges along its run still load the Danube with significant pollution. Moreover, the dilution capacity of tributaries may be much weaker compared with the main river, exposing them to more dangerous threats. Pollution from urban wastewater is painful for everybody: not even the Danube can afford to ignore it.

1.1 Wastewater is a problem

Improperly collected wastewater is a local threat to human health and the environment. When collected but untreated (or poorly treated), wastewater is a key problem in certain Danube countries. In the European Union (EU), appropriate treatment of urban wastewater has been mandatory for many years on the basis of Council Directive 91/271/EEC. However, many Danube countries have accessed the EU between 2004 and 2013, and have considerable delays in the implementation of this Directive. The Danube river basin management plan highlights a clear divide between Upper Danube countries, with average emissions of less than 1 kg of organic matter (biological oxygen demand – BOD) per person-equivalent (PE) per year, and the other countries, with emissions four times as high or more. The divide corresponds neatly to a gap in economic conditions (expressed by gross domestic product, GDP, per capita) between EU and Organization for Economic Cooperation and Development (OECD) member countries, non-OECD EU member countries and non-EU countries (Figure 1). Slovenia, an OECD member of the EU with relatively high GDP, has significantly higher emissions than its peers due to the important share of emissions from rural areas and small settlements, undergoing less stringent treatment.

The weaker economic conditions of the Lower Danube countries, compared to the Upper Danube, significantly affect their capacity to implement wastewater treatment (WWT). Funding and financing are more difficult, as they depend to a large extent on transfers, often from EU funds. Tariffs also tend to cover a lower share of the costs, in part because of the population's lower ability to pay. Usually, "water poverty" is identified as a condition where the cost of water (including water supply, sanitation and treatment) exceeds a small percentage of the disposable income. Assuming this to be, for the sake of illustration, 3%, Figure 2 shows[3] that, while on average tariffs could be close to 2 Euro/m^3 or higher in all countries, the 10% poorest people could only afford between 0.5 and 1 Euro/m^3, with reference to the whole water cycle (hence about half as much for sanitation and treatment alone). Without a careful design of tariffs, considerate of the conditions of the poor, in many countries it may be difficult to pay for the cost of WWT. Even when considering average incomes, people in countries such as Romania, Bulgaria and Serbia are not likely to be able to pay more than 2.5 Euro/m^3 for the whole water cycle, i.e. slightly more than 1 Euro/m^3 for WWT alone. Low tariffs trigger a vicious circle, as they hinder further investments and prevent the recovery of water quality, in turn causing loss of attractiveness of the environment, and ultimately further impoverishment. Is there a way to achieve satisfactory WWT throughout the whole Danube region, without impinging on the living of the poorest part of the basin's population?

[3] Assuming a water use of 120 L/PE/day, the theoretical tariff is computed as $T=0.03 \times Income / (0.120 \times 365)$, with Income in Euro/capita/year.

Figure 1. GDP and pollution are inversely related in the Danube. Source: our mark-up on Figure 10 and Figure 44 in ICPDR, 2015. The cases of Slovenia and Serbia are highlighted, as they are the subject of feasibility studies presented below.

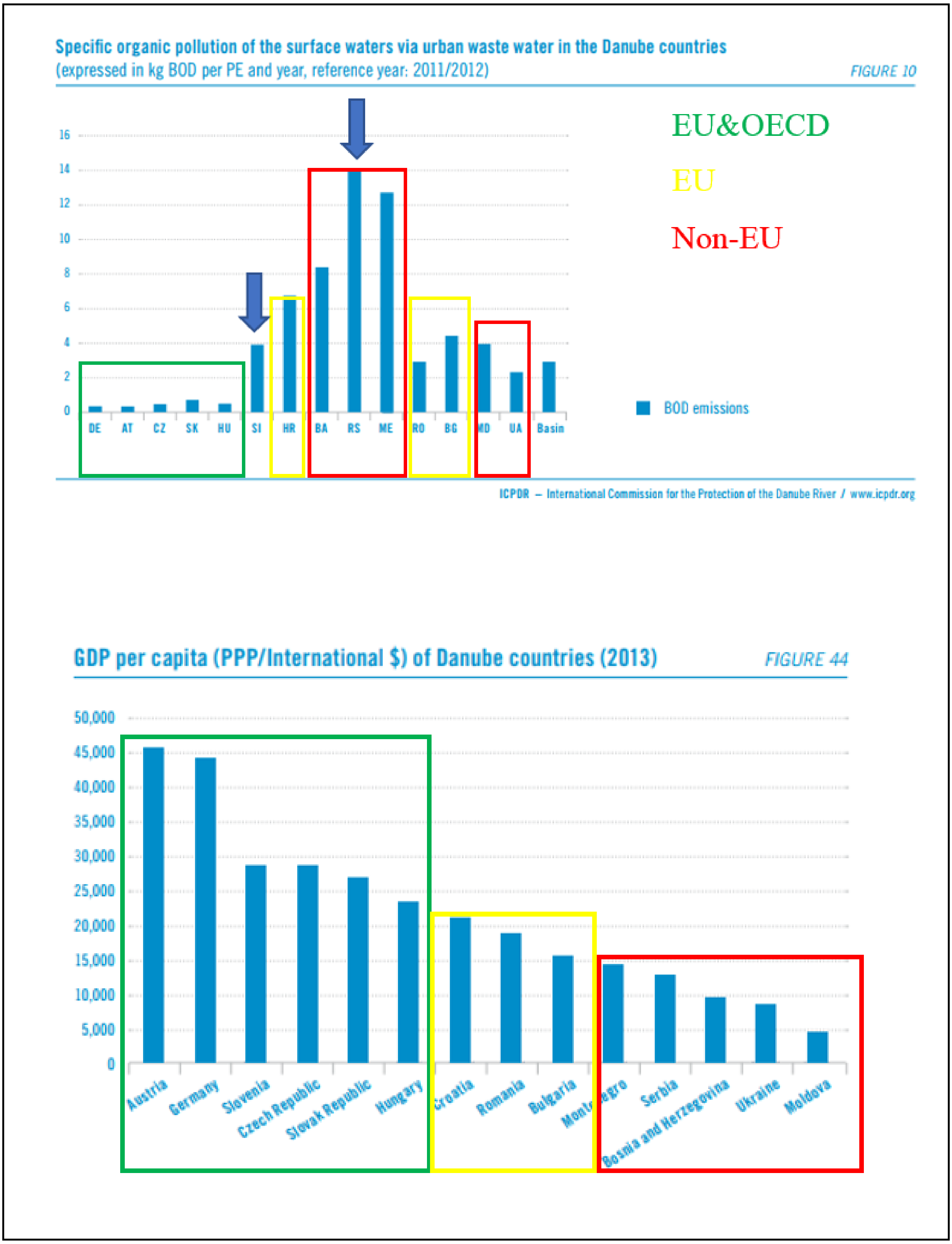
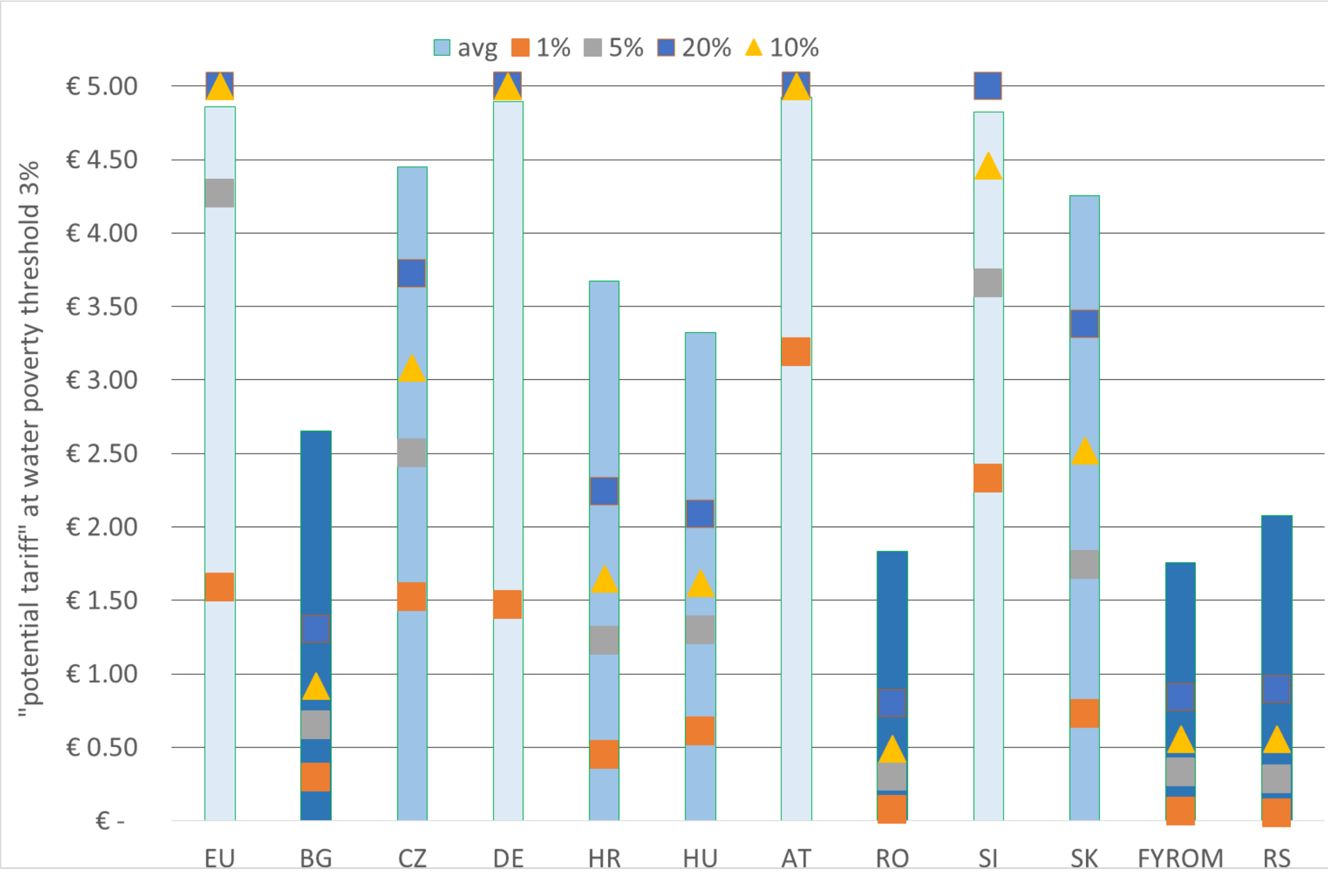


Figure 2. Theoretical tariff corresponding to 3% of disposable income for selected Lower Danube countries[4], considering the average income of the population as well as the income of the 1%, 5%, 10% and 20% poorest. Tariffs are constrained to not exceed €5/m^3. Based on EuroStat (2016 data) http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ilc_di01&lang=en



A case of special interest in the lower Danube is that of small rural settlements. Usually, these are the most expensive to connect due to the distance from central WWTPs, but at the same time they tend to have older and poorer residents.

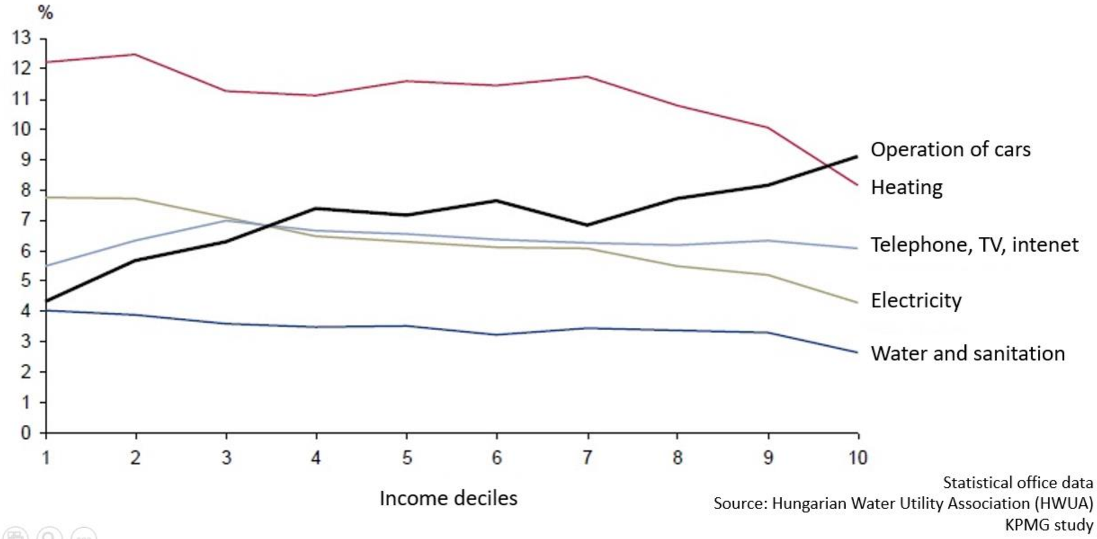
1.2 Conventional solutions are usually expensive

Typically, WWT is designed in the form of large central plants, often with activated sludge (AS) processes (see § 3.2.1), for the larger agglomerations. For smaller agglomerations and scattered settlements in rural areas, decentralised alternatives to large central plants usually consist of high-technology, smaller-scale plants such as sequencing batch reactors (SBR) or membrane bio-reactors (MBR) as described in § 2.2.1. While these solutions are technologically well-established and have proved to work well, they require energy and maintenance for operation. Moreover, large centralized plants usually occupy land, which may be expensive to buy and may be conflicting with other land uses in the vicinity. Finally, the delivery of wastewater to centralized plants entails a potentially long, and usually very expensive, network of sewers. Even in relatively small agglomerations, this may account for the lion's share of the investments.

Yet, in many cases, water and sanitation are not among the heaviest costs borne by families. For instance, in Hungary (a country with relatively high water tariffs in the Danube region), water and sanitation cost about a half of the operation of cars, electricity and telecommunications, and one third of heating (**Figure 3**).

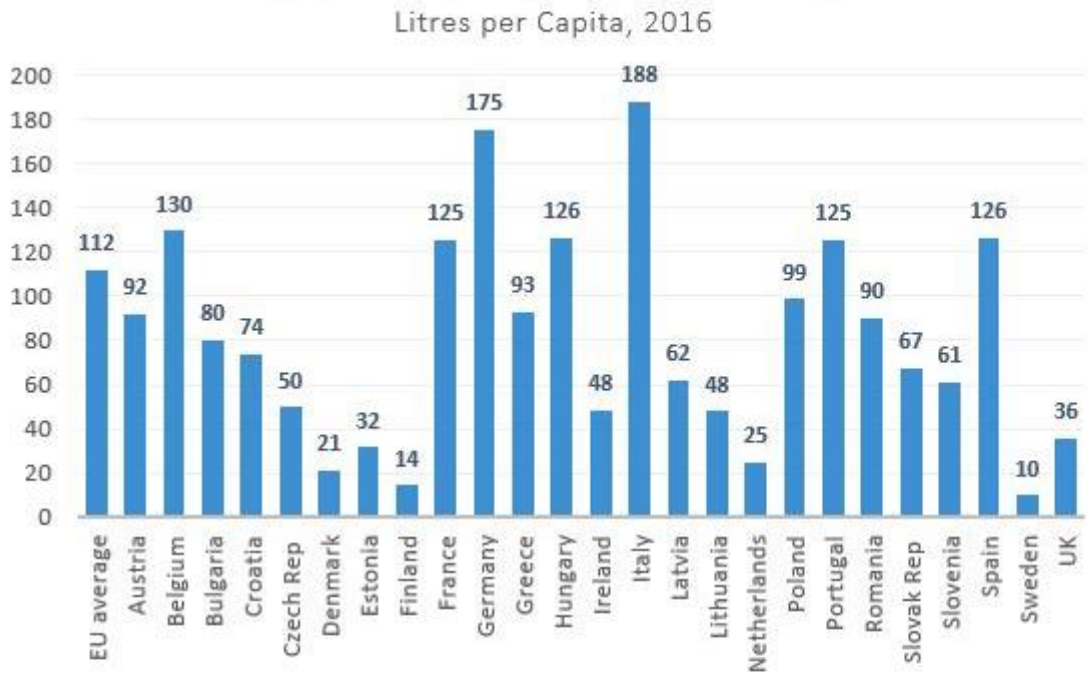
[4] EU= European Union average; BG=Bulgaria; CZ=Czech Rep.; DE=Germany; HR=Croatia; HU=Hungary; AT=Austria; RO=Romania; SI=Slovenia; SK=Slovakia; FYROM=Former Yugoslav Republic of Macedonia; RS=Serbia.

Figure 3 – incidence of costs on household disposable income (%) for different utilities in Hungary, 2012. Courtesy K.Kovacs (EWA).



With tariffs fully covering the costs of good quality water supply and sanitation (e.g. 3 Euro/m3), a water consumption of 120 litres per capita and day would cost about 130 Euro/year per capita. Bottled water, in contrast, may cost 0.3 Euro/litre or more. In Europe, the average consumption of bottled water is 112 litres per capita yearly, with Croatia at 74, Bulgaria at 80, Romania at 90, Slovenia at 61, and Hungary at 126 (**Figure 4**): hence bottled water would correspond to 15%, 17%, 14%, 12%, and 24% of the annual expenditure in tap water in these five countries, respectively. Underfunded water services limit investments, when not even operation and maintenance, hence tariffs kept artificially low on average to protect the poor threaten to make public water less and less reliable and, in the long term, might push more people to use e.g. bottled water for drinking, with significant economic impacts on households (not to mention the environmental impacts).

Figure 4 – consumption of bottled water in EU countries, 2016 (source: http://www.efbw.org/fileadmin/user_upload/images/Per_capita_consumption_2016_01.JPG)



When households can actually pay for water services, covering the real costs of the services can be seen, in the long run, as a way to ensure better conditions for the whole population: higher costs for water services, if still affordable, may generate benefits for the people over the whole life of the investment.

WWT requires significant investment and operation and maintenance (O&M) costs, and in the long term the full costs have to be covered in some way, in order to ensure quality and sustainability of this essential service. Moreover, the recovery of costs should not hamper an equitable access to the service, hence affordability should be ensured together with financial sustainability. While one possibility is to use tax revenues to allow subsidized water prices for all users, tariffs covering the real costs of water can be preferable in many situations. In order for such tariffs to be fair, they should be as low as possible, and flexible enough to allow economically disadvantaged users a fair access to the water service. Costs can be reduced by making water services efficient, and offset by additional revenues from WWT operation, particularly by selling energy and other resources recovered from the treatment processes. Lower costs and additional revenues may help in the design of tariffs which match the capacity to pay of different categories of users.

1.3 Can wastewater treatment be sustainable business?

WWT can be traditionally paid through tariffs, transfers and taxes (the "three Ts": OECD, 2009). Tariffs correspond to the users of the service paying (part of) the WWT costs on a use-proportional basis. Tariffs correspond to payments on a per-use basis, ground on the conception of water supply and sanitation as a service users should pay for. Taxes correspond to the general budget of the government (local or national) covering (part of) these costs. Users are consequently freed from (a part of) the burden to pay for the service. The rationale of covering WWT from the general budget is in the need to ensure WWT even when there is insufficient ability to pay by the users, water being deemed an essential service. The Water Framework Directive (WFD) 60/2000/EC, while introducing the general principle of the recovery of costs of the water services, allows flexibility in its application, considering the social, environmental and economic effects of recovery (art. 9(1)).

Transfers are payments for WWT made by parties third to the government and users. The rationale of transfers is in the need to foster the achievement of uniform application of WWT standards in a region, such as a river basin, beyond political borders. Transfers are an essential instrument for the achievement of the United Nations Sustainable Development Goals (SDGs), and are particularly important as a solidarity mechanism in the perspective of EU cohesion.

In principle, WWT can be sustainable business if the payments through the "three Ts" are certain. Indeed, it has represented an attractive market for industrial companies in the water sector, often based on taxes and transfers more than tariffs, although fuelled by adequate tariffs, particularly in Upper Danube countries[5]. However, there have been increasing difficulties with all "three Ts" in recent times: increasing tariffs alone may pose a risk of exposing the most vulnerable social groups to "water poverty"; government budgets are all the more under pressure during economic crises, making it difficult to invest taxpayers' money in WWT; and transfers may be less certain in a context of weakened global multilateralism and regional (including within-EU) cooperation.

This may mean for WWT a need to harness all possible opportunities to increase efficiency and revenues, in order to remain sustainable business. Opportunities include recovering the energy and resource content in wastewater and sludge along the process of WWT, and integrating WWT with other compatible industrial processes, in order to seize economies of scale and synergies. Other opportunities lay with the potential of certain nature-based (or nature–inspired) WWT solutions to deliver additional benefits in terms of human well-being, biodiversity and landscape quality.

[5] For an overview in the Danube river basin, see World Bank and IAWD, 2015

In this work, we assume that WWT will remain fundamentally a service, and will not turn into a market-oriented industrial production activity. This means the sale of commodities (such as energy or fertilizers) will not become the core business of the WWT operators, who continue to rely on receiving payments for their service as their key source of revenues. We aim at exploring ways to create enabling conditions to couple the WWT service with resource recovery and distribution. Technologies exist for a large part (without ignoring existing gaps and challenges), but difficulties arise when matching resource demand and supply, as well as with regulatory, governance, management (including relationships with stakeholders), and cultural barriers, also related to the history of the region. The sustainability of the WWT business may therefore benefit from the integration of a whole ecosystem of stakeholders and actors around a treatment plant.

