Project

SmartWaterTwin

Twinning for Smart Water- Thinking and Rethinking Wastewater Management in Circular Economy Frame

- Grant No: 101060110
- Call for proposal: HORIZON-WIDERA-2021-ACCESS-02
- Topic: HORIZON-WIDERA-2021-ACCESS-02-01 - Twinning Western Balkans Special
- Project duration: 1st September 2022 – 30th November 2025

D3.1 SmartWater Toolkit and factsheet	
Work package (WP)	WP3 - Establishing a methodological framework for applying circular economy principles into wastewater sector in Republic of Serbia
WP Leader	UPEC
Issued by	UNSPMF and UPEC
Issue date	25.11.2025.
Due date	31.10.2025.
Type	R - Document, report
Dissemination level	P-Public

Document history (Revisions -Amendments)	
Version and date	Changed by
/	/

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Grant Agreement: Twinning for Smart Water - Thinking and Rethinking Wastewater Management in Circular Economy Frame, No 101060110.

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1. SUMMARY

The SmartWater toolkit describes current practice in wastewater management and offers methodological framework for applying circular economy (CE) principles into wastewater sector in the Republic of Serbia.

This document is intended for decision makers on comprehensive understanding on important factors affecting circular economy potential in this sector and which can be useful when “thinking” and planning the construction or rehabilitation of urban wastewater treatment plants.

It was created by sharing best practices between project partners with harness the innovation expertise and support for the development of a roadmap for the transition from a linear to a circular economy in the Republic of Serbia.

It contains statistical data about current population of Serbia, water resources consumption, urban wastewater sanitation and treatment, industrial and agriculture activities as a basis for defining a clear reason and needs for reuse and resource recovery.

An overview of Policy and regulatory Context in Europe is given with separate chapters of analysis in France and the Republic of Serbia. The idea was not to mimic the policy, institutional and regulatory framework, rather to adopt guidelines for risk assessment and definition of limit values in legislation of developed countries, as well as technological options in the phase of “rethinking” with the greatest benefits for public utility companies and society as a whole.

The Toolkit emphasizes the importance of funding in wastewater research, innovation and knowledge development for the transition to a CE in the Republic of Serbia and necessity to align with the needs of the economy and society more effectively.

Taking into account, on the one hand, the water scarcity in some cities in the past period and, on the other hand, the climate and projected needs for irrigation of agricultural areas as a main drivers for circular economy, a methodological framework for wastewater reuse in the Republic of Serbia is proposed.

Another proposed framework and implementation roadmap was given for the application of treated and/or composted sludge for agricultural purposes in Serbia as one of the typical examples of the circular cycle in wastewater sector and still the most cost-effective sludge management solutions in EU countries.

Examples of best practice in wastewater treatment plants in the frame of circular economy in EU countries (France and Spain) and Serbia are part of Annex in this document.

2. INTRODUCTION

Sanitation and wastewater management systems have evolved over the years from systems for the protection and improvement of human health, through environmental protection to technically and socially acceptable systems (Kerkez and Bečelić-Tomin, 2024). Today, efforts are being made to develop long-term economically viable systems within circular economy (CE) concept, adding resource recovery to this evolution as one more of the important aspects to achieve self-sustaining wastewater treatment plant but also local, state and global sustainability. One of the general definitions of CE that can be applied to the water sector was given by Ruiz-Real et al., 2018: the circular economy is a mode of economic development whose goal is to protect the environment and prevent pollution, thus facilitating sustainable economic growth. In this context, the urban wastewater treatment plants (WWTPs) can be an important part of circular sustainability due to integration of energy production and resource recovery during clean water production (Neczaj and Grosser, 2018).

Demand for nutrients, water and energy were the main drivers for the implementation of CE actions in the wastewater sector, putting the hydrological water cycle and the biogeochemical cycles of N, P and C in focus. Developed countries have taken a step further by identifying and calculating potential of other resources recovery such as organic acids and alcohols, polyhydroxyalkanoates and volatile fatty acids, extracellular polymeric substances, proteins, enzymes, biopesticides, etc and market supply potential (Kehrein et al., 2020; Kerkez and Bečelić-Tomin, 2024). In this way, they show willingness to see wastewater as a source of resource in the same time by entering the competition for leading positions in the application of the circular economy in this sector. Anyway, during the process of adopting the circular economy in the wastewater sector, developed countries had to face challenges and opportunities for integrating this concept within the framework of the "rethinking". In practice it implies different way of thinking and the re-design of the contextual setting and operative aspects of the water use (Halog and Anieke, 2021).

Developing countries and country with economy in transition are facing infrastructural and financial challenges, lack of data, a lower level of awareness, stakeholder uncertainty, insufficient skills, ineffective legislature as a main barriers for circular economy adoption in wastewater management. Despite multifaceted obstacles to circular wastewater management, studies show space for overcoming this chellenges with appropriate policy planning and implementation with special attention on rural and peri-urban areas with decentralized approaches to wastewater treatment and management with combination of onsite and/or cluster systems (Massoud et al., 2009; Capodaglio, 2017; Orsini et al, 2023). On the other hand, Chryspim et al., 2020 note that resource recovery strategies are particularly important for large agglomerations from the perspective of economic benefits from recovered products. The authors state that in addition to size of the plant, legislation and treatment technologies it is necessary for developing countries to implement inventories of the quality and the quantity of the resources in municipal wastewater, their current application and possibility of future implementation. Other authors see opportunities in improved sector governance at different levels and adoption of modern technologies with proactive management approaches and effective partnerships which leads to sustainable business practices (Nyambiya et al., 2025).

This document provides proposals for a methodological framework for applying circular economy principles into the wastewater sector in the Republic of Serbia (wastewater reuse and sludge for agriculture) taking into account the current situation in wastewater sector, plans for the construction of new WWTPs and experiences of the EU countries.

3. STATISTICAL DATA FOR THE REPUBLIC OF SERBIA

The total area of the Republic of Serbia is 88499 km^2. It is territorially divided into 5 regions (Beogradski region, Region Vojvodine, Region Šumadije i Zapadne Srbije, Region Južne i Istočne Srbije, Region Kosovo i Metohija) and 29 administrative districts.

In 2023 the population is estimated at 6 623 183 of which about 75% live in agglomeration >2000. Around 2 471 059 inhabitants live in 4 agglomerations >150 000: Beograd (1 681 405), Novi Sad (368 967), Niš (249 501) and Kragujevac (171 186).

The largest number of inhabitants lives in the Region Šumadije i Zapadne Srbije, 1 819 318 (27.4%), while the smallest population is in the Region Južne i Istočne Srbije, 1 406 050 (21.2%).

Of the total of 4 709 settlements in the Republic of Serbia, every fourth is classified as small in size of population. These settlements occupy almost a fifth of the territory of the Republic of Serbia, but have only 55 444 inhabitants. The average size of a settlement is 43 inhabitants. The Region Južne i Istočne Srbije has the largest number of small settlements, 819 (62.9%), where more than half of the population of this region lives.

In the period between 2011 and 2022, the population decreased approximately 8.1%. Percentage of young people (0-14) remained on the same level, 14.4%, while the percentage of the population aged 65 and over increased from 17.3% (2011) to 22.3% (2023) (Statistics Serbia, 2024).

Average population density in the Republic of Serbia is 85.7 inhabitants/km^2, however, intraregional population distribution is rather unequal. The population density of 520 inhabitants/km^2 in Beogradski region is several times higher than in other regions of the Republic of Serbia (Statistics Serbia Note: statistical data is not processed for Region Kosovo i Metohija by Statistical Office of the Republic of Srbia). Region Juzne i Istocne Srbije with 54 inhabitants/km^2 has the smallest population density.

Analysis of internal migration indicated the resettlement of the population to the largest urban and regional centers, as well as the most popular tourist destinations.

Water resources

The territory of the Republic of Serbia represents a single water area for water management and includes parts of the Black, Aegean and Adriatic Sea basins and their sub-basins. The total number of surface water bodies is 3 216, while the number of identified groundwater bodies is 153 (Water Management Plan on the Territory of the Republic of Serbia until 2027).

The long-term average annual value of renewable water resources amounts to 170.98 billion m^3 and represents the sum of precipitation on whole territory and water inflow from the outside minus actual evapotranspiration. The average annual value in 2021 was 2.7% lower than the multi-year average and amounts to 166.3 billion m^3 (Report on the State of the Environment in the Republic of Serbia for 2022; Republic of Serbia - Ministry of Environmental Protection, Environmental Protection Agency life-not environment).

The Water Exploitation Index (WEI) represents the ratio of the total annual amount of water resources used and renewable water resources. It is an indicator of the pressure of affected water resources on the sustainable use of renewable water resources at the national level. Water Exploitation Index (WEI) (European Environmental Protection Agency (EEA) and the Environmental Protection Agency of the Republic of Serbia), at the level of the Republic of Serbia is below 5%, which puts the Republic of Serbia in the "safe zone". In the period from 2011 to 2020, there is an increasing (unfavorable) trend, but a very low average value of 2.86% (WEI-RS, EEA).