1.4 Can wastewater treatment help communities and the economy?

How can such integration happen in practice? While technical knowledge is relatively well consolidated, our understanding of the enabling conditions is still rather fragmented. Appropriate WWT solutions may improve the landscape and the water quality of rivers and lakes, and consequently support tourism or recreation activities. They can make water available for reuse to stimulate agricultural production, particularly in dry areas and during droughts. They may provide nutrients at lower cost and lower environmental impact than mineral fertilizers. They may produce excess electricity and heat to be sold on the market e.g. for greenhouse or district heating, swimming pools, or to be fed into the grid. They may be expanded to include additional processes, such as municipal organic waste digestion. Insofar as WWT may deliver such broader public benefits, there is a need to facilitate the search for a solution that is collectively beneficial.

However, initiatives must be planned in order to actually seize these opportunities. Such initiatives presuppose the capacity of actors such as WWT and industrial operators, local communities, government and WWT service users to gather and find arrangements for their collective and reciprocal benefit, exploiting one industry's waste as input to another's processes in the spirit of "industrial ecology" (Frosch and Gallopoulos, 1989). If such a capacity has not yet been experienced, it can be stimulated by creating occasions of dialogue and participation among the many stakeholders around WWT. The various stakeholders may not have all the information about the technical solutions and their costs and benefits.

It is now broadly recognized that research questions in environmental science should be driven by societal needs, and should be co-developed by social and biophysical scientists working closely together with those who apply scientific knowledge in decision-making. The latter include in particular land planners and environmental managers. Co-development of scientific knowledge, problem solving and innovation is the "synthetic approach" to research, whereby scientific knowledge acts as the seed of innovation in processes, services and products, at the same time abandoning a technocratic *hubris* and taking a "bottom-up" perspective. Such an approach requires "synthesis centres" to be active and operate in a specific context[6]. By "synthesis centre" we do not refer to a formalized institution, but only to the *ad hoc* gathering of stakeholders, service operators, government and the local community around the problem to be solved.

"Synthesis centres" should be able to activate a discussion on the organization of WWT, not just as a technically sound and socio-economically acceptable solution, but explicitly seeking to maximize resource recovery, the reduction of costs, and the environmental co-benefits of innovative processes and technologies. If they proved effective, they could be identified as a good practice to be generalized in Europe, and particularly in the Danube

[6] A clear description of the synthetic approach to research is provided in the web page of the US National socio-environmental synthesis centre – SESYNC (http://www.sesync.org/about). While "synthesis centres" usually indicates specific and formal applied research organizations, in this report we use the expression to denote an ad-hoc activity of putting together problem owners and solution providers taking all together a synthetic approach.

region, in order to fully seize the potential of environmental policy to stimulate jobs, growth and investments through innovative business models. The construction and operation of a WWT plant always entails investments, jobs (although some could be temporary) and possible growth (although this effect should be evaluated in comparison with alternative investments). However, a successful synthesis centre should as a rule turn WWT into a flywheel for *additional* investments, hence jobs and growth.

In the remainder of this report, we discuss how this all may play out in the real world, by referring to examples in the Lower Danube. After this overview of opportunities associated to WWT, we examine a case in Slovenia addressing WWT in small rural settlements, and a case in Serbia addressing a large, centralized WWT plant. We then analyse how the opportunities identified in these cases may, or may not, be translated in other Danube countries. The experience gathered in these cases leads us to formulating some general conclusions and recommendations to support the implementation of WWT in the river basin.

2 Feasibility study 1 – small decentralized treatment plants in Slovenia

2.1 Context

The location of this case is the Kamniška Bistrica Catchment, in Slovenia. For its geographic and socioeconomic features the basin is representative of other regions in Slovenia and Lower Danube countries (mountainous, hilly, and flat areas with different population densities, large number of small villages and settlements having no access to treatment facility). In Slovenia, 98% of settlements have less than 2000 population equivalents (PE)[7], hosting 51% of the national population; around 2/3 of the 5.867 small settlements (<2000 PE) have no treatment facilities and discharge a significant pollution load into surface waters.

Economic activities in the area consist of agriculture, industry, and tourism. The Kamniška Bistrica catchment has an area of 530 km^2. Two ground water bodies and 4 surface water bodies have been identified in the area according to the definitions of the EU Water Framework Directive (WFD). The chosen basin includes karstic zones with no surface runoff. Settlement patterns range from mountain huts to medium size towns. From the administrative point of view, the river basin is comprised of 8 municipalities having in total 100.746 inhabitants in 2015. The industrial pollution load is estimated to be equivalent to 120.000 PE, with a broad set of industries (metallurgic, textile, pharmaceutical, chemical, food processing). The population in large agglomerations and industry is already connected to the public sewerage system, treating water to advanced levels (mostly allowing an appropriate treatment of nutrients in addition to suspended solids and organic matter). The biggest challenge in Slovenia is therefore to reduce the pollution load of small agglomerations, still lacking proper wastewater collection and treatment.

In the study area, we have selected three representative settlements not equipped with wastewater treatment and complete sewer network: Trojane (Municipality of Lukovica); Dobeno (Municipality of Mengeš); and Vrhpolje pri Moravcah (Municipality of Kamnik), with 298, 223 and 825 residents (coincident with PE in this case) respectively.

2.2 Technical solutions

We have taken into consideration a range of technical alternatives for WWT, all applicable either with some degree of centralization (collecting discharges from a number of households) or as "individual appropriate systems" (IAS) for single households or small groups of households. These include:

1) Technological systems:
    a. Membrane bioreactor (MBR)
    b. Sequencing batch reactor (SBR)
2) Constructed wetlands (CW)
    a. Free water surface CW (FWS CW)
    b. Horizontal subsurface flow CW (HF CW)
    c. Vertical subsurface flow CW (VF CW)
    d. Hybrid constructed wetlands (HCW)
3) Enhanced constructed wetlands
    a. Forced-bed aeration (FBA)
    b. French reed bed (FRB)

[7] PE is a practical unit of measure of pollution. An amount of PE can be interpreted as the number of persons that would cause a given amount of pollutant load.

4) Resource-oriented solutions
   a. Algae bioreactors
   b. Evaporative willow systems (EWS)
   c. HF CW with water reuse
   d. VF CW with water reuse.

In the above list, the alternatives shown as underlined are suitable as IAS, while the others require a certain degree of centralization. The technical solutions are briefly described hereafter.

2.2.1 **Technological systems**

MBR and SBR are plant configurations that include processes similar to the larger, centralized treatment plants, but present a more compact design thanks to specific modifications.

In an MBR membranes are designed and operated in small spaces to eliminate contaminants such as nitrogen, phosphorus, bacteria, biochemical oxygen demand (BOD), and total suspended solids (TSS) with high removal efficiency. The MBR is suited for municipal, industrial, and commercial applications.

In an SBR, all the treatment phases to remove pollutants, usually occurring in different tanks in a centralized plant, are designed to occur in a single tank fed by pulses of wastewater. This system has been successfully used to treat low or intermittent flows of municipal and industrial wastewater. **Table 1** shows a comparison of the relative advantages and disadvantages of SBR and MBR.

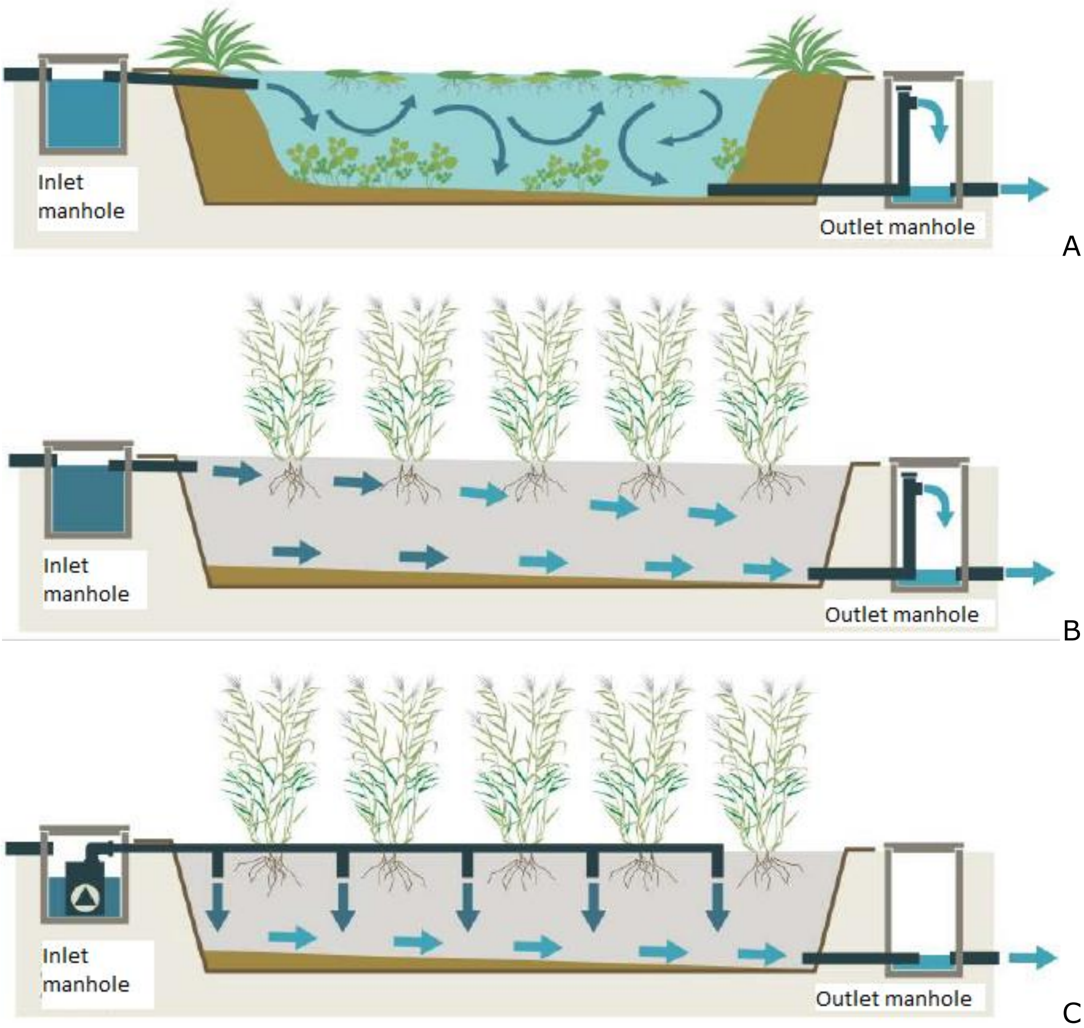
Table 1. comparison of SBR and MBR technologies. Source: EPA, 1999

Technology	Advantages	Disadvantages
SBR	Equalization, primary clarification, biological treatment, & secondary treatment in one single batch Operating flexibility and control Lower area footprint compared to CW and MBR Potential capital cost saving for extra equipment	More complex control is required for larger units Higher level of maintenance Risk of accidental release of sludge if not properly designed/operated Potential clogging of aeration devices during selected operating cycles Potential need for accumulation of the treated effluent
MBR	Better effluent quality, smaller space required, ease of automation Lower sludge production High-quality treated effluent , also for reuse in irrigation Lower area footprint than CW, but usually more than SBR	Higher capital/operating costs due to membranes. Need of chemical flocculants to produce settling of biosolids acceptable for disposal

2.2.2 **Constructed wetlands (CW)**

Constructed wetlands are engineered ponds with or without a filling of porous material (such as gravel or sand), where pollutants may be degraded by processes similar to those occurring in natural wetlands. In this section, we briefly describe the main typologies of CW usually implemented for wastewater treatment. The concepts of FWS, HF and VF CW are illustrated in Figure 5. Their respective advantages and disadvantages are presented in Table 2. When justified, HF and VF CW can be combined into "hybrid CW", where the two systems provide complementary processes in WWT.

Figure 5. Cross-sections of constructed wetlands with free surface (A), subsurface horizontal (B), and vertical (C) Flow. Source: original artwork by IRIDRA srl.



2.2.2.1 Free water surface (FWS)

This type of CW consists of basins or channels where the water surface is exposed to the atmosphere and the soil, constantly submerged, constitutes the support for the roots of the emerged and submerged plants; in these systems the water flow is horizontal and the water depth is generally limited to a few tens of centimetres (Kadlec and Wallace, 2009). Most natural wetlands are FWS systems, including bogs (where the primary vegetation is mosses), swamps (where the primary vegetation is trees), and marshes (where the primary vegetation is grasses and emergent macrophytes). The most commonly used emergent vegetation in constructed FWS wetlands includes cattail, bulrush and reeds.

2.2.2.2 Horizontal subsurface flow (HF)

These CW are one of the most diffused CW schemes, due to their simplicity and successful application for different types of wastewater such as municipal, industrial, agricultural, and stormwater runoff (Vymazal and Kropfelova, 2008; Vymazal, 2009). HF wetlands consist of inert materials such as gravel beds planted with wetland vegetation. *Phragmites australis* (reed) and *Typha latifolia* (bulrush) are common plant species used. The basin is excavated and covered with plastic liners, and sometimes concrete. The wastewater is intended to stay beneath the surface of the gravel bed and flows through the roots and rhizomes of the plants while the inert material is maintained saturated by water. The plant root system helps create aerobic, anaerobic, and anoxic zones which are beneficial to the development of highly diverse microbial populations, which increase the rate of purification from pollutants and pathogens. As the water within the process is not directly exposed to the air, the risk of pathogenic exposure of humans and wildlife is low, making this scheme suitable for being adopted in urban areas (Kadlec and Wallace, 2009).

2.2.2.3 Vertical subsurface flow (VF)

These CW are different from HF wetland in terms of the feeding of wastewater, the flow direction and the inert material used. The wastewater is fed through the main bed in discontinuous flow from pumps or self-priming siphons and infiltrates vertically within the inert material.

In HF wetlands the bed is usually saturated with water, hence it receives limited oxygen, reducing its ability to remove ammonia. VF wetlands, with an intermittent feeding system, allow the transfer of large quantities of oxygen inside the main bed filled with coarse sand (Nivala et al., 2013). The high oxygen content is suitable for the removal of organic matter and oxidation of ammonia to nitrates. Moreover, the hydraulic retention time (HRT) of VF wetlands (a few hours) is much faster than in the case of HF wetlands (generally a few days), allowing smaller area requirements. In these CW there is a possibility of phosphorous removal, while the removal of nitrates (denitrification) is limited. However, denitrification in VF systems can be improved by implementing a saturated layer at the bottom of the VF bed (Silveira et al. 2015). The capacity of VF wetlands to oxidize ammonia has led them to be applied in the treatment of wastewater with ammonia concentration higher than from the municipal or domestic sectors. This configuration is used e.g. for landfill leachate and food processing wastewater, which can be very high in ammonia (Kadlec & Wallace, 2009).

Table 2. Comparison of HF and VF CW

Technology	Advantages	Disadvantages
HF CW	Low operation and maintenance – process stability The system can be built and repaired with locally available materials and local workforce No chemicals required No energy in case of possible gravity feeding Efficient removal of suspended and dissolved organic matter, and pathogens It requires less space than a free-water surface constructed wetland No issues of mosquito proliferation as compared to free-water surface constructed wetlands	Larger land area requirement compared to MBR/SBR Relatively high capital costs Pre-treatment is required to prevent clogging Limited nitrification and P removal
VF CW	Low operation and maintenance – process stability It can be built and repaired with locally available materials	Larger land area permanently required in comparison to MBR/SBR

Technology	Advantages	Disadvantages
	Utilisation of natural processes No chemical required; no energy input required when fed by gravity Efficient removal of suspended and dissolved organic matter, ammonia (nitrification) and pathogens Lower land area requirement than a free-water surface constructed wetland High reduction in BOD, suspended solids and pathogens It does not present issues with mosquito proliferation as compared to free-water surface constructed wetlands Lower footprint in comparison to HF and free-water surface constructed wetlands (but higher in comparison to intensified CWs, such as aerated CWs)	Moderate capital cost depending on land, liner, fill, etc.; low operating costs Pre-treatment is required to prevent clogging Feeding system requires more complex engineering (and therefore higher O&M) in comparison to gravity-fed HF Limited denitrification
FWS CW	Low operation and maintenance – process stability It can be built and repaired with locally available materials Co-benefits of wetlands: biodiversity and natural value	It requires larger land area than HF and VF Moderate capital cost depending on land, liner, fill, etc.; low operating costs Pre-treatment is required More risks of odour issues Limited nitrification

2.2.2.4 Enhanced constructed wetlands[8]

The so-called French reed bed (FRB) is a specific CW solution which receives untreated raw wastewater. Therefore, its main advantage is that it does not require the primary treatment system (septic tank or Imhoff tank – Molle et al., 2005).

The FRB is a two-stage system: in the 1st stage a VF coarse gravel bed receives raw wastewater; the 2nd stage is another VF coarse sand bed. The solid materials from wastewater will create an organic top layer on the surface area of the 1st stage, which has to be removed after 10-15 years, i.e. when it is already stabilised and can be used as a soil conditioner (Molle et al. 2006). The system does not generate odour issues due to the fact that the sludge formed on the surface of the wetland is kept under constant aerobic conditions by the feeding method and the active rhizosphere growing in it. FRBs are being successfully applied in France, where more than 4000 treatment plants are now in operation, which has allowed gaining a deep understanding of this particular configuration (Paing et al., 2015). Moreover, FRBs have been also successfully applied in Moldova for an agglomeration of about 20,000 PE (Masi et al., 2017; see §5.1.4).

Aerated wetlands (patented Forced Bed Aeration™ - FBA) are "intensified CWs" where mechanical insufflation of air improves treatment performance and reduces the area footprint (Wu et al., 2014). FBA consist of one or more basins with horizontal or vertical flow and are usually applied as secondary treatment after the primary treatment (usually gravity settling). A coarse-bubble aeration network is placed under the gravel substrate of a sub-surface flow wetland, allowing a more efficient removal of organic contaminants and ammonia due to the higher availability of oxygen. This system is ideal for treating

[8] The text in this section is partly taken from Rizzo A., et al.: Water 2018, 10, 156; doi:10.3390/w10020156.

wastewater with high organic loads of BOD and chemical oxygen demand (COD) with minimal area footprint (Masi and Bresciani, 2013). FBA CW are suited for effluents high in ammonia (e.g. slurry from livestock, digestate) and for highly polluted water e.g. from contaminated sites, mining drainage, or airports (Nivala et al., 2013). **Table 3** summarizes advantages and disadvantages of FRB and FBA solutions.

Table 3. Comparison of FRB and FBA.

Technology	Advantages	Disadvantages
FRB	Among the nature-based options considered, this has the lowest operation and maintenance costs (no primary treatment – no yearly sludge disposal) The system can be built and repaired with locally available materials and local workforce Lower area footprint in comparison to HF and free-water surface constructed wetland (but higher in comparison to intensified CWs, such as aerated CWs)	Permanent higher space required in comparison to technological solutions Moderate capital cost depending on land, liner, fill, etc.; low operating costs Feeding system requires more complex engineering (and therefore higher O&M) in comparison to gravity-fed HF Limited denitrification
FBA	Minimization of area required for CW solutions Operation and maintenance costs lower than with technological solutions – process stability It can be built and repaired with locally available materials Utilisation of natural processes No chemical, construction and repair with local materials and local labourers Efficient removal of suspended and dissolved organic matter, and pathogens High reduction in BOD, suspended solids and pathogens Efficient nitrification	Larger land area permanently required in comparison to technological solutions, but of the same order of magnitude The system requires higher energy input than classical CWs, but lower than technological solutions Moderate capital cost depending on land, liner, fill, etc.; moderate operating costs Feeding system requires more complex engineering (and therefore higher O&M costs) in comparison to gravity-fed HF Aeration system requires more complex engineering (and therefore higher O&M costs) in comparison to classical CWs Pre-treatment required Limited denitrification

2.2.3 **Resource-oriented solutions**

EWS and algal bioreactors are solutions where the pollutants contained in wastewater are supplied as nutrients to biological systems capable of taking them up, thus releasing clean water or (in the case of EWS) transpiring it to the atmosphere. Table 4 summarizes advantages and disadvantages of EWS and algal bioreactors.

Besides algae bioreactors and EWS, another resource recovery solution is obviously the reuse of treated wastewater for irrigation. This entails essentially disinfection of the treated effluent, and a system of irrigation with as high efficiency as possible (e.g. drip irrigation). Reuse is studied in our case in conjunction with CW systems.

2.2.3.1 Evapo-transpirative willow systems (EWS)

These enable wastewater treatment and recycling of water and nutrients through the willow biomass harvest. They are most appropriate for on-site treatment of domestic wastewaters from single households or very small settlements where requirements for wastewater discharge are strict or where soil infiltration is not possible. Due to the zero discharge characteristic of EWS, they provide efficient protection of aquatic environments in sensitive areas, such as karst areas. EWS are also attractive for users interested in biomass production for energy use (e.g. for house heating). EWS consist of an impermeable bed with no outflow, where all the water is used for plant growth and evaporation into the atmosphere during the warm and hot season, and working as a sponge for the cold periods.

2.2.3.2 Algae-bacterial treatment plants

These consume nutrients (nitrogen and phosphorus), and CO2 for the growth of algae and the production of oxygen. The resulting oxygen promotes the growth and function of synergic bacteria that consume organic matter from wastewater and produce CO2 further used by the algae. The final products are treated wastewater, nutrients, algae biomass, active substances from algae, etc. These products can be used as bio-fertilizers or as a substrate for the production of biogas, or can be processed in biorefineries.

Table 4. Comparison of algae bioreactors and EWS.

Technology	**Advantages**	**Disadvantages**
Algae bioreactors	Simultaneous wastewater treatment and resource recovery Quick biomass production without lignin Algae biomass production usable as bio-fertilizers or for biogas production Sink of CO2, O2 production	Higher area footprint in comparison with technological solutions and of the same order of magnitude of that requested by classical CWs pH control by CO2 Higher cost for algae cultivation in comparison with CW, willow system Requires energy input, glasshouse Algae separation/harvest Novel technology with few data on long-term functioning
EWS	Simultaneous wastewater treatment and resource recovery of water and nutrients for irrigation Appropriate for sensitive areas – regarding effluent quality Close-loop treatment – no discharge Biomass production	Salinity control – high values can decrease water uptake by willows Higher area footprint in comparison to CWs Annual evapotranspiration must be higher than annual rainfall amount Application is limited to areas with biomass production demand

2.3 The "synthesis centre"

The above technical solutions were examined with specific reference to the case, and a pre-quantification of the costs to achieve appropriate WWT levels was conducted for all relevant alternatives. The alternatives were then compared in a multi-criteria analysis, using the socioeconomic, technical and environmental criteria listed in Table 5. Indicators for all criteria were identified and quantified, enabling a comparison of the alternatives.

The criteria in **Table 5** were weighted both by experts and by a panel of stakeholders convened in ad hoc meetings, yielding scores that reflect the relative preferences for the different alternatives (**Table 6**). The stakeholders represented were the municipality, water utilities, the Slovenian Environmental Agency, the International Laboratory of Health Environment and Food (interested in the reuse of treated effluents from the resource-oriented alternatives), the Slovenian Chamber of Engineers, the Sava River Basin Commission, the Slovenian Water Science Institute and the University of Ljubljana.

Table 5. Evaluation criteria for the WWT solutions in the Slovenian case.

Criteria	Indicators
Costs	Capital expenditure (CAPEX) - includes land acquisition and works
	Operational expenditure (OPEX)
	Avoided costs (e.g., avoided fertilisers due to nutrient reuse)
Social acceptability	Level of satisfaction of the local people regarding existing plants
	Contribution to local employment
	Compatibility with technical norms in place
Technical issues	Simplicity of maintenance
	Extra management requirements (for nutrient recovery)
	Robustness (risk of failure and capacity of the system to work properly in case of a problem)
Ecosystem services	Integration in the landscape
	Nutrient recovery (N, P)
	Support to biodiversity
	Greenhouse gas emissions

Table 6. Scores of the alternatives in the Slovenian case

Alternative	**Individual plant (IAS) or plant serving a whole agglomeration (Agg)**	**Mean score according to stakeholders**	**Mean score according to experts**
MBR	**Agg**	**0.15**	**0.21**
SBR	**Agg**	**0.29**	**0.30**
FBA	**Agg**	**0.56**	**0.57**
FRB	**Agg**	**0.60**	**0.59**
Hybrid CW	**Agg**	**0.57**	**0.56**
Algae bioreactors	**Agg**	**0.47**	**0.44**
HF CW	**IAS**	**0.71**	**0.70**
VF CW	**IAS**	**0.68**	**0.70**
EWS	**IAS**	**0.65**	**0.67**
HF CW + reuse	**IAS**	**0.74**	**0.75**
VF CW + reuse	**IAS**	**0.72**	**0.74**

The multi-criteria evaluation conducted in this case highlighted a clear preference for individual systems using CW, with a positive appreciation of the reuse of treated wastewater and its nutrients to irrigate fruit trees when possible. The preferences of the stakeholders do not distinguish among the various types of CW solutions (horizontal or vertical flow) considered. In this case the high costs of the sewer network (due to the karstic and hilly terrain of the study area) have weighted in favour of decentralized solutions. It cannot be excluded that a community could prefer to be served by a centralized system, in the presence of conditions allowing lower costs of the sewers.

It should be also noted that small SBR for individual households are presently a common solution in rural Slovenia. SBR shows advantages under certain practical conditions, e.g. when space is limited. However, operating this type of plants requires relatively high technical skills, hence it implies significant costs and management complexity. A decentralized approach offers real advantages – economic, social and environmental – particularly when very robust, low maintenance technologies are used.

2.4 The proposed solution and business model

Based on the outcomes of the multi-criteria analysis, four alternatives were selected for more in-depth comparison, taking into account the same criteria, but using a more detailed assessment of costs and technical aspects. These alternatives were the FRB for agglomerations and HF CW without and with water reuse as an individual appropriate system (IAS). In addition, the SBR was evaluated specifically as an IAS, in order to check whether its relatively low score in the previous analysis could depend on this solution being proposed for agglomeration-level treatment. SBR is also an option as a IAS when space is not available for a HF CW. This more in-depth analysis confirmed that HF CW as IAS were the preferred alternative in the local context, with a positive albeit small value added perceived in the case of water reuse for irrigation of apple orchards. The contribution of treated water to the nutrient requirements of apple orchards is anyway rather limited, and irrigation was not valued very high in the ranking exercise.

The Slovenian context (relative abundance of dispersed settlements and hilly or mountainous terrain) may be favourable for the implementation of decentralized treatment systems because of a general enforcement of cost recovery for water services.

Under current conditions, all the households either connected to a centralized WWTP or served by a decentralized plant have to pay a tariff for the service to a publicly owned utility company. The utility service tariff is differentiated between users connected to a centralized WWTP, who have to pay for the full O&M cost, and those equipped with individual appropriate systems (IAS), who have to pay only for sludge treatment and the monitoring of IAS performance. In addition to the utility services, all users have to pay a state-defined "water pollution tax", which differs according to the treatment level (none, primary, secondary, tertiary). The proceeds of the water pollution tax are then used by municipalities to invest in wastewater collection and treatment services. This setup allows a reasonable coverage of costs and puts all users on equal grounds in front of the obligation to adequately treat wastewater. At the same time, it allows a flexible approach, so that the choice between centralized and decentralized treatment does not have significant financial impacts on households, and is eventually driven by technical and economic considerations. The tariffs currently applied in the area for centralized systems slightly exceed 0.5 Euro/m3; together with some fixed costs, they raise a bill per household of around 150 euro/year, or an equivalent levelized cost[9] of about 0.8 Euro/m3.

The net present value (NPV) of investment, land acquisition and operation for the preferred solution (CW) and for the most expensive solution (MBR) are summarized for the three representative settlements in **Table 7**, together with the levelized cost of water treatment for CW. The "water pollution tax" allows municipalities to provide subsidies to households for investments in wastewater treatment. The amount of subsidies is usually around 1000 euro per household, and depends on the decision of the municipality. Moreover, a dedicated credit line ("Eco-Fund"[10]) is made available to further support household investments in wastewater treatment. This facilitates investments, while the subsidies from the "water

[9] "Levelized cost" is the net present value (NPV) of the unit cost of a product over the time of operation of its generating asset.
[10] https://www.ekosklad.si

pollution tax" would enable to cover part of the levelized cost of treatment with a "theoretical tariff after transfers", computed (assuming a contribution of 1000 euro for 4 PE) in **Table 7**. The costs of operation and maintenance (O&M) only, computed for this CW solution, are also reported for reference in the Table.

Table 7 – Comparison of the NPV of a CW and of an MBR solution, and tariffs theoretically required to finance the different alternative solutions in the analysed cases

Solution	**Dobeno**	**Vrhpolje**	**Trojane**
NPV of investment at 4% discount rate, CW (cheapest)	€ 276,000	€ 812,000	€ 302,000
NPV of investment at 4% discount rate, MBR (most expensive)	€ 960,000	€ 2,550,000	€ 965,000
Levelized cost of water treatment for CW	€ 2.01	€ 1.61	€ 1.68
Theoretical tariff after transfers	€ 1.68	€ 1.28	€ 1.35
Cost of water treatment for CW (O&M only)	€ 0.41	€ 0.38	€ 0.41

The water pollution tax currently paid by the users not having any treatment at all is about half the level that would be required to cover the total cost of the needed investments, and slightly higher than what would be needed to cover O&M costs alone. This is not encouraging households to invest in IAS. The reason for the inadequate level of water pollution tax is considered to be social, as the households living in dispersed settlements usually have lower incomes.

A possible risk of a decentralized treatment system is that, as monitoring effluent quality is often difficult for environmental authorities, the malfunctioning of plants could be very difficult to detect and manage in time. The risk is, however, considered acceptable for very simple and robust treatment systems, such as HF CW, which require very limited operation and maintenance interventions. The same does not apply to technological solutions (such as SBR) with higher management complexity.

While decentralized solutions would be financially more convenient, cross-subsidies active on the level of a local community with a single wastewater collection and treatment tariff for all users in the municipality may favour a centralized solution also on dispersed settlement areas, as its high investment and O&M costs are distributed over a larger pool of users within the community.

3 Feasibility study 2 – A large, centralized treatment plant in Serbia

3.1 Context

The study region consists of two neighbouring municipalities, Stara Pazova and Indjija, adjacent to the Danube in Serbia's autonomous province of Vojvodina. The two municipalities have a combined population of some 114,000 inhabitants, occupying an area of 736 km^2. Roughly 85% of the area is agricultural land featuring intensive crop and livestock production, and boasts a fairly developed industrial sector; agriculture and related industries (milk and meat processing) as well as manufacturing and metal processing are the main local economic activities. This area is one of the most developed regions in the country, with steady growth over the past several years. Other comparative advantages include well-developed infrastructure and transport networks, proximity to Belgrade, entrepreneurial culture, high quality soil, and spatial possibilities for further economic development.

Overall, the wastewater infrastructure in Serbia consists of 50 WWTPs and 15,159 km of sewer network (Salvetti, 2015), covering ca. 60% of the population. Out of 328 agglomerations with more than 2,000 PE, wastewater is treated in only 11% (ICPDR, 2015), in only eight optimally-operating WWTPs (JCI, 2011) (**Table 8**). Wastewater is treated mostly by secondary treatment (86% of evacuated wastewater, 32 agglomerations), while tertiary treatment is recorded in only one agglomeration (ICPDR, 2015). Rural settlements, which host 45% of the population, mainly discharge their wastewater into septic tanks, threatening groundwater, which accounts for 73% of Serbia's drinking water supply (Salvetti, 2015).

Table 8. Wastewater Treatment in Serbian Agglomerations ≥ 2,000 PE

	Number of agglomerations ≥ 2,000 PE	Agglomeration share	Share of total generated load
Wastewater treatment	36	11%	13%
Collected and evaluated	148	45%	58%
Not collected	144	44%	29%

Source: Adopted from IPCDR, 2015

The Danube River is the final recipient of all generated wastewater, either directly or through its tributaries. Serbia contributes the highest organic, phosphorus and nitrogen discharge loads in the entire Danube basin (IPCDR, 2015). High phosphorus discharges result mainly from ineffective urban water management (80%), with agriculture contributing an estimated 15% (IPCDR, 2015). Serbia's industrial sector is also a significant polluter, due mainly to inefficient or non-existing industrial wastewater treatment. Serbian industry generates the highest direct nitrogen industrial emissions in the Danube basin, accounting for 4,340 t of total nitrogen (TN) annually (IPCDR, 2015), originating mainly from the energy and chemical sectors. It is thus clear that Serbia has considerable potential to reduce its organic and nutrient pollution by restructuring its wastewater management sector.

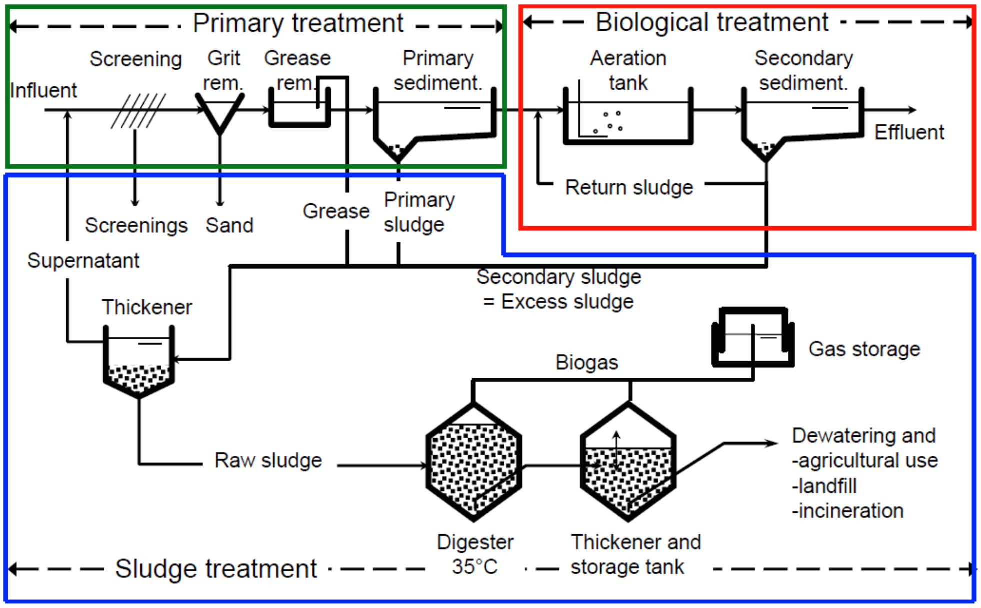
3.2 Technical solutions

The solutions explored in the CSR are different possible setups for a large, centralized WWTP with an activated sludge process (ASP), combined with different options for energy and nutrient recovery, which are briefly described below.

3.2.1 **The activated sludge process (ASP)**

The basic flow scheme of an activated sludge process (ASP) WWTP is shown in Figure 6.

Figure 6. Basic Flow Scheme of a WWTP with ASP



A WWTP based on ASP includes first preliminary treatment to remove settleable solids. In primary treatment, raw wastewater is filtered through coarse and fine screens, aerated in grit chambers with grease traps, and ends in sedimentation tanks where primary sludge is formed.

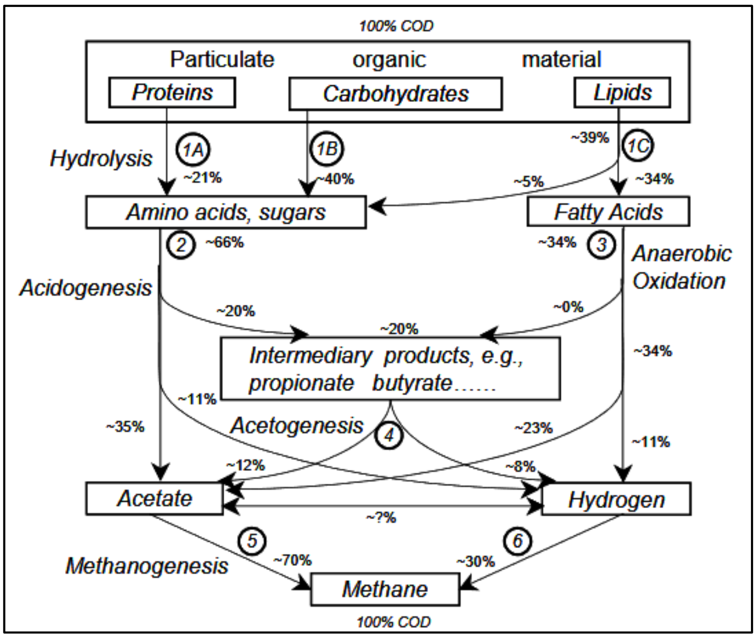
In the biological stage, wastewater passes through one (or more) aeration tank(s) in which carbon, nitrogen and phosphorus are removed by microorganisms that form flocs of biomass (the "activated sludge"). In a secondary sedimentation tank, the flocs of biomass settle, forming a secondary sludge. Part of this is recirculated to the aeration tank to continue biodegrading incoming wastewater, while the rest is combined with primary sludge, thickened and finally stabilised. This happens through digestion, very often using anaerobic processes. The final products of anaerobic digestion are biogas and digestate. Biogas can subsequently be converted into thermal and electrical energy by cogeneration; and the digestate can be used for further phosphorus (P) recovery (**Figure 8**), used as fertiliser, incinerated or landfilled.

3.2.2 **Energy recovery**

Biogas technology is based on anaerobic digestion, in which organic matter undergoes microbiological breakdown, converting it into biogas and a semi-solid digestate. Anaerobic digestion can be divided into four main stages (Figure 7), and is the result of a series of metabolic interactions among various groups of microbes.

The first stage of anaerobic digestion is hydrolysis, where complex organic molecules are broken down by fermentative bacteria into smaller molecules. Fats are decomposed into fatty acids and glycerol; proteins into amino acids; and carbohydrates into simple sugars (Kaseng *at al.*, 1992). The second stage, acidogenesis, turns the hydrolysis products into simpler organic compounds. The third stage, acetogenesis, decomposes the remaining organic compounds into simple single-carbon molecules, plus carbon dioxide and hydrogen. The fourth and final stage is methanogenesis, where methane and carbon dioxide are produced from precursors from previous phases. Methane can be eventually valorized in combined heat and power (CHP) units.

Figure 7. Scheme of Anaerobic Digestion Process. *Source: Lu, J. and Ahring, B. K., 2007*



3.2.3 **Phosphorus recovery**

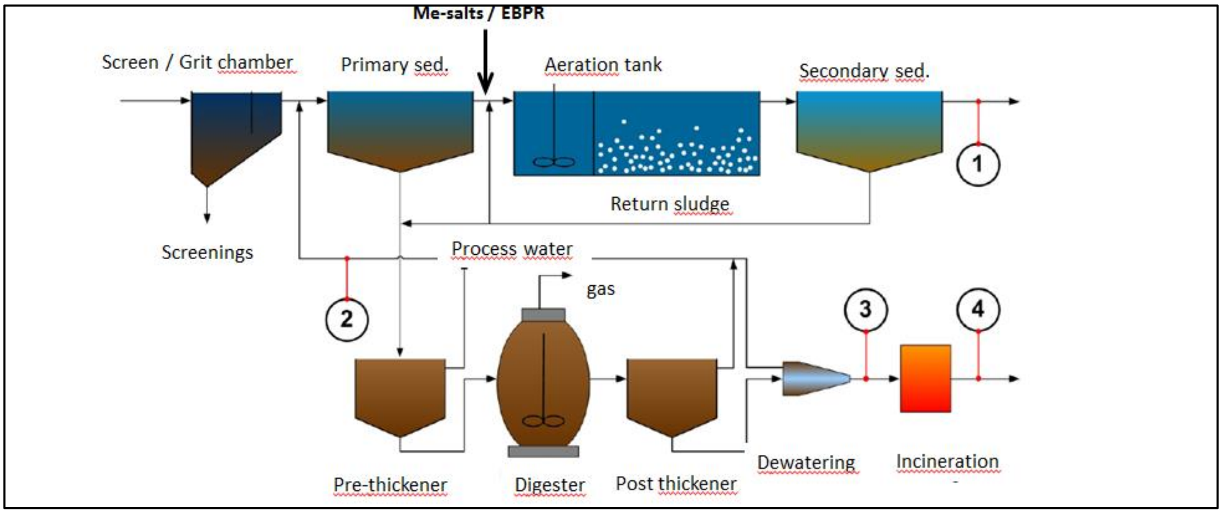
Phosphorus is an essential element and one of the main plant nutrients, in addition to nitrogen and potassium; agriculture and chemical industries cannot function without it. The majority of the world's phosphate deposits are located in just a few countries (China, USA, Morocco, Algeria and Russia), resulting in high import dependency and potential long-term insecurity for other countries.

Europe currently faces a phosphorus dependency of over 90% and, as a consequence, in 2014 the European Commission declared phosphate rock as one of the 20 critical resources for the European Union (EC, 2014). This has stimulated initiatives to develop phosphorus recovery technologies from secondary sources including municipal wastewater (Drenkova-Tuhtan et al., 2016). This is accomplished via biological and/or chemical phosphorus removal, transferring the phosphorus from the dissolved phase into the sludge. It is estimated that phosphorous recovery from wastewater could cover 15% of the European demand (P-REX, 2015). Besides the benefits for the agricultural sector and chemical industry, such a practice would reduce eutrophication of the receiving waters, in this case the Danube and Black Sea.

One possibility to recycle phosphorus is to apply stabilised sewage sludge directly on arable land. However, this practice raises issues concerning hazardous substances – especially heavy metals and micropollutants – that could enter the food chain. This is particularly a concern if numerous "indirect dischargers" (such as industries) are connected to the WWTP, since the type and amount of hazardous substances are nearly impossible to control. In practice, most European countries and regions have banned the application of sewage sludge as fertiliser.

Figure 8 illustrates the relevant wastewater treatment stages for phosphorus recovery from potential sources, including effluent, process water, dewatered sludge (digestate), and sludge ash incineration. If phosphorus is eliminated from the wastewater via enhanced biological removal or chemical precipitation, around 90% will end up in the sludge; thus, the greatest theoretical recovery potential is from the digestate, or ash after incineration.

Figure 8. *Suitable Locations for Phosphorus Recovery in Municipal WWTP: phosphorus may be recovered from WWTP effluent (1), process water (2), digestate (3) and bottom ash after incineration (4). Source: Pinnekamp et al, 2007*



Several technologies for phosphorus recovery have been developed to produce phosphate-rich products that possess good fertilizer qualities and low contaminant levels (Figure 9). While phosphorus recovery from wastewater has not yet become state-of-the-art, it is expected to become increasingly important and applied.