The territory of Serbia is characterized by pronounced spatial and temporal unevenness of the water regime, and therefore regional differences in exploitable possibilities and needs for water. WEI shows that water is available in terms of quantity, but it does not show the quality of that water and how it is distributed in space. In RS waters, the poorest and most populated lowland areas are the ones with the richest land resources, while the quality water resources are mostly around the country's periphery.

In 2024, 709 million m^3 water was abstracted for water supply purposes (61.5% from groundwater and spring water sources, 28.3% from watercourses, and 10.2% from lakes and reservoirs). 459 million m^3 water were delivered to users (households 330 million m^3, the industrial sector 49 million m^3 and other users 81 million m^3) (Note: Industrial sector: Mining; Processing industry; Electricity, gas and steam supply. Other users: Agriculture, forestry and fishing; Construction and service activities).

According to the UN Global Water Security Assessment, Western Balkan countries are considered as water-insecure, facing potential water crisis. Serbia is among the 8 lowest-scoring countries in Europe which are classified as water-insecure countries. Among 39 European countries, Serbia is ranked 36t with the water-security score of 57. Serbia has good water-security scores for water availability (proportion of the population with access to safely managed drinking water, around 75%), level of water stress (as mentioned according to WEI Serbia is considered as non-stressed country), safety due to water-disasters and water resources stability (inter-annual hydrological variability). However, for the rest of the water-security components, the scores of the Republic of Serbia are relatively low. The major problems regarding water-security are sewage and wastewater disposal and water treatment (including water recovery and reuse/recycling), especially in rural and suburban areas (Trends, Quarter III of 2023, Statistical Office of the Republic of Serbia).

Climate change

The trend of increasing average annual temperature in the Republic of Serbia is greater than the trend of increasing average global temperature, which is especially noticeable after 1980. The average temperature change trend for the territory of the Republic of Serbia in the period 1961-2017 was 0.36°C/decade, and during the period 1981-2017 it was 0.6°C/decade (Observed Climate Changes in Serbia and Projections of Future Climate based on Different Scenarios of Future Emissions, UNDP Serbia, 2018).

The average trend of decreasing mean annual flows of surface water bodies in central Serbia is about 20-25% per 100 years, but it varies by area. The smallest changes are recorded in watercourses in the southwestern part of Serbia, and the largest negative changes in the eastern part.

On average, over the last 20 years (1998-2017), the growing season has been extended by over 5 days, and in some areas, mostly at lower altitudes, by over 10 days compared to the reference period. This change over the last 10 years of the analyzed period has led to an extension of the growing season by 25 days in a large part of the territory, with a maximum in central Serbia, where an average longer growing season of over 40 days was observed. This is important information, especially for crops that are irrigated throughout the entire growing season.

In future periods, further breaking of temperature and precipitation records in Serbia can be expected with high probability (UNDP Serbia, 2018).

Urban wastewater

The total estimated amount of wastewater discharged into the public sewer system (residental+industry+other activities) amounts 300 mill m^3/year. Of the total wastewater, 69% origin from households, 19% from industry and 12% from other activities (Table 1). In agglomerations <50 000 the percentage of the population connected to the public sewage system is lower than average, 55%. The lack of sewage infrastructure is one of the biggest problems in small settlements, with far-reaching consequences for health, the environment and local development. According to the 2022 Census data, only 0.9% of households in small settlements have access to public sewage.Septic tanks constitute the most common method for receiving wastewater in rural area.

The percentage of households connected to the sewage network was highest in the Belgradskom Regionu (78%), and lowest in the Vojvodina Region, 57%. Sewage systems are in most cases separate and mixed. Average age of combined sewers is 35-40 years. It is estimated that around 10 400 km of new sewage network (main sewers and secondary sewer networks) needs to be built, which will provide service for additional 20 million users (Water Management Plan on the Territory of the Republic of Serbia until 2027).

Table 1. Connection to public sewage system and urban wastewater treatment in the Republic of Serbia

Length of public sewage system, km	18 681
No. of households	2 589 344
No. of households connected to public sewage system	1 612 641
Households connected to public sewage system by the region, %	- Belgrade region 78% - Vojvodina region 57% - Šumadija and West Serbia region 58% - South and East Serbia 53%
Population connected to public sewage system, %	62.2
Population connected to wastewater treatment, %	16.4
Treated wastewater, mill m^3/y - Primary treatment - Secondary treatment - Tertiary treatment	90 - 22 - 42 - 26
Share in total treated wastewater by regions, %	- Belgrade region 9.0% - Vojvodina region 25.5% - Šumadija and West Serbia region 44.5% - South and East Serbia 21%

Wastewater is considered in the Water Management Plan on the Territory of the Republic of Serbia until 2027 in the context of a source of pollution. This document contains an analysis of the risk from point and diffuse sources of pollution and proposed measures for individual water bodies.

The results of the risk assessment show that around 50% of surface water bodies are either “at risk” or “possibly at risk” of failing to achieve good status in the categories of organic and nutrient pollution

Concentrated and diffuse sources contribute equally to nutrient pollution of water bodies.

The analysis of significant pressures showed that the dominant sources of concentrated pollution are from agglomeration and industry (about 78% of total emissions).

The organic wastewater load from 4 agglomerations >150,000 PE accounts for 42% of total organic pollution in waters, while the share of agglomerations 50,000 < EC ≤ 150,000 and 2,000 ≤ EC ≤ 10,000 is the same, around 17%.

Significant pressure from diffuse sources is dominant for agglomerations of 2 000 to 10 000 PE.

One of the potentially significant drivers of pressures and impacts on surface and groundwater bodies is agricultural areas. Farms that can be classified as potential sources of pollution are those that generate environmental loads greater than 4000 PE (poultry, cattle and pig farms).

Approximately 92% of the territory of the Republic of Serbia is located in the Danube River Basin and the entire territory is a nutrient sensitive area. This implies that stricter wastewater treatment than secondary will be applied in agglomerations >10 000 PE.

Water management is under the jurisdiction of the Government of the Republic of Serbia. Institutional arrangements for wastewater and sludge management include national ministries and joint bodies:

- Ministry of Construction, Transport and Infrastructure
- Ministry of Environmental Protection (Agency for Environmental Protection)
- Ministry of Agriculture, Forestry and Water Management (Directorate for Water Management)

These institutions are responsible for regulations, policies, planning, incentives and other instruments that may create future necessary conditions for the transition to circular economy in this sector. For now, administrative fragmentation, capacity and insufficient integration of these institutions was observed as weakness for efficient management at the national level. Also, differences in the development of regions, administrative districts and settlements nationwide make it difficult process of implementation of wastewater legislation requirements.

Local Governments regulate and should provide the performance and development of utility services and maintenance of communal facilities and is responsible for the financing and management of WWTP. The public utility company (operators) is obligatory to implement the measure of maintenance, development and protection of communal buildings, plant and equipment. WWTP management models are in most cases public direct and public delegated management, with some cases delegated private management.

One of the most important roles of local self-governments in the Republic of Serbia is the performance and development of communal activities. In accordance with the law (Law on communal activities, "Official Gazette of RS", no. 88/2011, 104/2016, 95/2018 and 94/2024) the local self-government unit is obliged to create conditions for ensuring appropriate quality, volume, availability and continuity, as well as supervision over the purification and removal of storm and waste water. According to the same law, the utility operator (Water Utility Company) is obliged to implement measures for the maintenance, development and protection of communal facilities, plants and equipment. One of the most important preconditions for implementing circular economy in this sector is raising the capacity of local self-governments and taking responsibility for initiating preconditions on national level for its implementation.

Industrial and agricultural activities

Industrial activities. Observed by NACE Rev. 2 sections, in 2025 the following trends were recorded: the section of electricity, gas, steam, and air conditioning supply – growth of 14.3%, the section of mining – growth of 12.9%, and the section of manufacturing – growth of 3.2% (Statistics Serbia, 2025).

The most developed manufacturing industrial activities in the Republic of Serbia are food production and processing, metal production, and construction materials production.

Industrial plants are mostly located in urban areas and wastewater discharge into the public sewage system or directly into water bodies via individual sewage systems. The number of industrial zones is 359 located in 146 agglomerations of which 221 have their own sewage system. The predominant activity in industrial zones is metal processing and related activities. There are currently 50 more zones under construction (data on future business activities are not available at this time).

In 2024, 4 026 mill m^3 of water was used in the industrial sectors (99.6% from individual water intakes-98.7% surface water and 0.9% groundwater), and 0.4% from the public water supply system. Of the total water used in industry, 97.4% is water used in the supply of electricity, gas and steam (85% for cooling purposes), 1.9% in the manufacturing industry (27% for cooling purposes) and 0.7% in mining.