Magnesium-ammonium-phosphate (MAP, or struvite) can be produced from sludge water or sewage sludge through different methods, one being the Stuttgart process, and has good fertilizer quality (Massey et al., 2009; Römer, 2006). In the Stuttgart process, MAP is produced from digested sludge by chemical phosphate precipitation. Simplified, the Stuttgart process consists of two steps: first, acidic leaching of metal phosphates from anaerobically stabilized sewage sludge; followed by precipitation of MAP by addition of magnesium oxide adjusted with sodium hydroxide. Citric acid is added to complex the dissolved iron and heavy metals to prevent their transfer to the final product. Figure 10 shows a simplified schematic of the Stuttgart process. Chemicals are necessary to drive the process, and consumption is dependent on the sludge properties, the precipitant used, and the phosphorus recovery rate (Table 9).

In Germany, a new *Sewage Sludge Ordinance* mandating phosphorus recovery in municipal WWTPs larger than 50,000 PE entered into force in October 2017. The ordinance affects about 500 WWTPs, from which an estimated 66% of wastewater phosphorus can be recovered (BMU, 2017). This means that direct use of sewage sludge as a fertiliser in not allowed after the transition period of 12 years for WWTP > 100.000 PE or 15 years for WWTP 10.000<PE>50.000. According to the ordinance, there are two alternatives for phosphorus recovery: mono-incineration or co-incineration after obligatory chemical precipitation of struvite. Phosphorus recovery from sewage sludge can be integrated into existing WWTPs as an additional module, making the application flexible and adaptable.

Figure 9. Overview of Phosphorus Recovery Methods. Source: Mocker et al., 2011

Source waste water and process water	**Source sewage sludge**	**Source sewage sludge ash**
Cristallization and precipitation process • Phostrip • DHV Crystalactor • Ostara PEARL • Unitika Phosnix • Nishihara • Kurita fixed bed reactor • Ebara • MAP cristallization Treviso • CSIR fluidized bed reactor • REPHOS • P-RoC • PRISA process • Sydney Waterboard Reactor	Cristallization process • AirPrex MAP process • PECO process (mikrobiell. Oxid.) • FIX Phos	Wet chemical extraction process • RÜPA/PASCH process • SEPHOS process • SESAL (enhancement of SEPHOS) • BioCon • Eberherd process
Ion exchange process • REM NUT • PHOSIEDI	Acidulation process • Stuttgart process • Seaborne process • Kemira KEMICOND	High temperature process • SUSAN • Mephrec • ATZ iron bath reactor
Combined and special processes • RECYPHOS • Magnetic separation	Hydrothermal process • PHOXNAN LOPROX process • Kemira KREPRO • Aqua-Reci • Cambi process	Electrokinetic process • EPHOS
	High temperature process • Mephrec • YTZiron bath reactor	Bioleaching process • Inocre

***Figure 10**. Schematic of the Stuttgart Process. Source: P-REX, 2015*

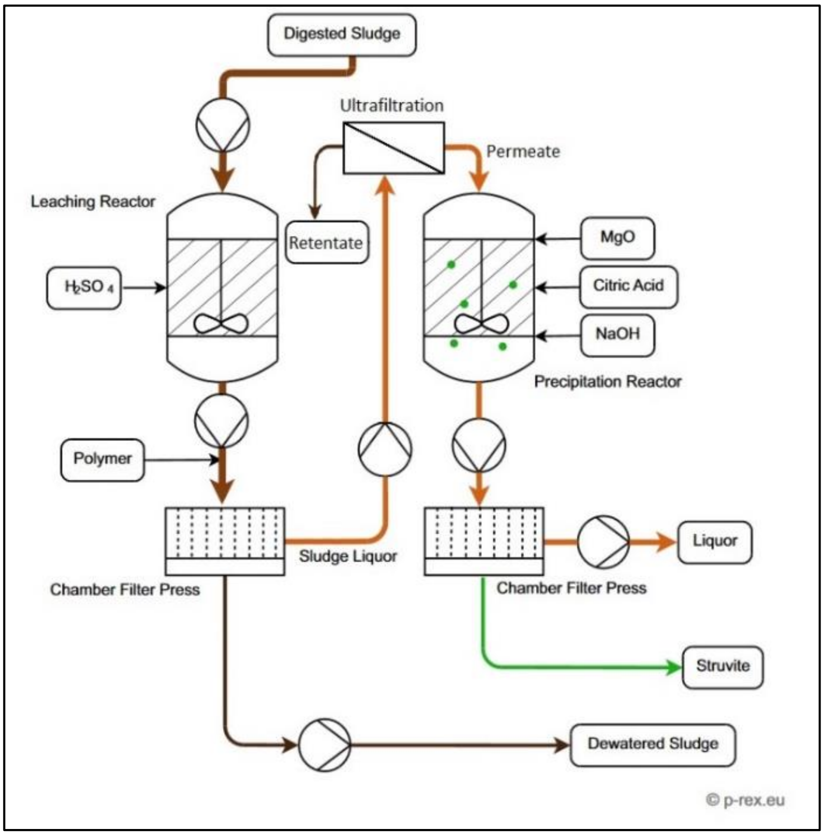


Table 9. *Chemical Consumption of the Phosphorus Recovery Process. Source: Meyer et al., 2018*

Chemical	Purity	Specific amount required
Sulfuric acid	78% (w/v)	1.7 to 5.7 L/m³ DS
Citric acid	50% (w/v)	3.9 to 11.5 L/m³ DS
Magnesium oxide	95% (w/v)	0.8 to 1.7 kg/ m³ DS
Sodium hydroxide	20% (w/v)*)	5.0 to 25.1 L/m³ DS (2.1 to 10.3 L/m³ DS)**)
Flocculant (stock solution)	0.4% to 0.6% (w/w)	3.0 to 5.7 L/m³ (DS)
*DS: digested sludge; *) solidification point @ approx. -25°C, note that NaOH of higher/lower concentrations may have a significantly higher solidification temperature; **) when ultrafiltration is applied*		

3.2.4 **Water reuse**

Wastewater, treated to standards appropriate for use, can contribute to preserving groundwater and surface water resources. While reuse options can include irrigation of agricultural land, parks, sport fields and recreation, in-house use (e.g. toilet flushing), and industrial process water, this study considers only irrigation.

WHO guidelines for safe use of wastewater, excreta and greywater have been established (WHO, 2006) to protect the health of farmers, local communities and consumers by proposing procedures that are adaptable to specific circumstances. Water reuse is one strategic option recently endorsed by the European Commission (EC) in the perspective of the Circular Economy[11]. The EC has adopted a proposal of a regulation, in line with WHO guidance, to overcome existing barriers to a broader uptake of water reuse.[12]

Effluents from conventional secondary wastewater treatment still contain significant quantities of coliforms and other pathogens, and require appropriate treatment (e.g. ultraviolet (UV) disinfection, ozone oxidation, membrane treatment or chlorination). This entails both investment and operation (including energy) costs; disinfection with ozone or chlorine may give rise to hazardous by-products.

3.2.5 **Additional resource recovery from the co-treatment of organic waste**

A WWTP may be a flywheel of a broader industrial ecological cluster, where materials and energy from the WWT process are used by other industries, and other energy and material flows may be directed to the WWTP together with those from urban wastewater. In particular, an anaerobic digestion process provides the opportunity of co-digestion of other substrates, such as organic waste. This option has been explored in the "synthesis centre" discussed below.

3.3 The "synthesis centre"

As in the Slovenian case discussed above, two alternative scenarios were developed, sharing a "core" centralized WWTP but differing in the strategy to cope with the most peripheral settlements. In the first scenario, all settlements are collected and treated in the WWTP, while in the second scenario the centralized WWTP does not treat wastewater from some settlements, which are instead addressed through decentralized treatment (constructed wetlands and a SBR – see § 2.2). The two scenarios are illustrated in **Figure 11** below, while the respective investment costs are reported in Table 10.

[11] http://ec.europa.eu/environment/circular-economy/index_en.htm
[12] http://ec.europa.eu/environment/water/reuse.htm

Figure 11. *Scheme of Wastewater Management under Scenario 1 (above) and Scenario 2 (Below)*

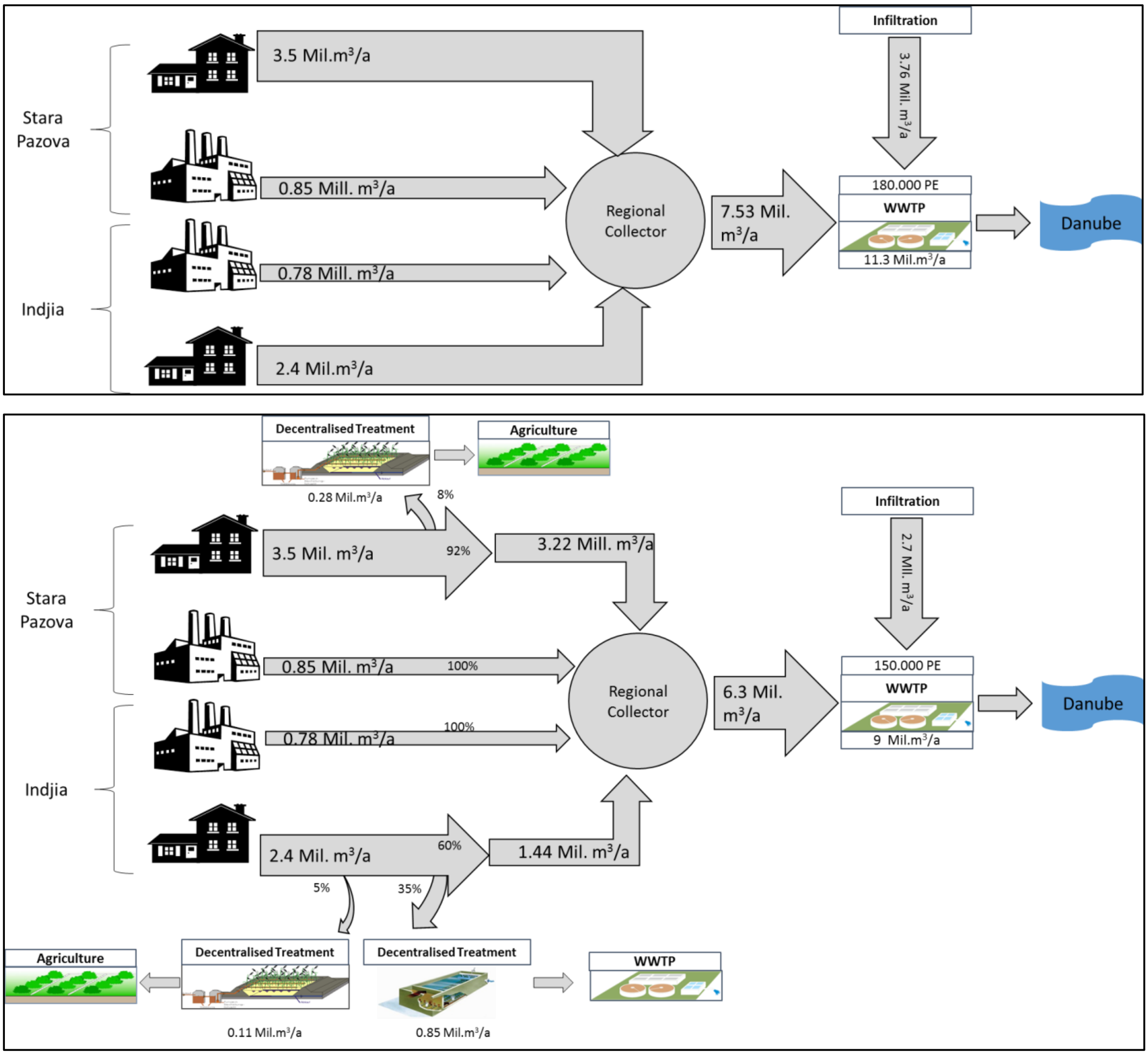


Table 10. *Preliminary Estimation of Total Investment Costs (expressed in EUR)*

TOTAL Investments	**Scenario 1**		**Scenario 2**	
	Indjija	Stara Pazova	Indjija	Stara Pazova
Sewer system	64,005,499	42,898,153	58,003,499	41,898,153
WWTP	10,436,448	12,007,292	12,993,274	12,731,054
Subtotal by Municipalities	**74,441,948**	**54,905,445**	**70,996,774**	**54,629,207**
Total		**129,347,393**		**125,625,981**

Table 11. *Preliminary Estimat of annual Operation and Maintenance Costs (EUR)*

Operational costs	**Scenario 1**		**Scenario 2**	
	Indjija	Stara Pazova	Indjija	Stara Pazova
central WWTP	426,058	905,383	395,362	840,362
SBR			81,180	
Constructed wetlands			4,200	10,500
Sewer network	564,000	503,300	265,370	546,000
Total		2,398,741		2,142,974

The difference between the two scenarios is rather small, with a fully centralized solution (Scenario 1) entailing higher investment costs due to the longer sewer network, in spite of the slightly lower investment costs of the WWTP in comparison to the partly decentralized solution (Scenario 2). Scenario 2 is also less expensive in terms of operation and maintenance (O&M) costs, due to the extra costs of maintenance for the longer sewer network in Scenario 1, and to slightly lower operating costs of the WWTPs in Scenario 2 (Table **11**).

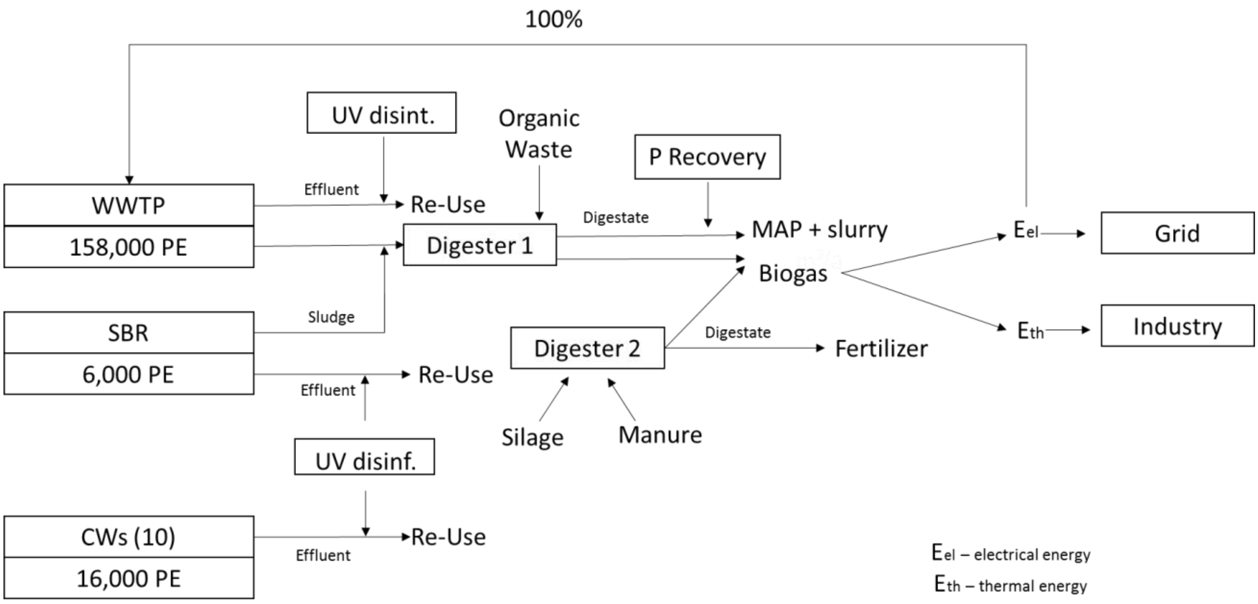
Energy, nutrient and wastewater recovery are possible in both scenarios, although Scenario 1 allows concentrating all flows and treatments in a single, centralized WWTP. In Scenario 2, part of the wastewater is treated in decentralized systems and is consequently not efficiently available for resource recovery.

The two alternative scenarios were presented and discussed with a group of stakeholders including representatives of the municipalities of Indija and Stara Pazova, academia and research, public utility companies, an environmental protection NGO, the Serbian Ministry of Agriculture and Environmental Protection and Serbian Environmental Protection Agency. The stakeholders were invited to compare the alternatives on the basis of environmental, technical and socioeconomic criteria.
The discussion and multicriteria comparison highlighted that the two scenarios are very close to each other, with relatively minor differences making Scenario 2 more rational on a technical basis. However, difficulties that may emerge with land acquisition could play against the partially decentralized scenario, making the centralized scenario preferable due simply to lower requirements of land.

3.4 The proposed solution and business model

Based on the above considerations, the solution of Scenario 2 was chosen. In addition, we explored a business model where the wastewater treatment plant is upgraded to serve also for the treatment of additional organic waste (**Figure 12**). This stems from the consideration that the central wastewater treatment plant can be a pivot of a broader industrial complex where the organic fraction of the municipal waste, as well as organic waste from agriculture, can be used for energy production and resource recovery, seizing economies of scale through common management and infrastructure optimization.

Figure 12. *Integrated Wastewater-Energy-Nutrient Treatment and Recovery Concept*



The substrates available for anaerobic digestion in the specific case are summarised in

Table 12. Agricultural residues represent the main potential source of substrate for biogas production (82% of fresh substrate). Agriculture waste streams also represent "clean" material, as opposed to sewage sludge and municipal solid waste that may contain heavy metals, micro-pollutants or other contaminants. Therefore, we have proposed separating the sources and treating them in two separate digesters.

Table 12. *Substrates considered for anaerobic digestion and nutrient recovery potentials*

Digester 1	Organic waste	OMSW	22,540	[t/a]
		Grass	5,437	[t/a]
		Green-cut	299	[t/a]
		Market waste	9,390	[t/a]
		Industrial waste	1,160	[t/a]
		Total available waste	38,826	[t/a]
			12,043	[t DM/a]
			7,254	[t oDM/a]
	Sludge	WWTP Volume of thickened sludge	70,872	[t/a]
			4,543	[t DM/a]
			203	[t oDM/a]
		SBR Volume of thickened sludge	3,066	[t/a]
			139	[t DM/a]
			6	[t oDM/a]
	Total Input Digester 1		112,764	[t/a]
			16,725	[t DM/a]
			7,464	[t oDM/a]
	Digestate		107,185	[t/a]
			5,480	[t DM/a]
			2,777	[t oDM/a]
	MAP*		820	[t MAP/a]
			104	[t P/a]
Digester 2	Crops	Weat	9,520	[t/a]
		Barley	3,116	[t/a]
		Soya	1,823	[t/a]
		Canola silage	473	[t/a]
		Corn silage	78,041	[t/a]
		Sugar-beat	89,213	[t/a]
		Sunflower	1,039	[t/a]
		Total available waste	183,224	[t /a]
			51,459	[t DM/a]
			47,874	[t oDM/a]
	Manure	Cattle	1,664	[t/a]
		Pigs	4,942	[t/a]
		Poultry	866	[t/a]
		Total available waste	7,452	[t/a]
			775	[t DM/a]
			602	[t oDM/a]
	Total Input Digester 2		190,675	[t/a]
			52,234	[t DM/a]
			48,450	[t oDM/a]
	Digestate		180,000	[t/a]
			43,000	[t DM/a]
			39,520	[t oDM/a]
* MAP - magnesium ammonium phopshate (Struvite) - NH4MgPO4.6H2O				

Digester 1 would treat sewage sludge from the central WWTP and SBR, plus organic municipal waste from communal, market and industrial sources; the amount of substrate available for anaerobic digestion amounts to 112,764 t/a (16,725 t dry matter (DM)/a; 7,464 t organic DM (oDM)/a); this quantity has the potential to generate 4.5 Mil.m3 of biogas annually[13] (equalling 25,762 MWh/a)[14] (Table 13).

Digester 2 would treat strictly agricultural residues: crops and manure; the amount of substrate available for anaerobic digestion amounts to 190,675 t/a (52,234 tDM/a; 48,450

[13] Calculated with specific biogas production for different substrates (e.g. 400 l/kg oDM for sewage sludge and 600 l/kg oDM for grass) (DWA, 2006).

[14] Calculated with specific energy content from biogas from sewage sludge of 6.5 kWh/m^3 and 5.75 kWh/m^3 from bio-waste (DWA, 2010).

t oDM/a), with the potential to generate 8.5 Mil.m3 of biogas annually[15] (equalling 51,092 MWh/a)[16]. Net of energy demand for the operation of the plant itself, there is surplus of electrical energy of 18,000 MWh_{el}/a and thermal energy of 21,000 MWh_{th}/a (Table 13).

Electric energy is valuable particularly as it can be sold at a pre-defined and stable feed-in tariff for renewable sources, which is usually profitable and can be a major leverage to offset the operation costs of the plant. The value of thermal energy depends essentially on the possibility to use it near the WWTP (e.g. for heating of public services or industrial processes). If this is not the case, thermal energy may have virtually no value. As demand for heat may not be sufficient near the plant, one might consider producing methane for sale to the grid, as an alternative to combined heat and power generation on site. This solution would entail a change in the investment (requiring a gas separation process), and it was not evaluated in this study.

The residue of anaerobic digestion (digestate) can be also reused as fertilizer. We expect to recover 180,000 t/a (43,000 t DM/a; 39,520 t oDM/a) of digestate from Digester 2, which can be applied directly as fertiliser on crops. The 107,185 t/a (5,480 t DM/a; 2,777 t oDM/a) of digestate from Digester 1 need further treatment to separate the nutrients from organic and inorganic pollutants. Through a modified Stuttgart process we can expect to recover 820 t MAP (104 t P/a) annually.

The proposed concept is compatible with water reuse. This requires effluents from all treatment units – WWTP, SBR and constructed wetlands – to be disinfected before use for irrigation in agriculture. The actual possibility to sell water for irrigation is presently limited by the fact that farmers can rely on other local freshwater resources at low prices.

Industrial and municipal organic waste would be collected on the basis of the existing legislation on waste. Agricultural organic waste is presently managed by farmers as fertilizer or soil conditioner, with crop residues often burned (which is illegal). The farmers would transport their substrate to the biogas plant and collect an equitable quantity of digestate which they can apply as a fertiliser. If applied equitably, this can represent a win-win scenario for both the farmer and the community, as the farmer can save money for conventional fertilizer and avoid potential penalties for improper disposal.

The benefits coming with the proposed solution may be better understood if we compare the additional costs entailed, vis-à-vis the operating revenues allowed (Table 14). The component yielding the clearest advantages is biogas production from sludge and organic waste: in this case, the process enables a treatment of waste required anyway by the legislation, and enables generating significant amounts of energy sold at a preferential feed-in tariff. Discounting these revenues from the costs of wastewater treatment would allow reducing tariffs accordingly. Struvite extraction, on the contrary, while enabling a virtual elimination of phosphorus loads from the WWTP, could not be paid back from revenues only, due to the high O&M costs. The recovery of treated effluent for irrigation is also not convenient from a purely economic point of view. For water recovery, revenues may be virtually nil due to the practical difficulties of water reuse. However, the situation may change in the future if water and phosphorus scarcity become more compelling.

The proposed solution broadens the scope of the WWTP by including treatment of organic waste (which is anyway a necessity), with a clear benefit in economic terms albeit after significant additional investments. The corresponding revenues may be used to reduce the service tariffs, which anyway remain the dominant mode of cost recovery. Assuming no money transfer to cover investment costs, a tariff of 0.95 Eur/m3 for household users and of 2.00 Eur/m3 for industrial users would enable full cost recovery. At such tariff, it would be possible to operate a WWTP at high standards of resource recovery and pollution control.

[15] Calculated with specific biogas production for different substrates (e.g. 200 l/kg oDM for crops and 450 l/kg oDM for manure) (DWA, 2006).
[16] Calculated with specific energy content from biogas from crops of 6 kWh/m^3 and 6.25 kWh/m^3 from manure (DWA, 2010)

This tariff would be reduced by only 5% by excluding struvite extraction and effluent disinfection for reuse. Considering that these tariffs cover only the sanitation and treatment service and would add up with the drinking water supply tariffs, affordability issues may emerge, requiring a careful design of how different categories of users should be charged.

The community benefiting from this service would probably receive broader benefits, in terms of economic growth and wellbeing, which could partly compensate the issue of affordability. First of all, an investment of about 130 million Euro is expected to generate an increase in economic output of about 13 million Euro (multiplier effect) due to the cascade effect of additional incomes and additional expenditure related to the investment.

The improved water quality also has an economic value. The "cost of no action" if pollution is not treated has been estimated in this case to be in the range of about 4 to more than 15 million Euro/year, depending on the methodology adopted. Notably, the improvement in water quality, particularly on the shores of the Danube where untreated water is currently discharged, has a potential to increase the value of properties and the attractiveness of the site for tourism and recreation.

The complexity of the processes added to the design makes it vulnerable to difficulties possibly stemming from the logistics (e.g., lower-than-expected participation of farmers with agricultural organic waste) as well as from technical problems (e.g. presence of contaminants in the organic waste or in the industrial part of wastewater, affecting struvite extraction and the usability of the digestate in agriculture). Improving the level of treatment while increasing the service costs may also lead to a significant reduction of water use by households (and industry), causing similar costs to be apportioned to smaller volumes, with an increase of the costs per cubic meter.

Table 13. *Energy Demand and Production Potential in Scenario 2*

Annual Gas Production Digester 1	4.5	[Mil.m3/a]☐
Annual Gas Production Digester 1	8.5	[Mil.m3/a]☐
CHP capacity	8	[MW]☐
Gross electricity production	30,700	[MWhel/a]☐
Gross thermal energy	34,600	[MWhth/a]☐
Net electrical energy	27,600	[MWhel/a]☐
Net thermal energy	22,500	[MWhth/a]☐
Energy demand WWTP (wastewater treatment)	4,740	[MWhel/a]☐
Energy demand WWTP (sludge dewatering)	47	[MWhel/a]☐
Energy demand digestate dewatering	4,864	[MWhel/a]☐
Energy demand digestate drying	1,269	[MWhth/a]☐
Blance electrical energy	**17,948**	**[MWhel/a]☐**
Balance thermal energy	**21,231**	**[MWhth/a]☐**

Table 14. *Additional costs and revenues associated with resource recovery*

Item	**Investment costs (Euro)**	**O&M (Euro/year)**	**Revenues (Euro/year)**
Biogas production	11,000,000	621,480	3,787,446
Struvite extraction	853,200	900,600	328,000
Effluent disinfection (sum of centralized and decentralized effluents)	2,250,000	21,945	0[17]

[17] Assumption of no market value for reclaimed wastewater.

4 Overview of solutions

The two cases outlined in the previous sections offer an overview of options available for WWT as well as resource recovery. In this section, we summarize their conditions of applicability, parametric costs and performance.

In the case of larger, centralized plants, the strategy that has been examined consists of (1) maximizing the recovery of resources (energy, nutrients, water) within the WWT processes, and (2) expanding the system boundaries by combining WWT with organic waste management.

In the case of smaller, decentralized plants the strategy consists of minimizing investment and operation costs through nature-based or nature-inspired solutions. These solutions may sometimes allow the recovery of resources, which needs to be appraised on a case by case basis. In this section, we quantify the key parameters required for the appraisal of the two strategies, building on the experience of the cases illustrated above.

4.1 Larger, centralized plants

AS plants are usually adopted in the presence of agglomerations of at least 2000 population equivalents (PE). Sequencing Batch Reactors (SBR) are used also for smaller agglomerations. **Table 15** provides an overview of indicative costs for AS plants[18].

Table 15. *Costs of AS plants*

Item	**Indicative Cost**
Water Treatment (investment)	125 €/PE[19]
Biogas extraction, P and water recovery[20] (investment)	37 €/PE
Water treatment (operation)[21]	6.7 €/(PE * year)
Water treatment with biogas extratcion, P and water recovery (operation)[22]	12.5 €/(PE * year)
Maintenance (assumed)	2% of investment per year

The typical energy consumption of AS plants is around 30 kWh_{el}/(PE*year) for wastewater treatment[23], 0.3 kWh_{el}/(PE*year) for mechanical sludge dewatering[24], 115 kWh_{el}/t dry

[18] These costs should be used only for a first orientation. More detailed cost assessment methods exist for use at the planning and policy evaluation level, including the FEASIBLE model of OECD. https://www.oecd.org/env/outreach/methodologyandfeasiblecomputermodel.htm

[19] The investment cost estimate for the central WWTP is based on wastewater treatment feasibility studies in four municipalities of similar size: Krusevac, 120,000 PE (Gauff Ingenieure et al.a, 2012); Vrbas, 150,000 PE (Haskoning Nederland B.V. Water et al., 2007); Leskovac, 150,000 PE (Haskoning Nederland B.V. Water et al.b, 2007); and Sabac 129,000 PE (Haskoning Nederland B.V. Water et al.c, 2007), adjusted for inflation (for Krusevac inflation rate 1,6% as pwer Eurozone inflation in the period 2013-2016, for Vrbas, Leskovac and Sabac inflation rate 13,1 % as per Eurozone inflation in the period 2008-2016).

[20] Computed assuming investment costs for digesters of 2,000 €/kW (IWR, 2017), for P recovery of 5.4 €/PE (Egle et al., 2016) and for effluent disinfection 7 €/PE (DWA, 2013)

[21] See note 19

[22] IWR, 2017; Egle et al., 2016; DWA, 2013

[23] Hartwig et al., 2010; Kaless et al., 2017

[24] Industry figure from Huber Technology: http://www.huber.de/en/solutions/energy-efficiency/sludge-treatment/dewatering.html

matter (DM) for mechanical digestate dewatering, and 30 kWh_{th}/t DM for digestate drying[25].

Similar costs apply for SBR. Typically there are economies of scale, with a reduction of both investment and operation costs per PE with increasing size of the plant.

AS and SBR perform in a similar way for what concerns chemical oxygen demand (COD), biochemical oxygen demand (BOD) and total suspended sediments (TSS). The removal efficiency is typically above 90% for all three parameters, while AS has typically better performance than SBR in the abatement of total N and total P.

Biogas extraction from sludge can be usually implemented at plants of at least 10,000 PE, with an investment cost of the digester of 2,000 €/kW (IWR, 2017). The typical amount of biogas that can be extracted is[26] 20 l/PE*d, corresponding to an energy yield of 17 kWh_{el}/ PE and 27 kWh_{th}/PE. About 10% of electricity and 35% of heat theoretically available are needed for the operation of the digester itself.

For the case of organic waste co-digested with sludge, **Table 16** provides the indicative additional energy yields contributed by materials from the different sectors.

Table 16. *Indicative biogas and energy yield of organic waste*[27]

Item	***Methane Nm^3/t***	***Biogas Nm^3/t***	***Electricity kWh_{el}/t***	***Heat kWh_{th}/t***
Domestic organic waste	73	123	283	318
Crop residues	85	160	384	432
Poultry manure	100	170	425	478
Pig/cattle liquid manure	18	30	75	84
Horse/cattle solid manure	40	70	150	168
Industrial organic waste: fruit/vegetable residues	54	100	230	259
Industrial organic waste: grease/oil	570	830	2000	2240

25 Husemann, J.; Steinmetz, H. Case study Serbia: Nexus orientated wastewater management. Watersolution 1/2016, 2016, s.22ff., 77-87.

26 Optimierung der Energieertages kommunaler Kläranlagen durch prozess- und standortbezogene Verbundstrategie, 2014 https://www.lanuv.nrw.de/fileadmin/forschung/wasser/klaeranlage_abwasser/140411%20-%20Zusatzbericht_TP2_Auswertung%20EAs.pdf

27 Corresponding to the energy content of substrate per m3 biogas estimated as: organic waste 6 kWh/m3; livestock 6.25 kWh/m3; organic waste 5.75 kWh/m3, industrial waste 5.75 kWh/m3; sewage sludge 6.5 kWh/m3. A combined heat and power (CHP) electrical efficiency of 40% and thermal efficiency of 40%. Ref: DWA, 2010

Typical costs of extraction of struvite (magnesium ammonium phosphate, MAP) are 5.4 €/PE (investment) and 5.7 €/PE * year (operation)[28].

Typical costs of water disinfection for reuse in irrigation are 7 €/PE (investment) and about 0.5 €/(PE * year) (operation)[29].

4.2 Smaller, decentralized plants

Parametric cost values for the technical solutions examined in the Slovenian case are provided in Table 17. When the costs are referred to a m^2 of plant, Table 18 provides an estimation of the area per PE.

Table 17. *Investment, O&M parametric values for small WWT plants examined in the Slovenian case.*

	Works									O&M	Source
	PE <10	10< PE <20	20< PE <50	50<PE<500			500<PE<1000				
	€/m²	€/m²	€/m²	€/m²	€/PE	€/m³	€/m²	€/PE	€/m³	€/y/PE	
MBR Without limits on Nitrogen					550			460		60	Masotti (2011)
MBR With limits on Nitrogen					620			520		90	Masotti (2011)
SBR Without limits on Nitrogen					360			310		40	Masotti (2011)
SBR With limits on Nitrogen					410			350		60	Masotti (2011)
FBA: septic tank						500			400	15[30]	IRIDRA expertise
FBA: bed				150			130				IRIDRA expertise
FRB: 1st stage				130			120			7	IRIDRA expertise
FRB: 2nd stage VF				110			100				IRIDRA expertise
Hybrid CW: septic tank						500			400	15	IRIDRA expertise
Hybrid CW: HF				100			90				IRIDRA expertise
Hybrid CW: VF				110			100				IRIDRA expertise
Algae bioreactor					150			150		24	WSI expertise
HF CW [31, 32]	180	130	110							10	IRIDRA expertise
VF CW[31, 32]	200	150	120							15	IRIDRA expertise
EWS[31]		185								10	WSI expertise

[28] Egle et al., 2016
[29] DWA, 2013, reports 0.63 €/(PE * year), while for typical Danube conditions this cost is expected to be lower.
[30] Plus energy consumption for aeration
[31] Sludge disposal costs should be added.
[32] Reuse for irrigation possible; costs of UV lamp for disinfection and drip irrigation equipment should be added.

Table 18. *Area requirements for the solutions in Table 17*

	Net area, m^2/PE	**Gross to net area ratio**	**Source**
MBR	0.25	3	Masotti (2011)
SBR	0.4	3	Masotti (2011)
FBA	1	2	IRIDRA expertise – Forced Bed AerationTM (FBATM) patented technology by NaturallyWallace (www.naturallywallace.com)
FRB, 1st stage	1.2	2	Morvannou et al. (2015); Molle et al. (2005; 2006)
FRB, 2nd stage with N limits	1.5	2	Platzer (1999)
FRB, 2nd stage without N limits	0.8	2	Platzer (1999)
Hybrid CW, 1st stage	2	2	Reed et al. (1995)
Hybrid CW, 2nd stage with N limits	1.4	2	Platzer (1999)
Hybrid CW, 2nd stage without N limits	0.5	2	Platzer (1999)
HF CW	3	2	Reed et al. (1995)
VF CW without N limits	3	2	Platzer (1999)
VF CW with N limits	4	2	Platzer (1999)
EWS	15	1.5	WSI expertise
Algae bioreactor	3	1.5	WSI expertise

More detailed parametric curves for investment (capital expenditure, CAPEX) and operation (operational expenditure, OPEX, including maintenance) have been built for the different CW solutions (FBA, HF, VF, hybrid and FRB). These curves, reported in Table **19**, are designed to cover a wide range of conditions in the Danube region.

Compared to the parametric costs of Table 17, these curves are expected to provide a more accurate estimation. The former are useful for early stages of planning and comparison of alternatives, while the latter can be used for a more advanced phase of planning once a specific solution has been identified.

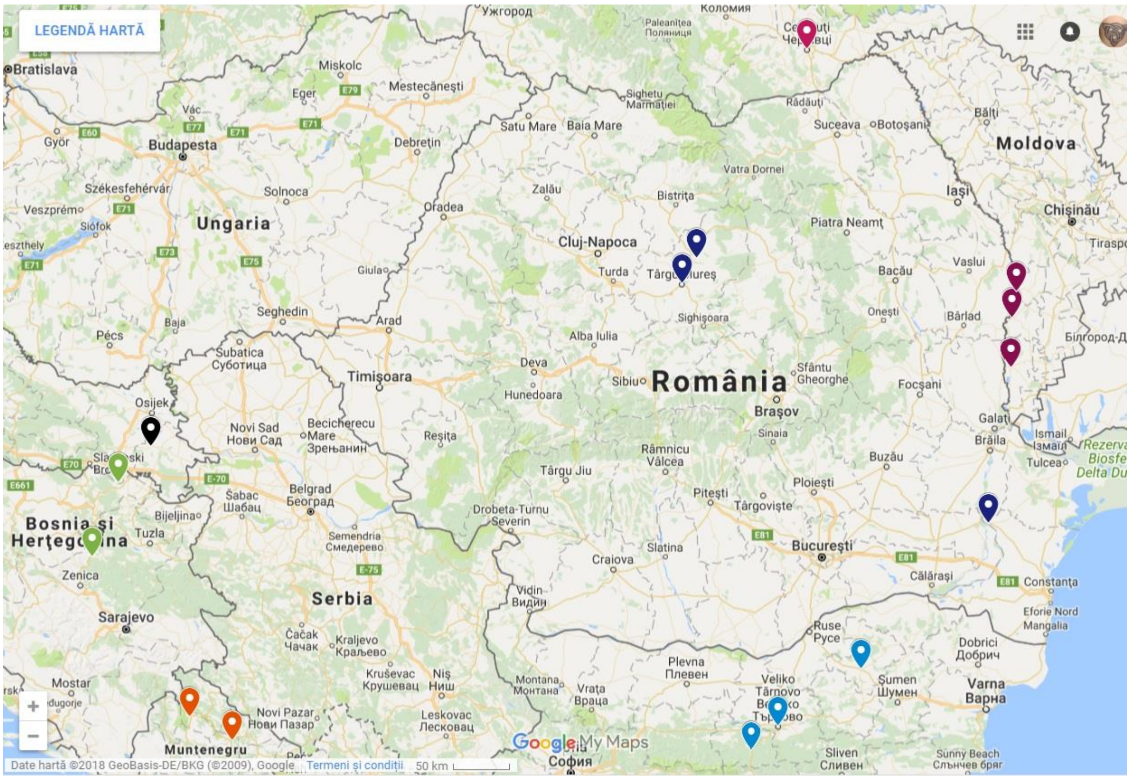
Table 19. *Parametric CAPEX and OPEX curves for selected smaller plant WWT solutions. The OPEX curve includes maintenance costs.*

	Condition for selection	**Net area m²/PE**	**Gross to net area ratio**	**CAPEX parametric curve €/PE**	**OPEX parametric curve €/PE/y**
FBA	Limited available area for NB solutions	1	2	$CAPEX = 629.57\ PE^{-0.144}$	$OPEX = 74.634\ PE^{-0.229}$
Hybrid CW	No limit of available area for NB solutions	2.5	2	$CAPEX = 784.26\ PE^{-0.147}$	$OPEX = 44.394\ PE^{-0.164}$
FRB	Minimizing OPEX No limitation for feeding of CW bed with raw WW (e.g. social, area too near to houses)	2	2	$CAPEX = 903.79\ PE^{-0.19}$	$OPEX = 99.155\ PE^{-0.375}$
HF CW with water reuse	Decentralisation plus resource-oriented reuse of WW for fertilization and irrigation	3	2.5	$CAPEX = 4226.3\ PE^{-0.471}$	$OPEX = 86.041\ PE^{-0.198}$
HF CW without water reuse	Decentralisation with most simple, cheap and robust NB solution	3	2	$CAPEX = 2383.8\ PE^{-0.41}$	$OPEX = 61.471\ PE^{-0.122}$
VF CW	Decentralisation with water quality limit for nitrogen pollutants	4	2	$CAPEX = 3746.4\ PE^{-0.391}$	$OPEX = 60.623\ PE^{-0.101}$

5 Which solutions for the lower Danube? A reality check on selected test cases

The two feasibility studies presented above indicate possible, sound and affordable wastewater treatment solutions that can be suitable in many areas in the Danube region: low-maintenance, low-technology decentralized CW for rural settlements (also limiting investments, by reducing sewer network length), and an expanded centralized plant with resource recovery, processing organic waste together with wastewater, for larger urban settlements. In the first type of solution the purpose is to minimize costs, whereas in the second case it is about maximizing economies of scale and collateral revenues. We have further investigated the applicability of these strategies through a "reality check" survey in selected test cases in the lower Danube river basin (Figure 13), which are documented in this section.

Figure 13 *– map of the selected test cases*



In the selected cases, local experts were asked to gather potential service operators, potential service users and/or other stakeholders and to present the solutions examined in the previous sections, either as options for interventions in the future, or as possible alternatives to the solutions actually adopted in the past. Depending on the local context, some were immediately discarded when it was apparent that they could not be applied for various reasons. The others were screened to examine the respective opportunities and limitations. In each test case, a wastewater solution was eventually selected as the most applicable to the case, and the possible challenges for its implementation were identified (see Table 20). In the following, we first introduce the contexts of the test cases, and then discuss the applicability of each solution, as well as the opportunities and challenges across the cases, drawing conclusions on possible strategies for wastewater treatment in the Lower Danube.

Table 20 *- summary of the options considered in the different test cases*

Case	**Population equivalent (PE)**	**Type of settlement/plant**	**Selected options**	**Outcomes**	**Concerns expressed by the stakeholders**
Žepče (BA)	10,000	Various scattered villages for a total of 10,000 PE; typical village 560 PE	CW preferable (among CW, FRB judged most cost-effective)	A FRB for a typical village would cost around 100,000 Euro and entail O&M of around 8400 Euro/year. O&M alone would be mostly covered by the current tariff (0.25 Euro/m3).	The investment cannot be covered with the current tariffs; transfers are improbable. The current legislation supports the solution, but it should be stricter on the implementation side (connection to the sewage network, when available, should be made mandatory).
Odžak (BA)	3,000	Same as Žepče; typical village 1200 PE	Same as Žepče	A FRB for a typical village would cost around 228,000 Euro and entail O&M of around 8700 Euro/year. Not even O&M would be covered by the current tariff (0.17 Euro/m3).	On top of the above, the opinion of local WWT operators is not favourable partly due to lack of knowledge about the solution, highlighting a need for capacity building

Case	Population equivalent (PE)	Type of settlement/plant	Selected options	Outcomes	Concerns expressed by the stakeholders
Razgrad (BG)	55,000 (100,000 after reconstruction of the plant)	A town of 55,000 PE	The existing WWTP could be equipped with phosphorus and biogas recovery (also from external organic waste); partly decentralized treatment with CW could be an alternative to further extending the sewer network	Struvite extraction would increase WWT costs from 0.112 to 0.124 Euro/m3; biogas valorization may reduce the costs of sludge treatment, requiring the current tariff to increase from 0.112 to about 0.18 Euro/m3; additional decentralized treatment increases the costs to 0.148 Euro/m3. Calculations were made assuming zero interest on loans. A recent feasibility study shows that the investment needed to upgrade the WWTP for using external organic waste for sludge improvement and production of compost is almost 1 million Euro. Depending on the quantity of sludge deposited and the purchase price of the compost, the break-even will be 2 to 4 years after the upgrade, (considering only the investment for the composting plant, and excluding the investment in adapting the other WWTP processes).	The upgrade of the WWTP requires capacity building as the necessary operation and management skills are currently judged insufficient. The stakeholders have expressed concerns about social aspects, i.e. the affordability for the poor of the expected new water tariffs. The costs and revenues (including a market analysis) of compost production need to be assessed more in depth.
Veliko Tarnovo (BG)	74,000	Centralized WWTP with 74,000 PE	P recovery; biogas energy recovery;	Investments in P and energy recovery would cause to more than double the current tariffs (0.061 euro/m), which would still remain below 0.15 Euro/m^3. Current tariffs are however particularly low, and do not allow recovery of costs.	The upgrade of the WWTP requires capacity building, as the necessary operation and management skills are currently judged insufficient. When implementing innovative technologies, the technical and administrative capacity of the water operators must be upgraded. Moreover, the market for by-products is not yet developed.