In line with water consumption, 41% is water discharged from the section of electricity, gas, steam, and air conditioning supply, 36.6% from manufacturing and 22.4% from mining (data on industrial wastewater treatment are given in the **Table 2**).

Table 2. Industrial wastewater treatment

Total industrial wastewater produced, m^3/y	112 000 000
Treated wastewater, m^3/y	30 000 000 - Primary treatment 56.2% - Secondary treatment 22.5% - Tertiary treatment 21.3%
Treated wastewater by sectors, %	- Basic metal production 16.8% - Food production 16.2% - Production of chemicals and chemical products 15% - Production of paper and paper products 11% - Other sections 41%

There are 220 IPPC plants in Serbia. Sectoral shares of IPPC installations in 2022 shown in **Figure 1**.

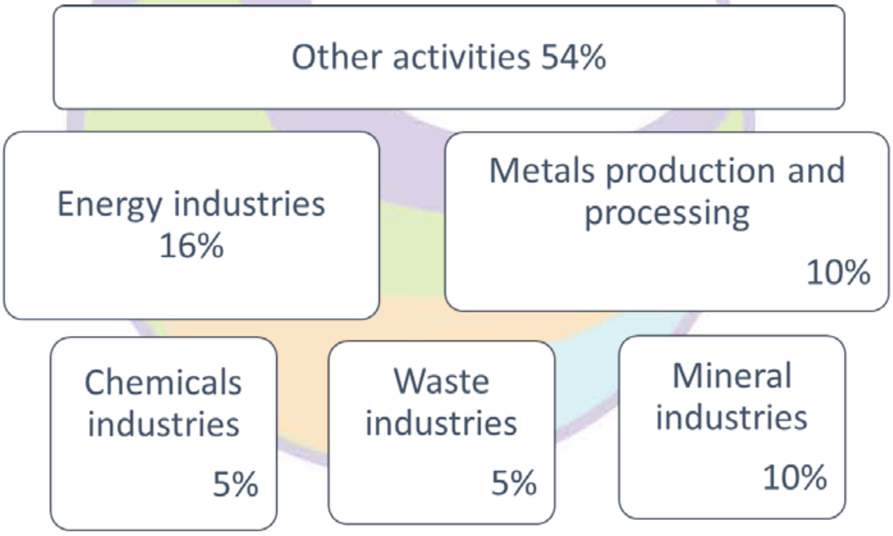


Figure 1. Sectoral shares of IPPC installations in the Republic of Serbia, 2022

Categories of industrial activities:

- Energy industries: 30 operators
- Production and processing of metals: 22 operators
- Mineral industry: 25 operators
- Chemical industry: 11 operators
- Waste management: 13 operators
- Other activities:
- Industrial plants for the production of: (a) pulp from timber or other fibrous materials; (b) paper and cardboard with a production capacity exceeding 20 tonnes per day: 4 operators
- Treatment and processing intended for the production of food products: 20 operators
- Installations for the disposal or recycling of animal carcases and animal waste with a treatment capacity exceeding 10 tonnes per day: 3 operators
- Installations for the intensive rearing of poultry or pigs: 88 operators
- Installations for the surface treatment of substances, objects or products using organic solvents, in particular for dressing, printing, coating, degreasing, waterproofing, sizing, painting, cleaning or impregnating, with a consumption capacity of more than 150 kg per hour or more than 200 tonnes per year: 4 operators

The spatial layout of the installations registered in E-PRTR is shown in the **Figure 2**. On the smaller picture are the locations of the IPPC installations for the most common activity, intensive rearing of poultry or pigs. Republic of Serbia currently has ca. 15 mill head of poultry, which represent 75% of all livestock head in country territory. The largest number of installations is located in the Vojvodina Region. This region is also known for production of animal and vegetable products from the food and beverage sector.

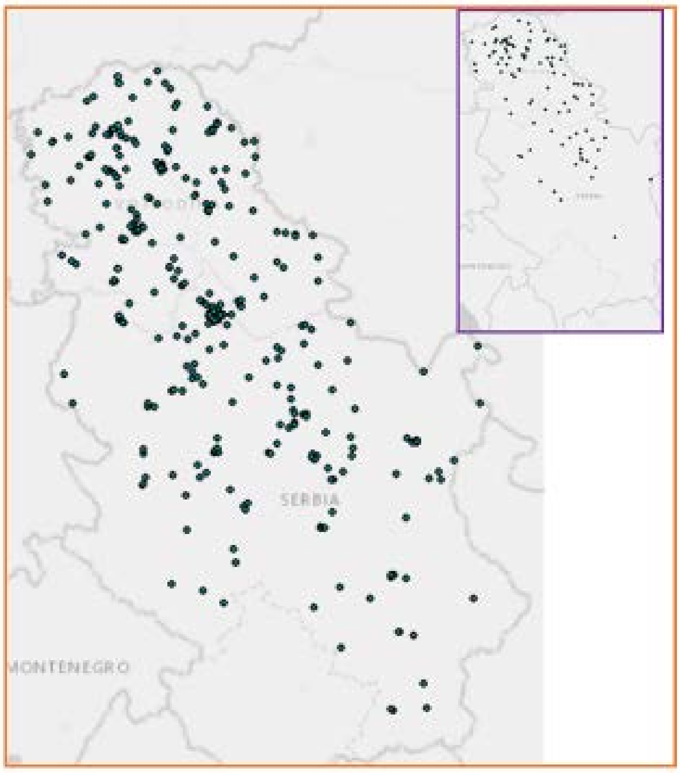


Figure 2. The spatial layout of large industrial complexes in the Republic of Serbia (Vojvodina Region is shown in the interior of the picture)
Source: European Industrial Emissions portal

Agriculture. Utilized agricultural area in the Republic of Serbia is 3 336 786 ha (arable fields and gardens-77.2%, permanent grassland-16.5%, fruit plantations-5.7%, vineyards-0.5%, other agricultural land-0.1%) (Statistics Serbia, 2024). Compared to the ten-year (2014-2023) average, in 2024 more soybeans (by 5.9%), sunflowers (by 15.9%), corn (by 0.4%) and sugar beets (by 3.3%) were sown. Agricultural activities and land use vary greatly across regions (**Table 3**). The largest number of agricultural holdings in all regions is on a utilized land area < 2 ha (predominantly livestock).

In the Vojvodina region, the share of utilized agricultural land is even 70% in the total territory of that region. The most numerous size group in Central Serbia is medium-small farms of 2-5 ha, whilst in Vojvodina there is a more even spread of farms across the 2-5, 5-10 and 10-50 ha bands.

Table 3. Utilized agricultural land by regions

Region	Total area (km^2)	Utilized agricultural area (ha)	Agricultural holdings by utilized agricultural area
Beolgrade region	3 234	151 856	26 211
Vojvodina region	21 614	1 552 472	111 950
Šumadija and West Serbia region	26 493	954 623	224 419
South and East Serbia region	26 248	677 835	145 745

In 2024, 66.7 million m^3 of water was used for irrigation of legal entities (Serbian Statistics, 2024).The estimated total water use of 426 million m^3 represents the amount delivered for all irrigating farms (Supporting the development of an irrigation strategy for Serbia, FAO, 2021).

Water sources for irrigation supply are: groundwater (most common water source, used by 98 000 farms for individual irrigation of 71 000 ha from private wells and boreholes, average 0.73 ha), Dunav-Tisa-Dunav hydrosystem (the second most common source of water, used by 50,000 farms to irrigate 62 000 ha, average 1.24 ha), surface water on the holding (it is used by 17,000 farms to irrigate 16 000 ha, average 0.90 ha), public water-supply network (used by 12 000 farms to irrigate 4 000 ha, average 0.30 ha).

The six-year period from 2012 to 2018 saw a dramatic and predominantly positive development of irrigation: the total irrigated area increased by 60 % from 100,000 ha to 160,000 ha and the number of irrigating farms increased by 92 % from 97,000 to 186,000. By 2018, one-third of all Serbian farms were making some use of irrigation. As the number of farms grew faster than the area, the average irrigated area per irrigating farm fell by 17 % from 1.03 ha to 0.86 ha. This small average size of irrigated plots is closely connected with what is irrigated and how, and plays an important role in the economics of irrigation in Serbia (Supporting the development of an irrigation strategy for Serbia, FAO, 2021).

Of the total irrigated area in 2018, 65% of the area was irrigated by surface irrigation, 29 % of irrigating farms used some form of pressurised irrigation (sprinkler, drip or both) and 6 % of farms that used pressurised irrigation on some plots and surface irrigation on others. Sprinkler irrigation is particularly common on larger fields and arable crops, so 80 % of the total area under sprinklers lies in Vojvodina region while 70 % of the drip irrigated area lies in Central Serbia.

Arable land and gardens (93.5%) have the largest share in the total irrigated areas, followed by orchards (5.9%) and other agricultural areas (0.6%). The fact is that farms irrigate only part of crop areas: farms up to 10 ha irrigate on average less than 1 ha and use water less than 2 500 m^3/year, farms of 10-50 ha irrigate on average 1.6 ha and use less than 5 000 m^3/year, farms over 50 ha irrigate an average of 63 ha and use ca. 90 000 m^3/year.

According to farmers' census in the Republic of Serbia conducted in 2023, taking into account registered farms, 268 255 ha of agricultural land is irrigated foremost using ground water at the property (51%) and surface water in the vicinity (25%). The use of some sort of purified – technical water is only 1%. According to this source, there is a same share of surface and drip irrigation (40% each) and sprinkler irrigation (around 20%). (Statistical Office of the Republic of Serbia).

Irrigation is being increasingly concentrated on those crops for which it gives the greatest return, with the increase in irrigated fruit and vegetables being found across all regions of Serbia. Most fruit production is found in areas of low hills, with almost half of the total in the region of Šumadija and West Serbia. Fruit may offer the greatest potential for the profitable expansion of irrigation, but availability of water supply is obstacle (Supporting the development of an irrigation strategy for Serbia, FAO, 2021). Fruit and vineyards constitute high-value crops even without irrigation, but irrigation substantially increases returns.

It is estimated that by 2034, the area under irrigation will increase significantly, which will require the provision of additional quantities of water (Water Management Strategy until 2034). From a circular economy perspective, this represents potential for improvement, as part of the water used to irrigate arable land for agricultural production could be replaced with purified municipal wastewater (Circular Economy Development Program in the Republic of Serbia for the period 2022-2024).

Data on the use of inorganic fertilizers are not available in national databases. According to FAOSTAT statistics (Agri-Environmental Indicators Fertilizers indicators (National - Global - Annual) – FAOSTAT), in 2019 farmers in Serbia used: 76.22 kg/ha nitrogen (N), 13.76 kg/h phosphorus (expressed as P_2O_5) and 20.13 kg/h potassium (expressed as K_2O). A significant decrease in the use of N and P fertilizers compared to 2012 was noted, 59% and 32% respectively.

Science and inovation

In the total number of organizations engaged in research and development (R&D), in 2024, the non-financial sector participated with 64.9%, the public sector 12.3%, higher education 22.0% and the non-profit sector 0.8%.

The number of research projects and studies increased in 2024 by 4.5% compared to 2023, where fundamental science participate with 54.1%, applied with 28.2%, and development project and studies with 17.7%. In 2024, the non-financial sector invested 55.5% of its own funds in R&D while public and local self-government invested depending on the sector: the public sector 71.3% and higher education 61.8%.

Investment in research and development in 2024 by regions: Beogradski region 64.4%, Region Vojvodine 29.1%, Region Šumadije i Zapadne Srbije 3.6%, Region Južne i Istočne Srbije 2.9% (Statistics Serbia, 2025).

In the total number of innovations, the largest share is production process innovations, 41.3%.

Of the total of 445 entities of the national innovation system, the largest number are startups, 268, while there are 5 innovation centers within the faculties.

4. POLICY AND REGULATORY CONTEXT IN EUROPE: OVERVIEW

[NB: acomprehensive document on wastewater reuse in Europe. Cameron Mclennan, Gabrielle Rudi, Yvan Altchenko, Nassim Ait-Mouheb. Will the European Regulation for water reuse for agricultural irrigation foster this practice in the European Union? Journal of Water Reuse and Desalination, 2024, 14 (2), pp.115-135. ff10.2166/wrd.2024.012ff.***]***

Circular Economy Action Plan (CEAP) is one of the main "building blocks" of the European Green Deal, agenda for sustainable growth. The intention of the EU transition to a circular economy is to reduce pressure on natural resources and create conditions for sustainable growth and new jobs. The circular economy is in two-way synergy with the following policies:

- The EU Action Plan „Towards Zero Pollution for Air, Water and Soil";
- The European Commission Communication "Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability";
- The EU Climate Law for climate and
- The EU Biodiversity Strategy.

Zero pollution and circular economy have the greatest mutual importance and they linked throught electronics, batteries and vehicles, plastics, and food, water and nutrients sectors. Zero pollution target for 50% reduction of nutrient losses by 2030 stimulate the markets for recovered nutrients and by managing nitrogen and phosphorus better throughout their lifecycle (nutrient reuse from wastewater and sludge).

The Urban Wastewater Treatment Directive, UWWTD (91/271/EEC) has been regulating the collection, treatment and discharge of municipal wastewater as well as biodegradable industrial wastewater in EU countries for thirty years. It aims to protect human health and the environment from the effects of untreated wastewater. The evaluation of the Directive confirmed that it is overall very effective when fully implemented (Commission Staff Working Document Evaluation of the Council Directive 91/271/EEC of 21 May 1991, concerning urban waste-water treatment). However, new social problems and challenges such as the presence of contaminants of emerging concern and energy neutrality led to the revision of the Directive. Also, Directive contains provisions that could encourage the use of water, and thus the integration of the circular economy in the wastewater sector, but this legal potential has not been fully utilized.

Water reuse as an important measure is identified in the document The Blueprint for Safeguarding European Waters. This was further the subject of the Communication 'Closing the loop - An EU action plan for the Circular Economy' which identified a series of actions to promote the reuse of treated wastewater. One of those activities is the recommendations of the Guidelines on Integrating Water Reuse into Water Planning and Management in the context of the WFD (CIS document, 2016).

Another important activity is the development of legislation on minimum quality standards for the reuse of water for irrigation of agricultural areas. Thus, the circular approach is encouraged by the adopted Regulation on minimum requirements for water reuse (Regulation EU 2020/741). As stated in the CEAP, the European Commission has facilitated the reuse and efficiency of water by adopting the Regulation.

Table 4 shows regulations and practices in water reuse in some of the countries in EU.

Table 4. Water reuse regulations and practices in selected European countries

Belgium	Though Belgium does not have any national regulation (wastewater reuse is not the subject of dedicated plans at national level); in September 2022, a regulation on amendments to the law on water was published. This regulation ensures the partial implementation of Regulation 2020/741, which means that the first actions have started. The level of wastewater reuse varies greatly from one region to another in Belgium. Flanders, for example, adopted a dedicated plan in 2020 (the Blue Deal) to systematize reuse, while Wallonia, which is less exposed to water-related risk, has yet to develop this practice among its citizens. In Belgium, however, water reuse is widespread on a smaller and larger scale, there are many non-agricultural uses, including the direct production of drinking water. For example, on the southwest coast of Belgium (Torreele Water Reuse Scheme), water from WWTP Wulpen is used to recharge an artificial aquifer.
Denmark	Danish industry and WWTPs have significant experience in internal water reuse. However, reclaimed water is not used in agriculture. The law does not regulate the quality and classes of reclaimed water.
Cyprus	In Cyprus, legislation regulating urban waste water management and containing elements of water reuse is quite dispersed and includes the Environmental Impact Assessment Act, Water Pollution Control Law, Water Pollution Control (urban wastewater discharge) Regulation, Code of Good Agricultural Practice, and Regulation on Small Waste Water Treatment Plants < 2000 p.e. Quality requirements for reclaimed water are defined in accordance with Regulation No 269/2005. Moreover, the Code of Good Agricultural Practice provides guidance to ensure the protection of public health and the environment, while the Water Pollution Act and related regulations set legally binding limit values for parameters used in waste water treatment plants. Limit values and quality requirements are defined for more than 20 microbiological and physicochemical parameters. Irrigation with treated waste water is prohibited for leafy vegetables, bulbs, tubers eaten raw, export crops, and ornamental plants.
Germany	Based on the collected data, there was no need for additional irrigation across the country in Germany. Selected laws and regulations include legally binding minimum requirements for water quality, quantitative limits for the use and discharge of certain substances, and recommendations for estimating flow or concentration. There are many guidelines that can be considered when using reclaimed water for agricultural irrigation, e.g., DIN 19650. There is no federal regulation regarding the use and quality of water obtained from wastewater treatment.
France	General regulatory framework for the use of rainwater and treated wastewater: Wastewater may not be used without treatment. Many regulations are dealing with the reuse of treated wastewater. Decree 2023-835 of August 29, 2023 sets out the conditions for the use of treated wastewater and rainwater for all non-domestic purposes, and establishes the authorization procedure for the use of treated wastewater. It repeals the decree of March 10, 2022 on the uses and conditions of reuse of treated wastewater. The decree of July 28, 2022 completes this text by specifying the composition of the authorization application file. This decree will be supplemented by “thematic” decrees specifying the conditions of use of treated wastewater by type of use. As long as projects comply with the required water quality and implementation conditions, the opinions of the regional health authority (ARS) and the Departmental Council for the Environment and Health and Technological Risks (CoDERST) will not be mandatory, but may still be sought. In this context, two decrees relating to the conditions for producing and using water from urban wastewater treatment for irrigating crops or green spaces were published in December 2023. These decrees repeal the August 2, 2010 decree on the use of water from urban wastewater treatment for irrigating crops or green spaces, and specify the implementation procedures for these two uses: • The decree of December 14, 2023 on the conditions for the production and