Case	Population equivalent (PE)	Type of settlemen t/plant	Selected options	Outcomes	Concerns expressed by the stakeholders
Gaborovo (BG)	100,000	Centralized WWTP with 100,000 PE	P recovery; biogas energy recovery;	Investments in P recovery are slightly less convenient than for V.Tarnovo, while energy recovery would be more convenient. Both P and energy recovery require slight increases in the current tariffs (from 0.141 Euro/m3 to slightly more than 0.15 Euro/m3 for both options).	The upgrade of the WWTP requires capacity building as the necessary operation and management skills are currently judged insufficient.
Ivankovo (HR)	8,000 PE	One main settlement and two separate villages	FRB for sludge mineralization from existing WWTP	Investment of 250,000 Euro and annual O&M of 11,000 Euro; after 10 years, revenue of about 300,000 Euro from sale of soil conditioner	Legislative barriers and lack of a market for the sale of composted sludge
Cahul (MD)	25,000	Centralized WWTP with > 50,000 PE	WWTP under renovation, meeting BOD5 standards and (nearly) N, P standards; proposed sludge dehydration + thermal treatment	Investment >15 million Euro for additional sewerage and sludge treatment. Additional costs of sludge treatment (O&M only) add 0.14 Euro/m3 to tariffs (presently 0.47 Euro/m3). Sale of stabilized sludge as soil conditioner expected to reduce tariff of 2 cents/m3	Use of stabilized sludge as soil conditioner is problematic due to limited willingness of farmers to accept it, unclear market conditions/prices, and costs of transport to agricultural land. Moreover, laboratory analyses for the control of sludge quality are expensive and may be an issue.
Leova (MD)	8,000	Small centralized plant	The current plant is obsolete and could be replaced by a CW solution on the same site, saving 2/3 of current electricity and coping with flow intermittency	Investment >7 million Euro for additional sewerage and CW. The cost of treatment (O&M only) would be 0.48 Euro/m3 (0.43 if reeds are then sold), and the total tariff is expected to be around 0.9 Euro/m3 (WWT + sewerage)	Unclear market and regulatory conditions for sale of secondary products such as reeds.

Case	Population equivalent (PE)	Type of settlement/plant	Selected options	Outcomes	Concerns expressed by the stakeholders
Cantemir (MD)	4,000	Small centralized plant with 8,008 PE	Same as Leova	Investment >9 million Euro for additional sewerage and CW. The cost of treatment (O&M only) would be 0.73 Euro/m3 (0.63 if reeds are then sold), and the total tariff is expected to be around 1 Euro/m3 (WWT + sewerage)	Technology not well known. Lack of business culture and need for innovation Barriers in legislation: stakeholders know, in most cases, only the classical treatment technology that is applied in most cities in the country. Well established but obsolete norms in design and construction hinder the penetration of higher-performance, more up-to-date technologies.
Mojkovac (ME)	8,000	Small centralized plant (5,000 PE) with very high costs (1.8 Euro/m3)	CW could be a better option (reducing O&M costs)	The WWTP has relatively very high costs of operation (1.8 Euro/m3), mainly due to high personnel costs. The current tariffs are of 0.17 euro/m3, <10% of costs. CW alone would have a much lower O&M cost (0.49 €/m3 calculated from daily water consumption data)	Insufficient technical capacity - not many engineers are aware of this technology, nor know how to apply it. Therefore currently foreign companies are promoting the technology through pilots. The process is going well anyway.
Žabljak (ME)	2,000	Small centralized plant (2,000 PE)	CW could be a better option (reducing investment from about 1 million to 0.4 million Euro, as well as O&M costs)	The actual present costs of service are not available, but likely significantly higher than allowed by a CW solution (0.27 €/m3 (assuming water consumption of 150 L/PE/day).	Lack of knowledge available Lack of management skills Lack of trained personnel Lack of suitable organization for implementation (public utility)

Case	Population equivalent (PE)	Type of settlement/plant	Selected options	Outcomes	Concerns expressed by the stakeholders
Tg. Mures (RO)	200,000	Large WWTP (>200,000 PE)	Phosphorus recovery, heat recovery from effluents of a nearby fertilizers factory, water reuse	The investment in P recovery would be 1.2 million Euro, an O&M 1.3 million/year, making it unfeasible considering the current price of P from phosphate rocks. Water reuse would require similar investment, O&M of 30,000 Euro/year and would generate revenues for 146,000 Euro at a water price of 2 cents/m3. Heat recovery would be the investment closest to feasible, although with a long payback period.	Technology available, but the business culture should be updated Lack of policy coordination Need for demonstrational pilot projects for capacity building and stimulation of innovation. Lack of markets for by-products.
Petelea (Habic village) and Harsova (Vadu Oii village) - (RO)	300-400	Small village	FRB, FBA	Investments entail costs close to 1 Euro/m3 or above. O&M costs alone would amount to between 0.26 and 0.6 euro/m3 for FRB, and 0.42 to 0.8 for FBA.	Lack of knowledge at a local level Difficulties in management, including limited communication between the community, stakeholders and plant operators. In small rural settlements, tariffs approaching 1 euro/m3 are regarded as unaffordable.
Chernivtsi (UA)	250,000	Large (>250,000 PE) centralized WWTP	Recovery of energy and fertilizers from sludge treatment	Investments in biogas + composting: about 2.4 million Euro. Additional operation cost of about 3 cents/m3, reduced to 2 cents with sale of fertilizer, electricity and heat. Current tariff 0.11 Euro/m3.	Lack of policy change support Lack of legislation Lack of new technologies and innovation Lack of trained personnel

5.1 The context of the lower Danube and the test cases

5.1.1 Bosnia and Herzegovina

Bosnia and Herzegovina is developing WWTPs under the financing programmes of EIB (WATSAN project[33]), the EBRD, the World Bank and the EU Instrument of Pre-Accession Assistance (IPA) funds[34]. Currently, Mostar and Bihać are the most significant WWTPs in construction, while 12 wastewater treatment plants are known to be in operation, covering more than 500,000 PE across the country. Not only is the wastewater treatment system under development, but difficulties arise in appropriately connecting users when a plant is built, due to the significant investments the sewer networks require. The limited investment capacity of the country makes it often dependent on transfers.

Žepče is a small municipality in central Bosnia and Herzegovina (31,582 inhabitants according to the 2013 census), with a main town of more than 5,000 residents and another 46 villages (communities). The city developed into an agricultural centre due to its rural background. The area is profiled on fruit growing (mainly raspberry cultivation). There is limited industrial activity; the area has two factories (lumber and leather industries). Further development is possible in the agricultural sector and tourism. The sewerage system serves only the town centre, with 750 households connected to a 9 km long network. For comparison, the water supply system serves 2,170 households. The condition of the sewerage system is satisfactory but a significant part of the town and its inhabitants have no access to the sewage network. The same applies for the neighbouring villages, where septic tanks (often not water-tight) are used. Future investments are currently planned only for drinking water.

The secondary treatment (activated sludge) wastewater treatment plant has been in operation since 2007. The designed nominal capacity of the plant is 10,000 PE, with an investment of 2 million EUR. The daily amount of wastewater received by the WWTP is approximately 1,000 m^3. Sludge is dehydrated and landfilled. The recipient of treated effluents is the Bosna River. The current tariff (0.25 Euro/m3) covers O&M costs only.

Odžak is a town in the north of the country, near the Croatian border (9,000 inhabitants in the 2013 census). In addition to the town, the municipality has 14 smaller settlements with a total of about 21,000 inhabitants. About 30% of the inhabitants have left the area in the last three decades.

The economy has traditionally relied on agriculture and the construction material industry. Nowadays, economic developments include wood processing and metal industry. In addition to the conflict in the 1990s, the economic development underwent a major setback caused by flooding in 2014.

The sewerage system is completed only for the central area of the town of Odžak, and spans over 14 km. Some 2000 households are connected to the sewerage system, but another 5000 remain uncovered in the neighbouring villages. Septic tanks remain in use there and, due to the lack of funding at municipal and national level, there are no current plans to invest into the sewerage system and WWTPs.

A secondary treatment level WWTP, destroyed by bombing during the conflict in the 1990s, was restored in 2012, and has been in operation ever since. Its capacity is 10,000 PE but due to the depopulation trend after the war, the number of inhabitants that live in the city throughout the year amounts to little over 3,000 PE. The investment value of the WWTP was 1.6 million EUR. The average inflow of waste waters is 1,203 m^3 per day (2017 data). The effluent recipient is river Bosna. The O&M cost of wastewater treatment is 0.27 EUR/m^3, but the current price of wastewater collection and treatment for households is 0.17 EUR/m^3. Thus the consumers pay for 63% of the cost of wastewater treatment, with the remaining cost being covered by the municipality. The sludge is aerated and stored in

[33] http://www.watsanfbih.org/index.php?lang=en
[34] https://ec.europa.eu/neighbourhood-enlargement/instruments/overview_en

tanks behind the WWTP, and eventually landfilled. The loadings are very small, and so far the storage tanks have only been emptied once.

Both in Odžak and Žepče, the central WWTP is suitable for the needs of the area despite its high cost, although improving the connection rate is necessary in order to make the treatment process more efficient. On the contrary, rural areas still lack a solution, and may be a case for CW. In the two cases, it was evaluated how a French reed bed (FRB) solution could allow sustainable treatment of effluents in a typical settlement between 500 and 1200 PE. The operation of such plant would entail costs of about 0.27 Euro/m3, leaving out the investment costs (which may be particularly high considering that, in many cases, sewers should be also built). The operation costs of FRB are compatible with, if slightly higher than current tariffs, and could be further reduced if it were possible to sell the biomass (reed) produced in the FRBs. In principle, the stabilized sludge cake formed at the top of the FRB, to be removed every 10 years, could be applied as fertilizer, but is likely to generate little or no revenues. Reuse of treated water is possible, but would probably not generate revenues due to the small-scale type of agriculture (hence lack of capacity to pay by farmers), or low demand for irrigation.

5.1.2 **Bulgaria**

The water supply and sanitation (WSS) sector in Bulgaria is very fragmented, with many water companies. More than 70% of the population is connected to urban wastewater collection and more than 60% is connected to an urban WWTP. Inefficiencies in the WSS sector contribute to a high level of operational costs, while investments have been constrained by the deterioration of the financial capacity of WSS companies and tighter credit conditions. The majority of the WWTPs built under the former Instrument for Structural Policies for Pre-Accession (ISPA) programme (Cohesion Fund Regulation 1164/94) were oversized while, during the transition to a free market economy before EU accession, they could not get enough waste water loads due to depopulation and the phasing out of industrial activities, which in turn led to operational and, eventually, financial issues.

The Razgrad agglomeration is located in the North-Eastern part of Bulgaria. Razgrad is in the western part of Ludogorie, which is part of the Danube hilly plain. The plateau is made of limestone, marl and loess. The town of Razgrad is the administrative centre of Razgrad Municipality and is in the valley of the Beli Lom River. According to the latest National Statistics Institute (NSI) data from 31/12/2015, the population of Razgrad is 31,739 people. The main industrial activities are concentrated on:

- extraction of primary products for the food industry through deep processing of maize;
- transport and logistics;
- production of refined sunflower oil, feed products, secondary sunflower products and others;
- dairy processing and foods.

The average domestic water flow is 4605 m^3/day, while the average industrial water quantity is around 3064 m^3/day.

The agglomeration associated with the town of Veliko Tarnovo is situated in Northern Bulgaria. According to data from 2015, the city ranks 16th in population with its 70 000 inhabitants, and is one of the four cities in Bulgaria with positive natural growth from 2006 to 2014. Situated between the Danube Valley and the lower hills of the Stara Planina mountain, Veliko Tarnovo is the administrative, industrial and educational centre of the region. The economic activities present in the area include: a petrol station; production and bottling of drinks; food processing; beer production; machinery manufacturing; ICT technology for financial services; auto-repair; and felted textiles. The average household water discharge is 28,514 m^3/ day, while the daily average industrial water discharge is 802 m^3/ day.

The Gabrovo agglomeration is located in the Central part of Bulgaria. The town of Gabrovo is situated along the Yantra River at the northern foot of the Shipka part of the Balkan Mountains. According to the latest NSI data, the population of Gabrovo is 54,950. The territorial development of the area and the priority development of certain economic sectors are facilitated by its varied semi-mountainous and mountainous relief and favourable climate.

The main industrial activities ares: textile; plastic materials, machine building and light industry; production of metal cutting tools; crane manufacturing; dairy products; leather clothes materials; laundry for hotel and hospital linen, cleaning and dry cleaning. The average household water flow is 23,000 m3/day, while the average industrial water quantity is 453 m3/day. In the three cases of Razgrad, Gaborovo and Veliko Tarnovo, a secondary (activated sludge) WWTP exists and is already partly equipped for anaerobic stabilization of sludge (**Figure 14**, **Figure 15**). However, energy recovery is not in place or not effective. In these cases, phosphorus recovery is also a possibility, but is not presently implemented. Thanks to the significant revenues from energy and, in part, struvite, the investments required to develop energy and phosphorus recovery are estimated to have a negligible impact on current tariffs[35]; investments, though, would be difficult to support in the absence of funds presently not available in the three cases.

In the case of Razgrad, the option of a partially decentralized treatment of certain villages was also analysed, highlighting that the operation and maintenance costs would be similar to those of the central WWTP. The investment, on the contrary, would be significantly lower than required for wastewater collection and centralized treatment.

An analysis of the domestic organic material in the town of Razgrad was also carried out, as shown in **Table 21**. The organic fraction of waste could be used to increase biogas production by centralizing digestion in a single plant.

Table 21 *– organic material available in Razgrad*

Type	***Quantity***	***Share***	***Nitrogen content (N)***	***Carbon content (C)***	***C:N ratio***	***Humidity***	***Volume weight***
	t / y	*%*	*%*	*%*		*%*	*t / m3*
Sludges from WWTP	2100	65.04%	1.8	1.9	16.06	40	0.88
Grass	100	3.10%	3.4	0.1	17	82	0.3
Straw	20	0.62%	1	0.1	50	12	0.6
Leaves	700	21.68%	0.9	4.2	54	38	0.25
Green cuts	300	9.29%	1	1.6	53	15	0.25
Wood chips	0.126	0.00%	3.1	0.0	80	70	0.77
Hay and silage	8.2	0.25%	0.5	0.1	80	12	0.55
Paper and cardboard	0.45	0.01%	0.25	0.0	155	5	0.9
Total	3229	100%	1.57	0.25%			

[35] Current tariffs cover only plant operation, not investments. The increases in tariffs include the payback of investments at zero interest. Adding interests would not change significantly the overall balance. For details on tariffs, see **Table 20**.

Figure 14 *– View of the Razgrad (A) and Veliko Tarnovo (B) WWTPs. Courtesy C.Dimitrova.*

A

B

5.1.3 **Croatia**

We consider the case of Ivankovo, a small municipality in the east of the country, near the Serbian border. The entire municipality had 8,000 inhabitants according to the 2011 census. Apart from the town of Ivankovo, another 2 villages are part of the municipality. Considering its geographical position (between two rivers, Sava and Drava), the area is suitable for agriculture and food processing industries. This part of the country has been heavily affected by the war in the 1990s. Tourism in this rural area has a potential, but is under development. The area is considered sensitive for water/environmental protection reasons and thus it is on the priority list for building a WWTP. The recipient of wastewater is eventually the Rakovec river. A new sewerage system (19 km) and a WWTP have been built and put into operation in 2017 for a total investment cost of 3.1 million Euro (secondary treatment). Due in part to the high cost of connections for individual households, the population connected is below 60% of plant capacity and the plant operates only at primary (mechanical) treatment level, hence possibly not yet meeting standards for COD, BOD, N and P reduction.

The household WWT tariff is 0.8 €/ m³. Separate WWTPs for the remaining settlements in the municipality are being built using SBR technology. Due to the vicinity of 3 WWTPs in the municipality, a CW (reed bed) for sludge mineralisation would be a suitable option, if the required surface can be found, ideally at one WWTP to reduce sludge transport costs. For the existing WWTP, sludge mineralization on a reed bed has been evaluated to require an investment of 250,000 euro, with an operational cost of around 3,000 Euro/year. After 10 years, the mineralized sludge cake could be sold as soil conditioner at around 300,000 Euro, offsetting a large part of the costs. The extra tariff to be paid would amount to 0.06 Euro/m3, which is a relatively low increase compared with the current tariffs. These do not include sludge treatment although the latter will become necessary anyway.

Figure 15 *– The Gaborovo WWTP: Above: overview of the site; Below: left – combined heat and power (CHP) unit, right - digesters. Courtesy C.Dimitrova.*

Table 22: *Investments and tariff changes for the three test cases in Bulgaria.*

Case	Investment, P recovery Euro	Investment, energy recovery Euro	Current tariff Euro/m³	Change in tariff, P recovery Euro/m³	Change in tariff, energy recovery Euro/m³
Razgrad	304,983	4,306,854	0.118	0.006	0.002
Gaborovo	612,200	538,646	0.144	0.006	0.002
Veliko Tarnovo	453,935	2,614,491	0.066	0.003	0.012

5.1.4 **Moldova**

Within the Prut River basin, the Moldavian part of the Danube river basin, there are 43 centralised wastewater treatment systems, three times fewer than centralised drinking water supply systems. We consider three towns as test cases: Cahul (42,000 PE), Leova (12,000 PE) and Cantemir (6,000 PE). All these localities are situated close to the Prut

River, the last downstream tributary on the left side of the Danube River. The main sources of wastewater discharge within the basin are represented by the towns and rural settlements with a centralised sewerage system. The last 20 years have been marked by a steady, massive decrease in the volume of discharged wastewater, from 97 million m3 in 1990 to 10.2 million m^3 in 2013, due to the socioeconomic conditions of the region and the ongoing trend in depopulation. The legislation in Moldova only addresses the use of sludge in agriculture with a number of implementation aspects still awaiting conclusive guidance.

The town of Cahul is situated in the South-Western part of the Republic of Moldova, 175 km from Chișinău. It is the largest town in the South Development Region with a population of over 30,000 inhabitants; It is connected to the settlements of Roșu, Crihana Veche, Manta, Pașcani and Cotihana, which have a joint population of 12,071 inhabitants (with the total exceeding 42,000 inhabitants). Urban wastewater from domestic (522.9 thousand m3/year, 70.4%), and industrial sources (219.4 thousand m3/year, 29.6%) is collected in more than 50 km of separate sewers, mostly built in the 1970s with a substantial new part built in 2007, and designed for the much larger flow of 13.5 thousand m3/day required by the economy of the region at the time (canning factories, wine factories, knitting factories, reinforced concrete factories, the Nufărul Alb spa, and other water-using industries). The secondary WWTP was designed in 1966 and has been operating since 1972 (primary) and 1974 (secondary).

The volume of wastewater received by the WWTP in 1989 – 1991 still reached around 5.0 million m3/year. The current state of the sewerage system and WWTP is quite precarious, with worn-out installations at a low level of safety for the technological process and for the health of the operating personnel (see e.g. **Figure 16**). The population connected to the service includes 8716 households, i.e. 62.2% of the population. The remaining non-connected population uses for this purpose storage tanks (mostly non-sealed) or latrines, and it is estimated that 287 thousand m3 of untreated water indirectly reaches the local shallow aquifer yearly.

Figure 16*: Damaged Biological filter, Cahul. Source: P.Panus.*

The town of Leova is located in the South-Western part of the Republic of Moldova, on the left bank of the Prut River. Industry is made up mainly of the Leova Wine Factory. The town has a 43.6 km long water supply network and 12.6 km of sewerage. Wastewater discharged from the city comes through 3 pumping stations. There are 1856 dwellings connected to the centralized sewerage network, representing 47% of the city's housing stock. Although new sewerage networks have been built, the percentage of new consumers' connection has increased only by 2.7% between 2014 and 2017. The Waste Water Treatment Plant was built in 1990 (see **Figure 17**), with a capacity designed for a then-planned industrial growth. The treatment capacity was $4700m^3$ / day, including secondary treatment (active sludge process) and sludge dewatering and storage. Moreover, the plant was equipped with a tertiary stage consisting of biological lakes (aerated lagoons). In 2012, with the technical assistance of the Agency for International

Development of the Czech Government, works were carried out for the modernization of active sludge aeration basins. In the process of upgrading the biological step with new blowers, pumps and piping, the treatment capacity was reduced more than tenfold, to a flow rate of only 400 m^3 / day. In spite of a clear improvement in the biological treatment process, secondary pollution still takes place due to sediment remobilization caused by neglecting to clean up the sediments at the bottom of the tertiary stage (lagoons) for a long period.