	use of treated wastewater for watering green spaces. This decree sets out the requirements applicable to the use of treated wastewater for green spaces open to the public and green spaces with restricted public access. • Order of December 18, 2023 on the conditions for the production and use of treated wastewater for crop irrigation. This decree sets out the requirements applicable to the use of treated wastewater for different purposes such as food crops, fresh fodder and pasture and Industrial crops, energy crops and seed crops. These requirements are designed to ensure the protection of human and animal health, and of the environment. Both decrees define four different qualities (A, B, C and D) are defined according to physicochemical properties (suspended solids, BOD5, and turbidity) and microbiological factors (*Escherichia coli*, specific F-RNA bacteriophages and/or somatic phages, *Clostridium perfringens and Legionella spp.*). The water quality levels required for each use are set out in Appendix I of each decree.
Spain	Royal Decree 1620/2007 is a legal act establishing a mandatory water reuse system. Moreover, there is a NationalWater Reuse Plan and more comprehensive guidelines developed by some regions (e.g., Andalusia, Balearic Islands, and Catalonia), which complement legislation at the national level, i.e., Decree 1620/2007. The decree regulates urban uses, including irrigating gardens, cleaning streets, extinguishing fires, and indoor applications, such as flushing toilets. There are many possible routes of irrigation in agriculture and application in aquaculture. Reclaimed water can be used in other economic activities and for environmental purposes, including the recharge of aquifers. Water reuse is not permitted in certain food industry applications, hospitals, swimming pools, and fountains in public places or inside public buildings.
Italy	In 2003, new legislation was passed which takes into account the same water quality for three categories of reuse: irrigation of food and non-food crops, street cleaning and industrial uses (Decree of the 12th of June, 2003, N. 185: Regulation Containing Technical Standards for the Reuse of Waste Water in Implementation of Article 26 Legislative Decree 152/1999). This decree lays down technical standards for domestic, urban, and industrial wastewater reuse, the standards are set on the base of water use destination (urban, rural or industrial) and water resources quality requirements. The Decree facilitates water saving establishing limits to groundwater and superficial water abstraction and reduces the impact of water discharge on the receiving water bodies. In the case of irrigation reuse, the limits for phosphorus and total nitrogen may be raised to 10 and 35 mg/l, respectively, subject to the provisions of Article 10, Paragraph 1 with respect to nitrate-vulnerable zones of agricultural origin. 5. For all chemical and physical parameters, the limit values are to be referred to average values on an annual basis or, in the case of irrigation reuse only, of the single irrigation campaign. However, reuse must be immediately suspended if, in the course of monitoring, the point value of any parameter is found to exceed 100 percent of the limit value. For the parameter *Escherichia coli*, the limit value (10 CFU/100ml) is to be referred to 80% of the samples, with a maximum value of 100 CFU/100 ml. However, reuse must be immediately suspended where the point value of the parameter in question is found to exceed 100 CFU/100ml during the controls. For the parameter *Salmonella*, the limit value is to be referred to 100 percent of the samples. However, reuse must be suspended where *Salmonella* is detected during controls. Reuse can be reactivated only after the point value of the parameter(s) for which it was suspended has fallen below the limit value in at least three successive and consecutive checks.

The reuse of treated waste water must be undertaken in full compliance with the requirements of relevant EU legislation: Water Framework Directive, Groundwater Directive, Urban Waste Water Treatment Directive and Nitrates Directive.

Quality of sewage sludge as a residue resulting from wastewater treatment are regulated by Council Directive 86/278/EEC. This Directive aimed to encourage and ensure the correct use of sludge in agriculture in such a way as to prevent harmful effects on soil, vegetation, animals and humans. Correct use implies the use of treated sludge or untreated (raw) sludge if it is injected (introduced) into the soil. In this way, the Directive promotes the most economical and cheapest way of sludge management, the use in agriculture, which, according to data from EU countries, is considered a cost-effective option, allowing farmers to save on the use of fertilizers and reduce nutrient losses without worsening soil fertility. The use of sludge as a waste stream, as it is still classified in EU legislation, for agricultural purposes is a typical example of a closed circular cycle.

Fertilizing Products Regulation 2019/1009, FPR, should encourage the reduction of the use of mineral fertilizers and the EU's dependence on their imports, and on the other hand, encourage the greater use of organic fertilizers and the development of a circular economy for nutrients. According to this Regulation, fertilizer obtained from waste sludge cannot currently be placed on the EU market nor can it be traded between countries. However, with the development of technologies for the recovery of P from waste sludge and as the production process becomes scientifically based, fertilizers obtained from sludge will be able to move smoothly to the EU market in the near future. The European Commission has proposed the adoption of acts that would allow products that can be used as fertilizers in the EU to include precipitated salts and thermal oxidation materials obtained from the processing of sewage sludge (JRC, Technical proposals for selected new fertilizing materials under the Fertilizing Products Regulation (Regulation (EU) 2019/1009).

5. ANALYSIS OF POLICY AND REGULATION IN THE REPUBLIC OF SERBIA

Multilateral policy Sofia Declaration on the Green Agenda for the Western Balkans obligates the countries of the region to implement measures in the prevention of climate change and pollution, energy development and biodiversity, mobility and circular economy, sustainable agriculture and food production.

Recommendations that are expected to be adopted as a path to fulfilling goals of Green Agenda in the Republic of Serbia and other Balkan countries are (Commission Staff Working Document Guidelines for the Implementation of the Green Agenda for the Western Balkans Accompanying the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions An Economic and Investment Plan for the Western Balkans {COM(2020) 641 final}):

- Implementation of legislation related to water, which requires resources to invest in water infrastructure and management structure for sustainable water management;
- Self-sustainable utility companies in the Western Balkans with full cost cycle and preparation for the future use of EU structural funds;
- Necessary public administration reform to ensure the coherence of policies at all levels of management and better synergy between the economic, ecological and social dimensions of sustainable socio-economic development and reduce the compromise between these dimensions.

The Water Law ("Official Gazette of the RS", 30/2010, 93/2012, 101/2016, 95/2018) regulates water management in the Republic of Serbia. Water management is carried out through relevant ministries, bodies of the autonomous province, bodies of the local self-government unit and the public water companies. The territory of the Republic of Serbia represents a unique water area for water management and is divided into five river basin districts. Water units are the basic territorial units for performing operational tasks in water management, based on established criteria, such as the characteristics of the water area from the aspect of water use, water protection and protection from the harmful effects of water. Water Management Strategy of the territory of the Republic of Serbia is a master planning document that serve as a blueprint for the implementation of water sector reforms through the year 2030, aimed at achieving needed water management standards at the national, regional and local levels, and at fulfilling water management objectives. Based on this document, it was adopted the Water Management Plan until 2027. The largest part of the programme of measures consists of basic measures related to the full transposition of EU directives. According to current estimates, around 80% of the total costs for the implementation of the WFD in the Republic of Serbia are attributable to mandatory technical basic measures for the three most investment-intensive EU directives: the Urban Waste Water Directive, the Drinking Water Directive and the Nitrates Directive. The additional measures are mainly regulatory instruments and conceptual measures. The first programme of measures contains measures to prepare and facilitate the implementation of cost-effectiveness analyses to select additional measures, in particular in the areas of wastewater treatment in small settlements and improvement of hydromorphological conditions of surface waters. A program of measures is determined for each water body.

One of the newly adopted programs is the Circular Economy Development Program in the Republic of Serbia for the period 2022-2024. The document covers the most important areas of importance for the circular economy (eg waste management, renewable energy sources and energy efficiency) which are discussed in the context of the current state and potential for the application of the circular economy. The Program does not deal significantly with wastewater, only indicates possibilities/opportunities in the future for the application of this concept (recycling treated municipal wastewater and using sludge into agricultural and energy purposes). The reason for this is as stated the fact that a large number of WWTPs operate with efficiency far below the design and that some of these plants are not in operation.

National document Sludge Management Program in the Republic of Serbia for the period 2023-2032 is the first document that states the vision and refers to the general and specific goals of sludge management in Serbia.

The establishment of a sludge management system on the territory of the Republic of Serbia is planned through the application of short-term/medium-term and long-term solutions.

- Solutions in the short and/or medium term include: disposal of sludge in industrial landfills and re-cultivation of devastated sites; co-incineration in energy facilities; use of dried sludge for daily covering of sanitary landfills by mixing with inert material and disposal at sanitary landfills in special cassettes in the short term.
- The long-term sludge management solution envisages mono-incineration of sludge in combination with mono-landfills. It is based on the establishment of four Regional Centers for Sludge Management: AP Vojvodina; the area of the city of Belgrade; Šumadija and Western Serbia and Southern and Eastern Serbia. According to this solution, medium/large WWTPs could get the status of Regional Sludge Management Centers and District Sludge Treatment Centers.

Implementation plans for approximation to EU environmental acquis are not still conducted by the end in the Republic of Serbia. Directive 91/271/EEC was partially transposed into Serbian state regulations through the Water Law and by-laws, which primarily regulate the quality of waste water and the natural recipients into which it is discharged, and the by-law on monitoring the quality of waste water (Status and plans of transfer and of the implementation of the EU acquis for chapter 27 - environment and climate change, 2015).

Most of the provisions of the Directive 86/278/EEC have been transposed into secondary legislation, The Regulation on the manner and procedure of sludge management from municipal wastewater treatment plants ("Official Gazette of the RS", 103/2023). Regulation provides conditions for the prevention and reduction of human health and the environment in the process for the establishment of a regional system of municipal wastewater treatment system. The Regulation sets limit values for heavy metal concentrations (**Table 5**) and microbiological-parasitology parameters (**Table 6**) in sludge for use in agriculture and also for concentrations of heavy metals in soil where treated sludge is used (**Table 7**) as well as amounts of heavy metals which may be added annually to agricultural land, based on a 10-year average (**Table 8**). According to the provisions of this Regulation, it is not allowed to use more than 1.2 t sludge DM/ha/year.

Table 5. Limit values for heavy metal concentrations in sludge for use in agriculture

Heavy metals	Limit values (mg/kg DM)
Cd	2,5
Cu	700
Ni	60
Pb	120
Zn	1500
Hg	1,6
Cr	100

Table 6. Limit values of microbiological-parasitology parameters in treated sludge used in agriculture

Microbiological parameters	Unit	Limit values
Salmonella	MPN/10gSO*	0-10
Enterovirus	MPCN/10gSO**	3
MPN- most probable number MPCN- most probably number causing a cytopathic effect		

Table 7. Limit values for concentrations of heavy metals in soil where treated sludge is used in agriculture

Heavy metals	Limit values (mg/kg)		
Soil pH in 1 M KCl solution	5,0<pH<5,5	5,5<pH<6,5	pH>6,5
Cd	0,5	1	1,5
Cu	40	50	100
Ni	30	50	70
Pb	50	70	100
Zn	100	150	200
Hg	0,2	0,5	1
Cr	50	75	100

Table 8. Limit values for amounts of heavy metals which may be added annually to agricultural land, based on a 10-year average

Heavy metals	Limit values (kg/ha/year)
Cd	0,15
Cu	12
Ni	3
Pb	15
Zn	30
Hg	0,1
Cr	10

This Regulation entered into force at the end of November 2023 but for now, the provisions of this Regulation do not apply to agricultural land used for agricultural production. Compliance with legislation in agriculture sector is expected.

In the Republic of Serbia, there is no regulation that specifies the use of treated wastewater for irrigation purposes. In this regard, there are several documents that more closely determine the possibilities of using certain waters for irrigation:

- Rulebook on permitted quantities of hazardous and harmful substances in soil and irrigation water and their testing methods (Official Gazette of the RS, No. 23/94) - the maximum permitted quantities of hazardous and harmful substances in soil and irrigation water that can cause damage are prescribed or changes in the productive capacity (fertility) of agricultural land and the quality of irrigation water, which come from discharges from factories, spills from landfills, improper use of mineral fertilizers and plant protection agents.
- Regulation on limit values of pollutants in surface and underground waters and sediment and deadlines for their achievement ("Official Gazette of RS", no. 50 /2012) - regulates the quality of surface water intended for irrigation and Regulation on limit values of emissions of pollutants into water and deadlines for their achievement ("Official Gazette of the RS", no. 67/2011, 48/2012 and 1/2016) which prescribes the limit values of the emission of treated municipal waste water that is discharged into surface waters used for bathing and recreation, water supply and irrigation, and refer exclusively to microbiological parameters.

6. POLICY CONTEXT IN FRANCE

Water policy

Water policy in France is based on four major laws and framed by the European Water Framework Directive published in 2000, which defines the notion of “good overall status”, towards which all member states, including France, must strive. France is divided into 12 river basins: six in mainland France and six in the overseas territories. The management of these basins is based on the governance of a basin committee and on financial solidarity organized by a water agency in mainland France and by a water office in overseas France (excluding Mayotte).

Law n° 64-1245 of December 16, 1964 relating to the regime and distribution of water and the fight against its pollution established the principle of water management by large catchment areas, the hydrographic basins linked to the main French rivers. Under this law, public establishments were created, known as Water Agencies, with the mission of collecting water use charges and financing projects to preserve and restore water resources to good condition. The agencies thus implement the “polluter pays” and “user pays” principles, in a way that can be summed up by the phrase “water pays for water”. They are public bodies under the tutelage of the Ministry of Environment, they help building the Master Plan for Water Management (studies and research), they implement financial program every 5 years. The Water Agencies bill consumers, mainly industries, on the basis of the level of pollution generated and reinject this income in the form of aid to communities, industries and agricultural operations for water. The basic principle is that (the price of) water pays for the water!

Law no. 92-3 of January 3, 1992 on Water organizes water planning. It stipulates that a master plan for water development and management (SDAGE) is to be drawn up for each river basin. These plans are drawn up by basin committees, local water parliaments that bring together representatives of local authorities, the State, users (industry, farmers, consumers) and associations. The guidelines set out in these plans apply to all administrative decisions concerning water. In addition, water development and management schemes (SAGE) can be drawn up locally, at sub-basin level. The law also introduces the obligation to declare or request authorization for projects likely to have an impact on water resources. Under the authority of the prefects, these applications are examined by the water police, with the aim of ensuring that they are compatible with the objectives of balanced water resource management. The authorities may oppose projects or issue the necessary instructions to ensure compatibility.

Law no. 2004-338 of April 21, 2004 transposing Directive 2000/60/EC of the European Parliament and of the Council of October 23, 2000 establishing a framework for Community action in the field of water policy sets ambitious objectives for the preservation and restoration of water and aquatic environments in a management plan, the SDAGE, implemented by a program of measures. The 2004 law has established an initial list of 33 substances (metals, pesticides, hydrocarbons), supplemented by Directive D 2008/105/EC, which sets environmental quality standards applicable to eight other products.
Law no. 2006-1772 of December 30, 2006 on water and aquatic environments overhauls the principles of water pricing, in particular to guarantee greater transparency for consumers. It introduces the principle of the “right to water” and provides for climate change to be taken into account in all water management decisions. It also overhauls the tools used by the water police to respond more effectively to alterations to water resources caused not by a single activity, but by the existence of a multitude of activities in the same area, with cumulative impacts. It provides additional tools to meet new challenges and strengthens the scope of SAGEs. It creates the National Office for Water and Aquatic Environments.

Recent regulatory developments Decree no. 2021-795 of June 23, 2021 on the quantitative management of water resources and the management of drought-related crisis situations harmonises water abstraction restrictions at national level. It should be noted that this decree authorises higher levels of abstraction for farmers in critical situations. It is supplemented by Decree no. 2022-1078 of July 29, 2022 on quantitative resource management outside the low-water period, which extends the conditions for water abstraction to periods of low water.

Facing severe droughts and scarcity of water resources, the French President announced in 2023 a “Water Plan” to facilitate the development of 1000 projects of water reuse for 2027, and to multiply by 10 the volume of treated wastewater reused for various usages. Several laws were passed subsequently (order of December 18, 2023 related to usage of treatment wastewater for agriculture irrigation, and decree of August 29, 2023 related to uses of rain water and treated wastewater). Its 53 concrete measures are organized around 3 issues:

- Sobriety of use: counting the resource, planning its use, saving it;
- Optimizing availability (reduce losses, make the most of non-conventional water sources, improve storage);
- Preserving quality (preventing diffuse pollution, preserving and restoring the water cycle).

Regulations on wastewater management

The main regulations governing sanitation in France are:

- European Directive of May 21, 1991 on urban wastewater treatment;
- The ministerial decree of July 21, 2015 on collective and non-collective sanitation systems;
- Under French law, sanitation is governed by several legal codes:
    - o The French General Code of Local Authorities regulates the operation and payment of communal wastewater services, the responsibilities of communes

in this area and relations between communes and inter-communal cooperation bodies: Local authority responsibilities: article R.2224-17 CGCT; Control: article L.2224-8 CGCT; Sanitation zoning: Articles L.2224-10, R. 2224-7, R. 2224-8 et R.2224-9 CGCT; Sanitation charges: L.2224-12-2 et R.2224-19 CGCT.

  - The Environment Code, through the "water law" nomenclature, governs the management of wastewater, and in particular its treatment or discharge, which may present nuisances or risks for the environment or neighboring populations, requiring special supervision by the authorities.

- Local documents, such as Prefectoral decrees issued by government departments under the "water law" regulations can also impose sanitation requirements.