The economic decline of the local industry in 1991-1998 caused a decrease in the volume of wastewater discharged to the WWTP, currently reaching an average level of 200 m^3 per day. "Sludge platforms" (drying beds) are only partially functional, and have had no intervention since commissioning. The biological lakes are interlinked, and used for the mineralization of the sludge from biologically treated wastewater. The surface of the lakes is partly covered with reed, grown naturally. It will be necessary for the development of the sewer system to build an additional 39.2 km of sewerage networks, and connect around 2224 dwellings (5560 PE). The local water operator JSC Apa Canal Leova does not have a laboratory that could permanently monitor the quality of treated wastewater. Monitoring is conducted by the Cahul Ecological Agency. The test is performed at the operator's request and consists of 4 samples taken at the inlet and outlet, both upstream and downstream of the discharge site. This method does not allow for the actual values of the determined wastewater flow to be detected, given the residence time in each decanter. In winter, with low temperatures, biological treatment is reduced due to temperatures below 6°C. This is also demonstrated by the results of laboratory tests that show samples to not match emission standards for BOD, ammonia and other parameters.

Figure 17 *- The WWTP of Leova: primary (mechanical) treatment stage. Courtesy P.Panus.*

Chemical and bacteriological analysis of the dehydrated sludge on the sludge platforms was not performed. The amounts of sludge accumulated since 1994 on the dewatering platforms amounts to 1557 m^3 on a surface area of about 0.42 hectares. The operator does not have a strategy for using the sludge yet, because the platforms are not overloaded. Farmers who request to use this sludge assume total responsibility for this use, as there are no official procedures for sludge reuse.

Figure 18 *- Biological filters in the WWTP of Cantemir. Courtesy P.Panus.*

The Cantemir town is situated on a plateau in the South of the Republic of Moldova near the Prut River. The population of the town is 5800 inhabitants. The most important industrial activity of Cantemir was a canning factory, which closed its activity in 1994. In one of the former factory halls, in 1999, a smaller canning factory began operating, which presently represents the only significant industrial discharge. Cantemir has 8.9 km of sewer networks (including 1.8 km of large-diameter collectors), of which only 6.9 km are functional, and one main pumping station conveying wastewater to the treatment plant. The Cantemir Municipal Water Enterprise estimates water consumption in 62.2 thousand m^3/year of treated drinking water (domestic users: 56.5 thousand m^3/year; public institutions: 6.4 thousand m^3/year; economic activities/industry: 4.3 thousand m^3/year). The wastewater is charged at a rate of 30% from the volume of water used. The approximate volume of annually billed wastewater is 700 m^3, slightly more than 1% of the treated drinking water. There are 1700 subscribers connected to the sewerage services, of which 1000 are backyard houses and only 700 apartments in multi-storey buildings, with only 700 m3/year of wastewater billed. The wastewater treatment plant of Cantemir-town was built as early as 1963 -1965, including secondary treatment (AS) and sludge dewatering platforms. The capacity of the plant according to project data was 3500 m^3/day. The plant has now a high degree of physical wear and damage (**Figure 18**), which does not allow the rehabilitation or modernisation of the existing construction and installations, and makes it necessary to build a new station. In practice, wastewater passes through the installations almost as if untreated. The connection pipes inside the WWTP installation are damaged, and water flows to the ground. In the biological stage, none of the 4 biological filters work. Biological filters are partially disassembled. In the biological ponds, water pollution occurs before their discharge into the tributary, the Tigheci River that, after a run of 5.1 km, flows into the river Prut. There are plans to build a new WWTP in Cantemir, also treating wastewater to be collected from nearby settlements of Cania and, in the longer term, Epureni and Porumbești. This would allow the increase of connections to the sewerage system for a total of 7000 PE.

For the two smaller plants of Leova and Cantemir, replacing the existing plant with a CW solution would enable saving two thirds of the current electricity consumption; moreover, CW would be far less sensitive to the intermittency of flow currently impacting on the operation of the secondary treatment in place. The investments required in the two cases are estimated be of about 7 and 9 million Euro respectively; a tariff covering O&M costs would be of about 0.48 and 0.73 Euro/m3, respectively, while selling reeds from the CW could pay back 0.05 and 0.1 Euro/m3, respectively. In similar cases, an oversized and obsolete conventional WWTP would provide land areas, which could be reused for the implementation of CW solutions with significant savings.

For the larger plant of Cahul, extending the sewerage to the whole agglomeration requires significant investments. In terms of plant operation, the current tariff (0.47 Euro/m3 enables covering current costs. Sludge management (dehydration and thermal treatment) would require additional investments that could be covered with an additional tariff estimated at 0.14 Euro/m3. This could be cut by 2 cents/m3 if stabilized sludge could be sold as soil conditioner.

Moldova features an example of a French reed bed constructed wetland designed to treat 20,000 PE in Orhei[36], supported by the World Bank, and considered one of the biggest in Eastern Europe (**Figure 19**). This plant partly replaced an existing, but obsolete, traditional WWTP (**Figure 20**). Although initially planned to serve the whole agglomeration, the new CW plant was not connected to parts of the sewer network due to several contingent problems during implementation.

All in all, CW may offer an effective solution in Moldova, where the recent trends in depopulation have made some traditional plants clearly oversized and obsolete.

[36] http://www.worldbank.org/en/news/press-release/2013/09/18/world-bank-supported-wastewater-treatment-plant-to-provide-improved-sewerage-services-for-orhei-33000-inhabitants. See Masi et al., 2017, for further details on the plant.

Figure 19 *– A-D: views of the FRB plant in Orehi, Moldova (courtesy F.Masi); E: water inflowing (plastic bottle with blue lid) and outflowing (glass bottle) the plant (courtesy C.Nanu).*

***Figure 20** – views of the pre-existing, obsolete WWTP in Orehi, Moldova (courtesy C.Nanu)*

5.1.5 **Montenegro**

Montenegro comprises 21 municipalities. According to the 2011 census, it has 625,266 inhabitants, 392,020 of which live in urban areas. The country has a developing economy, with important regional disparities. Its inhabitants are mainly located in the central and southern parts of the country. The economy is characterized by low labour productivity, import dependence, high unemployment, and undeveloped financial institutions and capital markets. The northern part of the country has a higher rate of unemployment and a lower income per capita than the central and coastal areas. Public water utilities use groundwater to produce drinking water. In 2012, 114 million m^3 of water were abstracted for public water supply, 90% of which came from groundwater. Industrial facilities use raw water, approximately two-thirds of which comes from surface water and one-third from groundwater. Prevailing pollutants are mainly the result of wastewater from point sources. Industrial wastewater treatment is performed in only a few industrial plants, and there are only four municipal wastewater treatment plants for the whole country. In coastal areas, wastewater is discharged directly into the sea. Of the four large WWTPs, all equipped with secondary treatment, three were built between 2003 and 2007, and one in 1978. Half of current investments are funded by international loans, with an estimated financial demand of € 813 million (€560 million planned for wastewater and €253 million planned for water supply) until 2029 to reach full EU standards, around twice the current level of investment. Some EU funding (through the Instrument for Pre-accession Assistance, IPA) should be available to finance these investments. Efforts will have to be made to improve both the quality of drinking water delivered, since the compliance rate is only 85%, and the effective level of collection of wastewater and its treatment.

In Montenegro we consider the two test cases of Mojkovac and Žabljak. Mojkovac is a small town on the banks of the Tara river within the Danube catchment. According to the 2003 census, the town had 4,429 inhabitants. In the 2011 census, that number fell to 3,590, in line with the depopulation trend in the Northern (mountainous) part of the country. The population of the whole municipality may be just above 8,000 persons. While industry (wood processing and zinc mining) was present in the past, tourism is presently the main driver of the local economy.

Figure 21 *- Constructed wetland for sludge treatment in Mojkovac (Courtesy Alenka Mubi Zalaznik)*

A 7 km sewage network is in place (completed in 2008), covering 37% of the municipality's population, while the remaining population is difficult to connect. The existing WWTP was designed and built for 5,250 PE, with an average expected daily flow of 780 m^3 and influent loads of 315 kg/d of BOD, 630 kg/d of COD, 9 kg/d of P and 58 kg/d of N. The WWTP performs a secondary treatment with nitrogen removal. After coarse screening, wastewater is brought into one denitrification pool, then moved to one nitrification (aeration) pool, and finally pumped into the secondary clarifier. Sludge is transferred directly onto a reed bed (**Figure 21**) while effluents are discharged into the Tara river. When the WWTP was built (in 2008), dehydration presses were bought and installed for sludge processing. Due to high operating costs, this technology was never used and sludge was stored in a tank originally planned for use with dehydration technology. The reed beds were introduced when sludge storage tanks were nearly filled, and have been in operation since 2016. Two reed beds are sufficient for sewage sludge treatment as the WWTP operates at 50% capacity. The mineralised sludge is planned to be used for fertilising surrounding forests that were affected by wildfires in 2012. The water from the reed beds is recirculated to the WWTP.

***Figure 22** – Žabljak: realization of a constructed wetland for sludge treatment, next to the waste recycling centre (courtesy Gregor Plestenjak)*

Žabljak is a small town in the Northern part of Montenegro, in the Danube catchment. The town is a popular tourist destination throughout the year. According to the 2011 census, it has 1,723 inhabitants, while the entire municipality has 4,204 inhabitants, in 28 dispersed settlements. Due to the constant influx of tourists, the served population is more stable in numbers[37]. While the current flow of tourism is of about 4,800 yearly overnight stays and increasing, summer peak days may result in at least 2,000 daily visitors. Due

[37] Town inhabitants: 1723 PE; Overnight guests add: 4800 PE/y = 400 PE/m; Summer peaks: add 100 PE/m (April -September)

to uncontrolled urban development, the existing sewer system is no longer fit for the demand. At least 1,500 cottages have been built without a permit in recent years, and have no access to sewerage systems. The sewerage has been completed only for the central part of the town. The wastewater treatment plant became operational in 2012. It has a capacity of 2,000 PE and ensures secondary treatment through SBR technology. The design average daily flow is 500 m^3/d. The sludge is distributed to reed beds in the vicinity of the WWTP, in the site of the waste recycling centre and landfill - **Figure 22**).

In both Mojkovac and Žabljak, the plants are already coupled with reed beds, but a full, stand-alone CW solution could have been considered from the beginning, avoiding the need for technological, more operationally demanding solutions. The currently high costs of plant operation, not matched by the tariffs in place[38], could be reduced considerably. The following table summarizes the estimated costs for the two cases.

Table 23 *– financial elements for the Monenegro test cases*

Item	**Mojkovac**	**Žabljak**
CW: investment	€ 472.500	€411.000
CW: operation and maintenance costs	€ 15.000/y	€30.000/y
CW: potential revenues	0[39]	0
Required tariff considering revenues	n.a	n.a
Required tariff excluding revenues	0.5	0.17

5.1.6 **Romania**

At the time of its EU accession (2007), Romania had a good professional culture, operational organization, and qualified personnel in the water management sector. Currently, large differences persist between urban and rural areas in the water service sector, and the country has the highest number in the EU of rural people not serviced by public utilities (about 60% of the rural population according to World Bank and IAWD, 2015). Water Supply and wastewater service provision is the responsibility of local administrations. A process of reorganization of water utilities into better structured Regional Operational Companies (ROC) started in 2008-2009. Local administrations started to join intercommunal development associations (IDAs). IDAs are the shareholders of the ROCs, which, in turn, sign a delegation contract with the IDA to provide services in a particular jurisdiction. The process, however, is still far from complete despite general improved service performance, and has uncovered difficulties in the cooperation among different organizations at the local level. While major transfers from EU funds have occurred, the WWT sector is still underfunded. A target to expand WWT in rural areas is included in the Operational Program Great Infrastructure (POIM) for 2014-2020[40]. However, investments made so far by ROCs have focused on improving (usually already

[38] For details, see **Table 20**.
[39] Reclaimed water cannot be sold in these relatively water-rich areas.
[40] http://www.fonduri-ue.ro/poim-2014. Major projects proposed by mid 2018 in the water sector: http://www.fonduri-ue.ro/images/files/programe/INFRASTRUCTURA/POIM/2018/25.07/Lista_proiectelor_majore_cu_modificarile_propuse.pdf. All project with 3.2.

existing) wastewater services in larger urban agglomerations (cities with more than 100,000 PE). In 2016, only 40% of the rural population was connected to public piped water services: of these, 50% were still served by local water operators, and the other half by ROCs.

In Romania, we considered three test cases: the villages of Vadu Oii (town of Hârsova) and Petelea (city of Tg. Mures), and the Tg. Mures Cluster.

The town of Hârsova (about 10,000 inhabitants) is located on the right bank of the Danube River, in the North-West part of Constanta County, 10 km from the Danube confluence with the Borcea branch and 85 km from Constanta. Within the municipality, the village of Vadu-Oii is located 10 km north-west and has approximately 390 inhabitants in 192 households. The town has a sewer network and a WWTP operated by a ROC built to service a population of 12,750 PE with secondary treatment, P removal, sludge dewatering and storage, and UV disinfection of effluents.

On the contrary, Vadu-Oii is served by water supply but has no sewer system. Domestic wastewater is collected in septic tanks before release into the environment. As an alternative to collecting wastewater from Vadu-Oii and sending it to the Hârsova plant, a local solution with either FBA or FRB was considered. Such solution would entail local collection of wastewater (about 5 km pipelines), representing the dominant investment (500,000 Euro). FBA would require an investment of 90,000 Euro, whereas FRB would require up to more than 120,000 Euro if nitrogen emission limits are to be met. The area required by FBA is 400 m^2, but could more than double for FRB with nitrogen emission limits. While in general land costs may be significant, in the specific case of Vadu Oii this would not be an issue because the Municipality owns sufficient land for the WWTP.

The tariffs required to cover both the investment and operation costs of the WWTP in Vadu Oii would exceed 2 Euro/m3, which may be an issue given the local socioeconomic conditions (relatively aged and poor population). A tariff allowing coverage of O&M costs alone would amount to 0.42 Euro/m3 for the FBA solution, and 0.26 Euro/m3 for the FRB. Selling reed could generate revenues covering about 10% of the O&M costs annually. As a reference, the tariff applied in Hârsova with the existing WWTP is 1.1 Euro/m^3.

The investment requires some transfers anyway, as it cannot be supported with tariffs only, and the main cost is represented by sewerage. In order to reduce investment costs, a solution could be to resort to small scale WWTPs for individual or small groups of households, with an increase in the cost of treatment, but also a possibly significant reduction of the cost of sewers. A drawback may be related to the ownership of the land required for FRB, which is presently not available to the wastewater treatment operator but is in private hands.

Given the strong variation of temperature between winter and summer in the region, the effective functioning of CW was called into doubts by the local plant operators, also based on past negative experiences with this type of solution. However, positive experiences are documented with CW in similar climates (see Masi et al., 2017).

Implementing a more traditional "technological" solution such as SBR, which the local plant operator sees as preferable, would entail an investment cost of 170,000 € and an additional 500,000 € for the connection of households, and would require a tariff of 0.3 €/m^3 to cover O&M costs alone. An SBR solution is more expensive, and its operation requires skilled personnel and adequate knowledge.

Petelea is located on the left terrace of the Mureş Valley, 25 km northeast of the city of Tg. Mureş, and 6 km south of the city of Reghin. The main village has approximately 3000 PE, while a smaller nearby one, Habic, has approximately 300 PE. Petelea's wastewater is partly collected by a 4,8 km sewer system with pumping stations, and another 7,6 km of sewers for the rest of the village are planned. This water is going to be pumped to the newly revamped wastewater treatment plant of Reghin city. Thus, the village does not need a wastewater treatment plant. The village of Habic, in contrast, is located approximately 8 km away and has no sewer system nor treatment plant. A sewer system for the whole village would need to be approximately 4,0km long, and there is an area of 1.3 ha available for a treatment plant, property of the local administration. The situation is therefore very similar to Vadu Oii. In this case, the O&M costs may be around 11,000 Euro (FBA) to 8,000 Euro (FRB) yearly, requiring a tariff between about 0.8 and 0.6 Euro/m3 to cover O&M costs only. As tariffs approach 1 Euro/m3, they are judged high in the local context, due to the socioeconomic conditions (ageing population and high unemployment) in the area.

The city of Târgu Mureş, together with the surrounding selected area consisting of 18 settlements, has a total of approximately 200,000 PE. Industrial activity around the cluster consists of a chemical plant producing fertilizers, as well as slaughterhouses, dairy production, poultry, meat processing, breweries and pharmaceutical industry. The largest industrial company is a producer of chemical fertilizers, which in 2015 opened its own wastewater treatment plant. All the wastewater from the 18 settlements is to be collected and discharged into the Târgu Mureş wastewater treatment plant and, after treatment, into the Mureş river. The plant has recently been renovated with EU Instrument for Structural Policies for Pre-Accession (ISPA) grants and a loan from EBRD. It is designed to handle wastewater for the whole cluster, 230,000 PE, for 14,000 kg COD/day and 1.1 m3/s. This is the expected situation until 2028. Today, the treatment plant handles 10,000 kg COD/day at a flow of 0.8 m3/s, running at about 70% of its capacity due to the fact that not all 18 settlements have implemented sewer systems, and not all inhabitants are connected to the sewer network. The load reserve for the WWTP is around 30%, and the hydraulic reserve around 25%.

At the moment, the sludge line consists of digesters, gas storage, a combined heat and power (CHP) plant using biogas, and a newly build belt drier. During the winter period the thermal and electrical energy from the CHP is not enough for the demand of the plant.

The Târgu Mureş plant is adjacent to the WWTP of the chemical industry producing fertilizers, which in turn is *de facto* operated by the same company of the urban WWTP. This creates ideal conditions for industrial-ecological relationships.

One opportunity lies with the recovery of the heat from the effluents of the fertilizers plant (22,000 m3/day at a temperature of 20-30 degrees all year round). The heat can be extracted using heat pumps and may be used for the digesters of the WWTP. This would save approximately 1300 thermal MWh and about 130,000 Euro yearly for the operators of the urban WWTP. Heat pumps would require an investment of about 1.5 Million Euro, and would entail O&M costs of about 24,000 Euro/year. The investment would not require a raise in tariffs of WWT, because it would be supported by the privately owned fertilizer company, which can use the energy to reduce costs for biological sludge dewatering, now operated at the municipal plant at a cost for the company.

Another opportunity of industrial ecological relations could be in principle with the extraction of phosphorus from wastewater. This would entail an investment of about 1.2 million Euro and an annual O&M cost of 1.3 million. The recovered P (260 tonnes/year) could be used directly by the fertilizer producer, which is currently buying mineral P from phosphate rocks at a cost of about 400 Euro/tonne, corresponding to 104,000 Euro/year. However, unless motivated by the need to achieve stringent effluent standards, P extraction would not yet be justified economically.

Water reuse is also an interesting option in this case, because the fertilizer plant withdraws 7.3 million m3/year of river water at a cost of 0.02 Euro/m^3; this cost is very low, but river water needs to be filtered to reduce suspended solids, and this consequently generates sludge that must be treated and disposed of. Using reclaimed wastewater would save the chemical plant the associated costs. Water reuse would require an additional 1.16 million euro investment in the urban WWTP, and O&M costs of about 30,000 Euro/year. The revenues would be at least the cost of using river water for the fertilizer plant, or 146,000 euro/year. Table 24 summarizes the costs and revenues associated to the above-mentioned opportunities.

In spite of the long payback of this investment, heat recovery seems more of an interest to the management of both the water operator and the fertilizer factory, in the light of possible grants available in the context of public stimulus to the circular economy.

Water reuse by the fertilizer company, although possible, seems unlikely due to the new investments in the treatment of raw river water made by the company. If this option had been explored at the right time, it might have brought to a different investment decision.

Table 24 – costs and revenues for the Tg. Mures cluster

Option	Investment	O&M	Revenues
Heat recovery	1,500,000 €	24,000 €	130,000 €
Water reuse	1,160,000 €	30,000 €	146,000 €
P recovery	1,200,000 €	1,300,000 €	104,000 €

5.1.7 **Ukraine**

As in the case of Romania, Ukraine has a large population living in rural areas with very limited access to centralized water supply and wastewater processing services. Among 13.5 million rural dwellers, around 4.6 million have access to piped water for drinking. The remaining 66% of the rural population rely on non-piped, self-supply systems (wells).

In 2011, in Ukraine, 446 out of 459 cities (97.2%), 512 of 885 urban-type settlements (61.2%), and only 727 of 28,471 rural settlements (2.6%) were covered by wastewater collection systems, although the most recent estimates indicate a more-than-doubling (6%) of the share of rural wastewater that is collected and treated.

The average collection rate is 46.5%, with 64.8% of the population served within cities and towns, and 45.6% of the population in villages. In 2011, collected wastewater was estimated at 2.2 billion m3, of which about 80% was biologically treated.

The treatment of municipal wastewaters generates a significant amount of sludge, and the dominant practice is the disposal on sludge fields in order to be dried and for subsequent excavation. This practice may cause uncontrolled releases of methane and other greenhouse gases.

Anaerobic treatment of sewage sludge with controlled release of methane and its utilisation takes place only in the urban wastewater treatment plant in Kiev (Bortnicheskaya aeration station). The methane tanks were built in the 1960s and 1970s, and half of them do not work at the moment. Generally, the conditions of the cities' sewerage system are characterized by worn-out equipment and outdated technologies (some of them with a lifespan of more than 30-35 years).

Chernivtsi is the centre of Chernivtsi Oblast (or Bucovina province) of Ukraine, a historic city with a population of more than 250,000 inhabitants on both banks of Prut River, at altitudes of 100-250m above sea level. The population density is 1645.6 persons /km^2 and the population slightly increased in 2000-2010, thanks to internal migration from rural areas. The region has borders with Romania and Moldova. It occupies a convenient geographical location, and has good road infrastructure. The Prut River crosses the city over 18km, dividing it between a right side with hills and a left side with lowland.