Current regulatory framework for wastewater management in France is based on the transposition of the Wastewater Directive (Directive n°91/271/CEE Council Directive 91/271/EEC of 21 May 1991 concerning urban wastewater treatment) and the Water Framework Directive (WFD - Directive 2000/60/EC), and more recently on several plans and laws dedicated to developing circular economy and reuse of treated wastewater. The required treatment levels for wastewater treatment are set according to the size of the sewage agglomeration and the sensitivity of the environment receiving the final discharge.
The Wastewater Directive has been transposed into the French Environmental Code and several specific decrees, for example, Articles L.211-1 and following define the general principles for water management and pollution prevention, and Articles L.214-1 and following regulate facilities and activities impacting water, including wastewater treatment plants. Articles R.211-94 to R.211-111 establish discharge thresholds and quality standards for wastewater. Specific decrees (e.g., Decree of July 21, 2015 on collective sanitation systems and non-collective sanitation installations, with the exception of non-collective sanitation installations receiving a gross organic pollution load less than or equal to 1.2 kg/d of BOD5) define technical requirements for wastewater treatment systems and discharge thresholds for BOD5, COD, TSS, total nitrogen, and total phosphorus, as well as monitoring and self-monitoring obligations for operators.

Besides, the Wastewater Directive obligations are currently enshrined in the French General Code of Local Authorities (articles R.2224-6 and R.2224-10 to R.2224-17 on wastewater collection and treatment) and the Decree of June 22, 2007 (Order of June 22, 2007 on the collection, transport and treatment of wastewater from sanitation agglomerations, as well as the monitoring of their operation and efficiency, and non-collective sanitation systems receiving a gross organic pollution load in excess of 1.2 kg/d of BOD5) on the collection, transport and treatment of wastewater from wastewater treatment plants. The Order of June 22, 2007 groups together all the technical requirements applicable to wastewater treatment facilities (design, sizing, operation, purification performance, self-monitoring, and control by government departments).

Concerns about ***emerging pollutants*** such as micropollutants and endocrine disruptors led to evolutions in the regulatory framework, including a Micropollutant Plan since 2016 aiming to reduce micropollutants in wastewater discharges and to get more knowledge on their occurrences and concentrations. The technical note of August 12, 2016 explains the procedures for the search for micropollutants both in treated wastewater and in the raw wastewater entering WWTP in metropolitan France. The WWTPs covered by this note are those with a nominal capacity equal to or greater than 600 kg/d of BOD5, with the exception of WWTPs whose treated wastewater is discharged by infiltration into the ground. This note constitutes a roadmap for the communities covered by its application to encourage the development of action plans contributing to the reduction of emissions of 96 micropollutants. The aim is to promote reduction actions at source in order to limit the flows arriving at wastewater treatment plants.

Regulations governing the spreading of sewage sludge

Regarding sewage sludge, the Directive 86/278/EEC of June 12, 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture, has also been transposed into specific decrees and the Environmental Code, stating the objectives of soil and water management, including agricultural practices using sludge, regulation of sludge spreading and quality standards requirements, including concentration limits for heavy metals and organic contaminants or sanitization requirements to eliminate pathogens as well as the frequency and types of analyses to be conducted before spreading.

Consequently, the legal and regulatory framework for the agricultural spreading of sewage sludge was defined by the ministerial decree of January 8, 1998, with the following procedure:

- Carrying out a preliminary study, accompanied by analyses of the sludge to be spread and the soil in which it is to be applied;
- Scheduling of operations, including a provisional program, prior information, sludge and soil analyses, field monitoring by a designated person in charge, and keeping of a spreading register;
- An agronomic report duly recorded each year.

In addition, regulations define the quality standards required for sludge to be declared suitable for spreading. In particular, they set limit values for trace element and organic trace compound content.

A spreading program must first define the type of crops and their surfaces, the cropping systems (before and after sludge application), the amounts of inputs of other fertilizers, and must be based on a duration of 10 years (reaching at most 30 t.dw/ha of sludge). For each type of crop, the complementary inputs (in terms of N, P_2O_5 and K_2O) needed to supplement the inputs from sludge can be calculated using abacuses to reach the expected yields per hectare.

Table 9. Maximum cumulative flow of sludge within 10 years (Order of 08/01/98)

Trace metals (maximum cumulative flow in 10 years)		Organic micropollutants (maximum cumulative flow in 10 years)	
• Cd	0.015 g/m²	• Σ 7PCBs (28, 52, 101, 118, 138, 153, 180)	1.2 mg/m²
• Cr	1.5 g/m²		
• Cu	1.5 g/m²	• Fluoranthene	7.5 mg/m²
• Hg	0.015 g/m²		6.0 mg/m²
• Ni	0.3 g/m²		
• Pb	1.5 g/m²	• Benzo[*b*]fluoranthene	4.0 mg/m²
• Zn	4.5 g/m²		
• Σ(Cu + Ni + Zn + Cr)	6.0 g/m²	• Benz[*a*]pyrene	3.0 mg/m²
			2.0 mg/m²
• Se	0.12 g/m²		
if spread on meadow		if spread on meadow	

The agronomic value of the soil must be evaluated (organic matter, N, P, K, CEC, Ca, and micronutrients), as well as its contamination by trace metal elements (x7) before sludge spreading. Soils with trace metal concentrations higher than the defined thresholds cannot be amended with sewage sludge (Table 10).

Table 10. Soil characteristics (Order of 08/01/98)

Agronomic features				Trace metal contents	
Parameters	Units	Parameters	Units	Parameters	Threshold
Grain size	% or g/kg	Exch. Calcium (CaO)	g/kg	Cd	[2]
Organic matter	%	Exch. Potassium (K_2O)	g/kg	Cr	[150]
pH				Cu	[100]
TKN	g/kg	Na_2O	g/kg	Hg	[1]
C/N				Ni	[50]
Total limestone ($CaCO_3$)	g/kg	***Micronutrients***		Pb	[100]
				Zn	[300]
Active limestone ($CaCO_3$)	g/kg	B	mg/kg		
		Co	mg/kg	in **mg/kg.dw**	in **mg/kg.dw**
CEC	cmol/kg	Cu	mg/kg		
Exch. Phosphorous (P_2O_5)	g/kg	Fe	mg/kg		
		Mn	mg/kg		
Exch. Magnesium (MgO)	g/kg	Mo	mg/kg		
		Zn	mg/kg		

Finally, the sludge must be also characterized, to know its agronomic potential (dry matter, organic matter, N, P, Ca, K, micronutrients etc.) and its contamination by trace metals (x7 +1), PCBs (x7) and PAHs (x3) (**Table 11**).

Table 11. Quality requirements for sludge spreading (Order of 08/01/98)

Agronomic value	Trace metal contents	Organic micropollutants
Dry matter (%) Organic matter (%) pH TKN* Organic Nitrogen* NH_4^+* C/N Total Phosphorous (P_2O_5)* Potassium (K_2O)* Calcium (CaO)* Magnesium (MgO)* Micronutrients : B, Co, Cu, Fe, Mn, Mo, Zn (in mg/kg.dw) * in **kg/t.dw**	• Cd 10 • Cr 1000 • Cu 1000 • Hg 10 • Ni 200 • Pb 800 • Zn 3000 • Σ(Cu + Ni + Zn + Cr) 4000 • Se 25 in **mg/kg.dw** **[threshold in mg/kg.dw]** **if spread on meadow**	• Σ 7PCBs (28, 52, 101, 118, 138, 153, 180) 0.8 • Fluoranthene 5 4 • Benzo[*b*]fluoranthene 2.5 • Benz[*a*]pyrene 2 1.5 in **mg/kg.dw** **[threshold in mg/kg.dw]** **if spread on meadow**

In May 2022, there has been an approval of the AFNOR standard NF U44-095 (NF U44-095 (2022) Organic amendments - Composts containing materials of agronomic interest, derived from water treatment (French regulation)) related to composts derived from water treatment, establishing thresholds for trace metals, organic micropollutants and pathogens in the final product, and also requiring monitoring and labelling of the product to be used by farmers. The product must undergo an aerobic fermentation phase (**Table 12**).

Table 12. Comparison between the quality requirements for sludge spreading (Order of 08/01/98) and composting for vegetable gardening (NF U44-095)

Trace metal contents SLUDGE	Trace metal contents NFU 44095	Organic micropollutants SLUDGE	Organic micropollutants NFU 44095
• Cd 10 • Cr 1000 • Cu 1000 • Hg 10 • Ni 200 • Pb 800 • Zn 3000	• Cd 3 • Cr 120 • Cu 300 • Hg 2 • Ni 60 • Pb 180 • Zn 600	• Σ 7PCBs 0.8 • Fluo 5.0 • BbF 2.5 • BaP 2.0 in **mg/kg.dw** **[threshold in mg/kg.dw]**	• Σ 7PCB 0.8 • Fluo 4.0 • BbF 2.5 • BaP 1.5 In **mg/kg.dw** **[threshold in mg/kg.dw]**

Main texts associated to sludge spreading:

- Decree no. 97-1133 of December 8, 1997 on the spreading of sludge from wastewater treatment.
- Order of January 8, 1998 laying down the technical requirements applicable to the spreading of sludge on agricultural soils in application of Decree no. 97-1133 of December 8, 1997 on the spreading of sludge from wastewater treatment.