The city has a diversified industry (agri-food processing, light industry, machine building, woodworking industry, a leather and rubber shoe factory, a textile factory, and machine-building plants for the oil and gas industry). The city's sewerage system consists of 293.39 km of collectors (main collectors: 36.2 km; street networks: 160.9 km; connections to the public pipelines: 96.3 km). The sewers in the historical part of the city are combined; in the newly built areas, they are separated. Wastewater is partly treated in a central WWTP built in 1960-1965 and restructured in 2014, with a capacity of about 55 million m^3/year.

The WWTP includes mechanical and biological treatment, sludge dewatering and storage, while tertiary treatment is planned but not yet functional. The currently treated volume is less than 19 million m^3/year. The Molnițea River, a tributary of the Prut, receives around 570 thousand m^3/year of wastewater without treatment from the city.

An opportunity offered by the existing plant is the investment in a module for sludge composting, and a system for the extraction of biogas, for a total investment of about 2.366 Million Euro. The former would allow producing compost to be used as fertilizer in agriculture; the latter would enable covering about 40% of the electricity needs and 100% of the thermal needs of the plant.

These investments would require a slight increase in current tariffs, from 0.11 to 0.2 Euro/m3, becoming 0.13 Euro/m3 net of the revenues from selling electricity and heat. At the same time, this would enable considerable improvements in the management and disposal of sludge.

5.2 Opportunities and challenges for innovative solutions

In the lower Danube, challenges of WWT may be classified in three broad types:

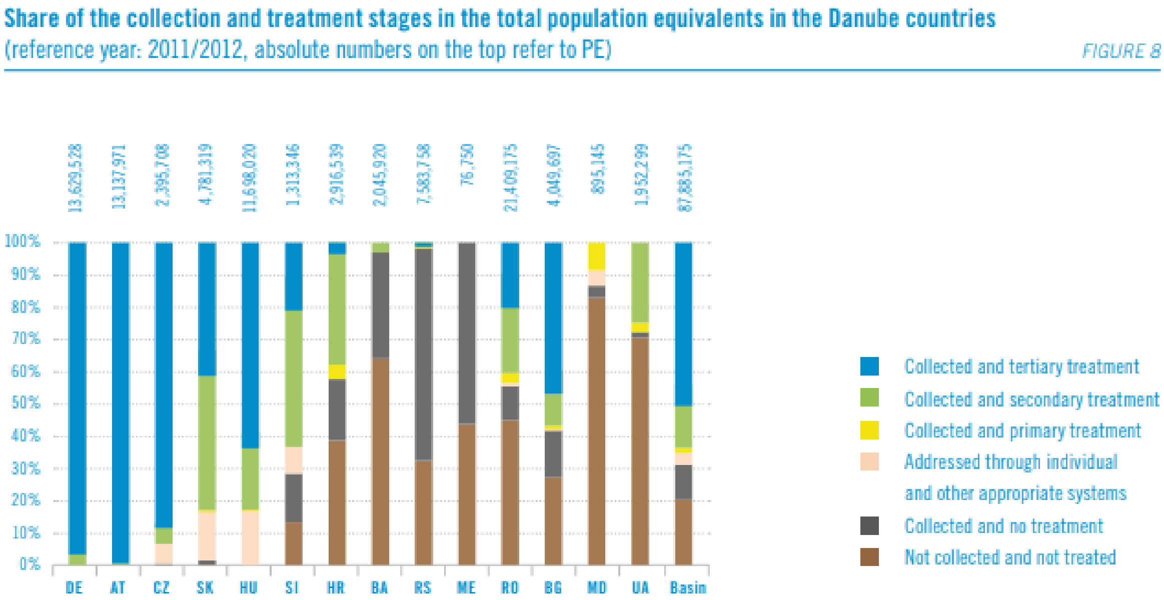
1) Completing collection and treatment in larger settlements, where sewerage is still incomplete, or where connections are not fully in place despite the existence of sewers; in some settlements the WWTP is still not present or is inadequate, because of the wear of the equipment, the lack of maintenance, errors of design or obsolescence, or a combination thereof. Figure 23 shows that collected but not treated population still accounts for about 10% of the Danube basin's total, concentrated in the Lower Danube and Slovenia.
2) Serving smaller settlements, especially in rural areas, where current levels of treatment remain low; while less of a priority in certain areas, the rural population represents a very significant share of the total in some countries. Figure 23 shows that the population with uncollected and not treated wastewater is still about 20% of the Danube basin's total, concentrated in the same countries as the population with collected but untreated wastewater.
3) Making operation sustainable in existing plants, where opportunities exist e.g. for resource recovery and where, in spite of an existing wastewater treatment line, sludge disposal is still not appropriately addressed.

Biological treatment through the activated sludge process is in practice a standard solution for plants with a size above a few tens of thousands PE, but is widely applied also for smaller settlements. For smaller plants, MBR and SBR are regarded as possible alternatives, together with CW. The latter definitely represent a favourable option for smaller settlements. As such they are already implemented at many sites in the Danube region, generally with positive experiences despite some limitations (e.g. poor performance under conditions of low winter temperatures reported in Hârşova), possibly due to lack of experience of the operators with these systems. Their main advantage is in the low cost of O&M, while a disadvantage may be the land requirements, usually higher than with technological solutions.

The high interest in these and other nature-based solutions (NBS) shown by stakeholders across all test cases discussed above may be also related to the potential co-benefits for the local communities, besides the expected lower investment and operational costs. On the other hand, the limited knowledge of local operators and stakeholders on these solutions may be limiting their uptake and the willingness of operators to explore their applicability. This may indicate a need for additional knowledge-sharing actions and demonstration projects.

Concerning land requirements, in many cases land acquisition may not actually be a problem, for instance because of the availability of marginal land owned by the municipality. In other cases a wastewater treatment plant already exists but needs to be rebuilt on the same site (as in Leova and Cantemir, MD). CW are a good alternative for replacing WWTPs in cases, such as Mojkovac and Žabljak (ME), where the existing ones do not operate effectively or efficiently. In these two cases, reed beds were built to treat the sludge downstream of the wastewater treatment processes, but could have completely superseded the WWTP if appropriately designed.

Figure 23 *– shares of the Danube's population equivalent with different levels of wastewater collection and treatment (source: ICPDR, 2015).*



When considering smaller settlements and rural areas, CW often represent the only economically sustainable solution. In these cases, however, the appropriate operation of these systems may be a challenge. In the case of Slovenia, these plants are incorporated in the wastewater treatment system of a district (e.g. a municipality). The owner (household) is required to spend in investment and maintenance an amount comparable to what they would pay if they were connected to the sewer network and to a centralized WWTP, but the supervision of the operation and maintenance, as well as the control of discharges, is in the remit of the operator. However, small IAS are usually not subject to sampling procedures and detailed monitoring of parameters except once, at the beginning of operation).

For existing plants, the anaerobic digestion of sludge, and the use in a combined heat and power (CHP) generator of the associated production of biogas, can cover a large share (sometimes even > 100%) of the electric and thermal energy demand of the WWT process. In order to be economically competitive, anaerobic digestion and biogas extraction require a minimum amount of feedstock, making it not attractive for smaller WWTPs. However, co-digestion with additional organic waste may offer considerable opportunities for win-win solutions and may enable achieving sufficient scale, also in the case of smaller plants. The digestion of sludge may be combined with that of the organic fraction of municipal, industrial and agricultural waste (including manure), thus seizing potential economies of scale. In this perspective, the WWTP becomes a node of a broader waste management system, and the overall energy recovery may be pushed to higher levels.

The theoretical resource recovery of larger plants may be significant, but may only become advantageous when there is a local demand, depending on the local context. For instance, water reuse is theoretically possible in most cases, but irrigation infrastructure may be inadequate and/or the current price of irrigation water may not justify wastewater reclamation. Part of the heat generated by biogas combustion in a CHP unit may be used for district heating or industrial processes, but this implies a greater integration with the industry and the existence of a heating service operator. District heating was found to be an interesting option only in Chernivtsi (UA), because the WWTP in Chernivtsi is well positioned in relation with possible clients (a private block of flats or state owned buildings). Often an incentivizing feed-in tariff can apply to electricity produced from biogas (this is the case, for instance, in Ukraine), improving the sustainability of investments in anaerobic digestion.

The digestion of sludge and waste generates significant amounts of digestate with a very high liquid fraction. The digestate may be reused wet as soil fertilizer, but may require various degrees of dewatering depending on how it is managed. Dewatering in turn creates additional effluent that may call for extra treatment. This may pose limits to the expansion of co-digestion if an appropriate management chain of digestate is not in place. The use of digestate as fertilizer poses safety concerns insofar as the product may contain contaminants at harmful levels, or that can accumulate in soils. Moreover, the higher the water content of the digestate, the higher the risk of nutrient and contaminant leaching from soil applications.

In the Serbian feasibility study, struvite extraction was considered from digestate originating from wastewater sludge and municipal organic waste, whereas digestate from agricultural waste and manure was considered for use as such in agriculture. As an alternative to anaerobic digestion, aerobic stabilization of sludge in reed beds is attractive especially for smaller settlements and rural areas. The extraction of struvite is often still not economically self-sustainable, and may require putting appropriate incentives in place to internalize the costs of possible negative consequences of phosphorus discharge, and of phosphate rock ore reserve depletion.

Water reuse is identified as an option to address water scarcity. It is increasingly supported by the European Union in the context of initiatives to promote a circular economy, including a recent legislative proposal on water reuse[41]. Reuse of treated wastewater may support irrigation, thus reducing water abstraction from water bodies. It can also enable a better use of the nutrients contained in treated effluents, which otherwise would just contribute to the pollution of water bodies.

Depending on the design, CW operation may provide nutrient and water recovery, while energy recovery is usually not possible. In the study region, little appetite has been shown for water reuse except in the case of Slovenia, where using effluents treated in CW to irrigate apple orchards was regarded as an attractive option. It is possible that climate change induced water scarcity, projected to increase particularly in the Lower Danube, raise more interest for water reuse in the future. In general, centralized WWTPs are more suitable for infrastructure-intensive irrigation whereas decentralized systems may offer favourable conditions for water reuse in irrigation near the plant (as in the case examined in Slovenia). The option was considered in Razgrad (BG) as well as Hârşova and Tg. Mureş (RO). Tg.Mures is an interesting example of favourable industrial ecological conditions, whereby the fertilizer factory near the WWTP might be interested in reusing treated wastewater as process water. In the Tg. Mures case, private industrial facilities such as a beer factory or a dairy processing factory could be also identified as potential users of recovered resources, although this could not be discussed with the local actors and stakeholders. Carbon-rich brewery wastewater could be combined with wastewater from the fertilizer factory, which is low in carbon, to enhance the biological treatment and decrease the consumption of external carbon added as methanol, hence the operational costs of the fertilizer factory's treatment plant. Moreover, recovery of heat from the latter treatment plant could help decrease the costs of municipal wastewater sludge management (now done with belt dryers).

The cooperation between WWTPs and industries, as well as households, as potential customers of additional services, should be strongly improved in the next years in order to effectively advance resource recovery from WWTPs. The cases examined in this study suggest that establishing a "synthesis centre" at the early stage of planning of a WWTP, with the involvement of industrial stakeholders and local communities, might help invent

[41] http://ec.europa.eu/environment/water/reuse.htm

more sustainable and effective solutions. Legislative gaps and lack of policy coordination with other sectors (environment, energy, social, financial, etc.) are adding difficulties to innovation in the (waste-)water sector. Legal barriers were reported e.g. in Romania, hampering the uptake of reuse/use of sludge as fertilizer.

In general, in the region wastewater treatment is still largely perceived by users as well as operators as a necessary, if costly, service with no ambition to harness it in the perspective of a circular economy. This is in itself a cultural barrier to more integrated solutions, further hampered by lack of state-of-the-art technical skills. Often, for instance in Moldova, engineering companies still apply old norms of the Soviet Union. All test cases unveiled a low level of cooperation with local communities and stakeholders, reflecting little awareness of opportunities from clustering and industrial ecology.

Management culture and practice may be also key in advancing WWT in the region. The majority of water operators in all the Lower Danube Basin countries are publicly owned, exposing them to the risk of political interference with management decisions. For example, the director of a public utility company might be changed after elections as part of a spoil system; or employment policies might be driven by political considerations rather than by the actual needs for efficient operation; tariffs are broadly reported to not reflect real costs, largely paid through general taxation. Perceiving themselves essentially as governmental entities, many water operators may not have been very concerned with developing *the quality of their services for the benefit of their clients*. Even neglecting these aspects, water operators may be primarily focused on technological development (without innovative technologies) and less interested in developing a relation with local communities and stakeholders in order to invent win-win solutions and improve the quality of the service.

A regionalization of water services has begun in several countries (such as Romania, Croatia). This has helped improve water services, compared to countries lacking such regionalization strategies (Bulgaria, Montenegro, Moldova, Bosnia-Herzegovina, Ukraine), although this process has stopped at a certain point[42].

In almost all countries, local administrations and other stakeholders have raised the issue of *the disadvantaged households* (most often, coinciding with low-income, ageing population in rural areas). As it is apparent that extending water services in rural areas will guarantee limited return on the respective investments, ensuring basic water access and sanitation services remains an economic challenge. The financing of investments in wastewater treatment and resource recovery is generally insufficient in the test cases, but tariffs still not covering even mere O&M costs are not uncommon in the region. Although affordability constraints may exist (e.g. in the Vadu-Oii and Habic cases in Romania), in many cases tariffs are so low that they could be raised without significantly impacting on livelihoods, while allowing to broadly improve WWT in the region.

[42] In Romania, the first step started with Dutch subsidy assistance in 2007, concluding with reduction of the number of regional water operators to 42 as it is now. Other small rural water operators to be integrated in a reduced number of operators on country level, process which already started in 2018 (tender organized by EBRD). In BA, HR and ME, the regionalization of services in the WWTP sector is also hampered by the relatively recent war in the region.

6 Conclusions and way forward

The Lower Danube requires more and better wastewater treatment. Investments are expensive and funds may be lacking, but this is only one reason for insufficient wastewater treatment. Sometimes, investments are supported by international transfers, but the operation and maintenance of plants proves challenging. Reasons for inadequate performance of wastewater services include:

- lack of technical capacity;
- lack of governance and management capacity;
- inadequate financing of the operation and maintenance of plants;
- and normative barriers to the recovery of resources.

In terms of technical capacity, while large plants in urban areas may be managed by large utilities with specialized personnel, often smaller plants in rural areas cannot count on adequate staff. A trend of depopulation especially in rural zones of the lower Danube further exacerbates this situation.

In terms of governance and management capacity, wastewater treatment services are often still under the mandate of small, local utility companies owned or controlled by the municipality. While this may be an opportunity for a better public and community control on the service in the interest of affordability and environmental protection, often these utilities do not have the dimension to develop an adequate level of effectiveness.

Financing is also a challenge in many cases, due to a lack of adequate business models and of clarity on the tariffs and other sources of income. It is worth stressing that the funding of investments does not seem, however, to be a strict bottleneck for the implementation of wastewater treatment. The European Court of Auditors, in a recent report[43] relative to Romania and other Danube countries (CZ, SK, HU), observes *inter alia* that available European funds were not fully absorbed to support investments in WWT, and tariffs were not always appropriately leveraged within the affordability constraints to make the financing of WWT sustainable. The Danube Water Programme's State of Sector Report (World Bank and IAWD, 2015) shows that, while a utility aggregation process is ongoing and more market-oriented business models in WWT are emerging, many utilities remain at municipal level and have a small size, which exacerbates difficulties in the financing of projects. While in certain cases tariffs have been raised up to levels that may be unaffordable for the poor, in general the cost recovery is far from complete, with "*many utility companies [...] barely recovering their operating costs from tariffs, and invest[ing] too little into asset management and development*" (World Bank and IAWD, 2015, p. 66). In the long run, this state of play threatens to undermine the overall sustainability of the system and universal access to WSS.

Finally, normative barriers exist particularly for what concerns the possibility to effectively recover resources. The legal status and requirements of reclaimed water and sludge as fertilizer are sometimes uncertain due to unclear or incomplete secondary legislation. The legal framework is also incomplete concerning the definition of markets for recovered resources. For instance, recycled water is not used in Slovenia because the current legal standards for treated wastewater released into watercourses or on soil do not include microbiological parameters, hence users are not guaranteed the quality of water for crop irrigation.

In Romania, Government Ordinance (GO) 344/2004 transposing Directive 86/278/EEC Directive, was judged initially too vague by the Romanian water sector and underwent a number of revisions (almost with annual frequency), also taking into account the results of the research

[43] Special report No 2/2015: EU-funding of Urban Waste Water Treatment plants in the Danube river basin: further efforts needed in helping Member States to achieve EU waste water policy objectives. https://www.eca.europa.eu/en/Pages/DocItem.aspx?did=32196

and analyses carried out on this topic at national and international level (see e.g. Traşcă et al., 2011). The last modification was made in autumn 2018[44].

Table 25 – Comparison of the key features of the two strategies for smaller and larger settlements

	Smaller settlements	**Larger settlements**
Strategic driver	Minimize costs and complexity	Maximize resource recovery
Energy	(No practically available option).	Heat and power from biogas in anaerobic digestion. Recovery of heat may be maximized in industrial clusters.
Nutrients	Mineralized sludge cake from filtration in reed beds.	Digestate; struvite extraction.
Water reuse	Local; possible fert-irrigation	Reuse for irrigation; possible use of reclaimed water in industrial clusters.
Greenhouse gas emissions	Higher risk of CH4, N_yO_x leaching	Risks of CH4 leaching in anaerobic digestion
Co-benefits	Landscape value, biodiversity	Economies of scale, flywheel of industrial ecology
Key stakeholders	Local community and other co-beneficiaries of nature based solutions	Industrial installations and housing blocks near the plant

In the last years there was a strong push by the Romanian water operators towards promoting the use of sludge from urban WWTPs in agriculture[45], but local communities and farmers were not particularly involved, and were not always aware of the potential risks involved (e.g. GO 344/2004 does not address pathogens). Information campaigns were not systematically planned, also due to a lack of coordination at the national level of policies for the recovery of resources from the water sector, although national policies could instead significantly help promote a more sustainable approach to sludge management.

On the other hand, Romanian farmers are making great efforts to reduce production costs in order to increase profitability. In this context, the use of sludge from waste water could become attractive, especially if transport and spreading costs can be shared with WWTP operators. Certain water operators (Apa Canal Galati, Aquaserv Tg.Mures, Aquatim Timisoara, etc.) manage specific programmes to support farmers and enhance collaboration, but these efforts are not backed up by market incentives and cooperation with public authorities and farmer associations for scaling up pilot projects already implemented in the region[46] to reach a real market dimension.

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[44] See e.g. http://citynews.ro/eveniment/se-schimba-legea-domeniul-serviciilor-publice-de-apa-canal-ce-trebuie-sa-stie-proprietarii

[45] http://www.aquatim.ro/posmediu/wp-content/uploads/2015/09/Pliant-utilizare-namol.pdf

[46] For instance, the Mioveni WWTP in Romania implements aerobic digestion of sludge from the wastewater treatment plant mixed with green waste to produce compost for agriculture. See https://www.youtube.com/watch?v=W2028D8OIJI

Beyond the specificities of each individual case, we have explored two general strategies to cope with WWT in the Danube: for smaller settlements, CW usually entail lower costs and are simple in terms of maintenance and operation, but require adequate design and performance monitoring. They should therefore be thought of not as private facilities, but as part of a distributed but collective treatment system, and placed under the supervision, if not direct operation, of a professional operator. For larger settlements, WWTPs should particularly aim at resource recovery and synergies with other industrial processes, so to optimize the overall performance of the system and achieve a reduction of operation costs (hence tariffs). The key features of the two strategies are compared in **Table 25**.

The feasibility study developed in Slovenia has highlighted that rural communities are open towards the development of decentralized CW. In that case, the users were sufficiently informed to compare the costs of centralized and decentralized treatment solutions, and a robust public programme of incentives for private investment is available. The feasibility study carried out in Serbia, by contrast, has highlighted that stakeholders are less aware of the benefits from industrial ecology, and there are difficulties - other than technical and financial - for the development of holistic solutions. In order to stimulate the invention of solutions, it may be even more important to make the service costs apparent and to aim at their sustainable coverage through appropriately designed and affordable tariffs.

7 Feasibility study reports available

Reports describing in full detail the assessments made in the two feasibility studies presented in this contribution, as well as additional information on the test cases examining the applicability of the various solutions in the Lower Danube, can be requested to alberto.pistocchi@ec.europa.eu (Alberto Pistocchi).

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List of abbreviations and definitions

(U)WWTP – (urban) wastewater treatment plant

AS – activated sludges

ASP – activated sludge process

BOD – biochemical oxygen demand

CAPEX – capital expenditure

CHP – combined heat and power

COD - chemical oxygen demand

CW – constructed wetlands

EC – European Commission

EU – European Union

FRB – French reed bed

GDP – gross domestic product

HF – horizontal flow (CW)

IAS – individual or appropriate system

ICPDR – International Commission for the Protection of the Danube River

ISPA – Instrument for Structural Policies for pre-Accession

JRC – Joint Research Centre

MBR – membrane bioreactor

O&M – operation and maintenance

OECD – Organization for Economic Cooperation and Development

OPEX – operational expenditure

PE – population equivalent

SBR – sequencing batch reactor

TSS – total suspended solids

VF– vertical flow (CW)

WFD – Water Framework Directive

WHO – World Health Organization

WWT - wastewater treatment

List of figures

List of tables

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