Circular economy

The anti-waste law for a circular economy (Law no. 2020-105 of February 10, 2020 on the fight against waste and the circular economy) aims to accelerate the change in production and consumption models in order to limit waste and preserve natural resources, biodiversity and the climate. The aim of the anti-waste law for a circular economy is to transform the French economy in depth, it is designed to combat all the different forms of waste. The law aims to transform the current linear economy - produce, consume, throw away - into a circular economy.

It has five main thrusts:

- eliminating disposable plastic;
- better inform consumers;
- combat waste and promote solidarity-based re-use;
- act against programmed obsolescence;
- produce better.

For circular economy and wastewater reuse, the decree of August 2, 2010 governs the reuse of treated wastewater for irrigation, industrial processes, and urban uses, defining quality standards for microbiological and chemical parameters depending on the intended reuse, and requires a risk assessment for human health and the environment before implementing reuse projects. In 2020, the anti-waste law prevents waste in several sectors including wastewater, modifying the Environmental Code to include the possibilities of treated wastewater reuse, especially in water-scarce regions, for urban purposes such as irrigation of green spaces and street cleaning.

In 2015, the Law of Energy Transition for Green Growth (LTECV) included objectives to develop methanization in order to reduce the dependency to fossil fuel, with the goal to reach 10% of renewable sources for total gas consumption in 2030.

7. CURRENT STATUS OF WASTEWATER AND SEWAGE SLUDGE MANAGEMENT IN FRANCE

Wastewater treatment plants

There are about 22,000 WWTPs in France, for a total treatment capacity of ~106 M population equivalent (PE). Each year, 2-3% of WWTPs need to be replaced/renovated because of insufficient capacity or outdated equipment. The number of WWTP commissioning increased regularly between 1960 and 2000, and peaked in 2006 with more than 1400 WWTPs built that year to meet the requirements of the Wastewater Directive n°91/271/CEE (**Fig. 3**).

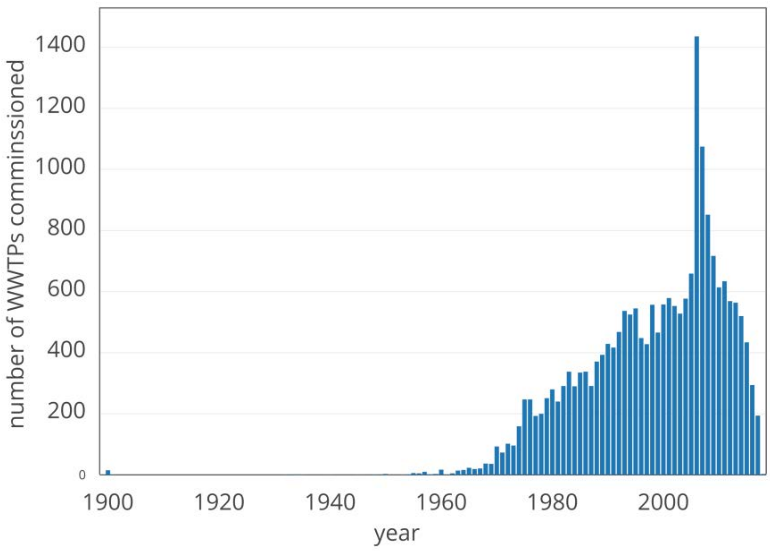


Figure 3. Construction of wastewater treatment plants in France (number of plants built each year)

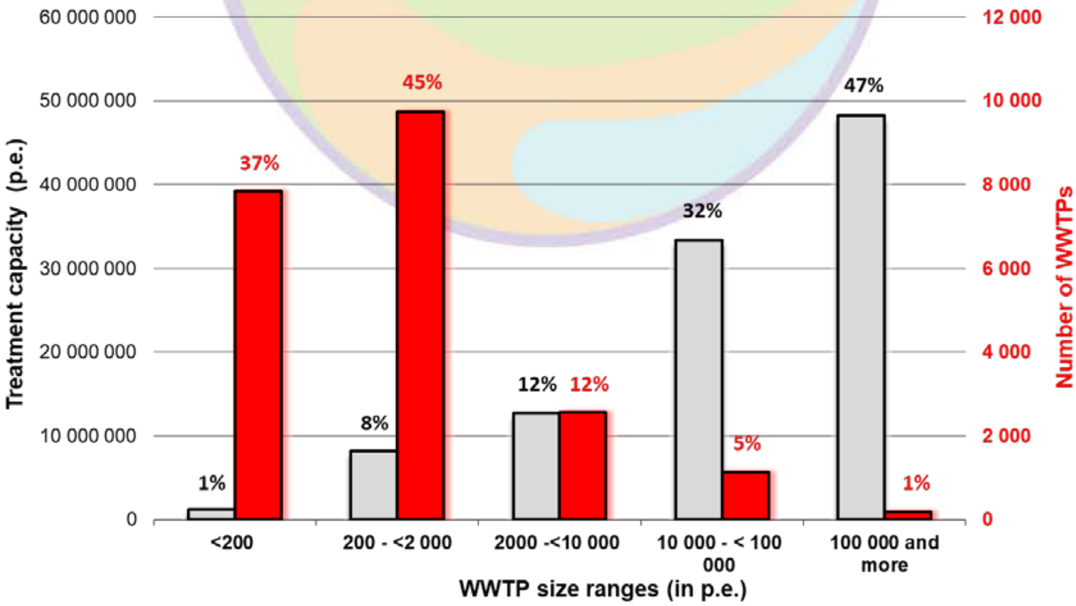
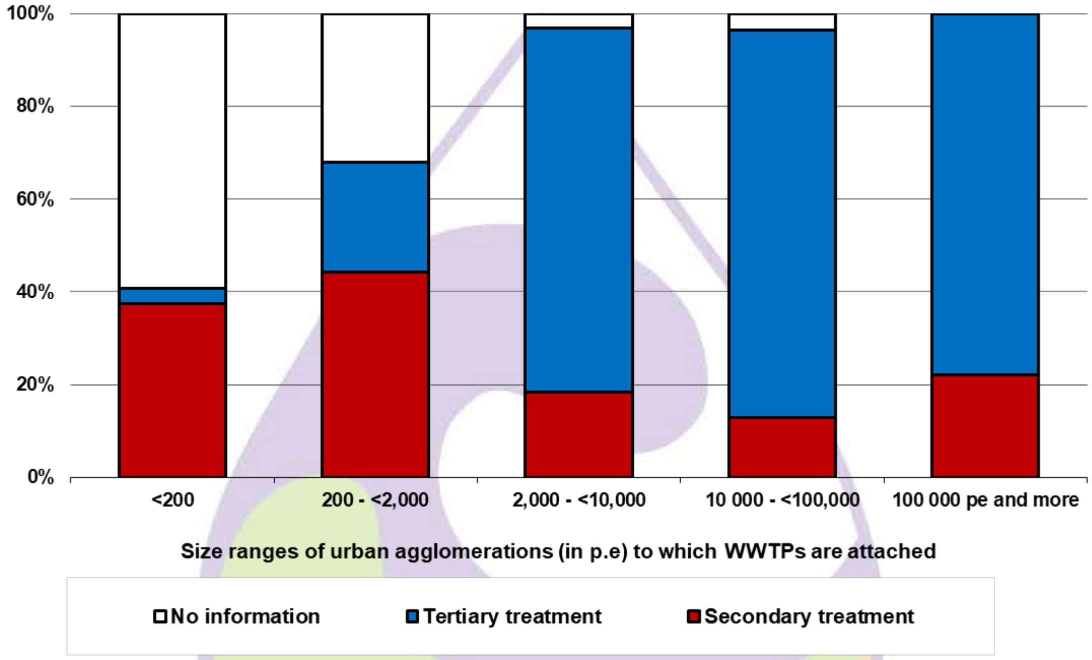


Figure 4. Treatment capacity (population equivalent) and number of WWTPs according to the size of their connecting conurbation

In France, there are many small plants: over 50% have a theoretical capacity of less than 500 PE. Conversely, 6% of plants have a capacity of at least 10,000 PE, and together account for over 80% of the total capacity of WWTPs in service in France (Fig. 4).

A plant's compliance with European regulations is judged based on its equipment (treatment level) and performance (pollutant concentrations in discharged treated effluent and plant efficiency). In 2016, at least 94% of WWTPs, covering 98% of total treatment capacity, were equipped in accordance with European regulations. In terms of overall performance, at least 86% of WWTPs, representing 89% of total installed capacity in France, were compliant (**Fig. 5**).



Source: Ministry of Ecology, Water and Biodiversity Department, Roseau database (ex BD-ERU). Treatments: SDES, 2018.

Figure 5. Number of urban wastewater treatment plants by treatment level and size of their connecting agglomeration (year 2016)

Sewage sludge management

The management of sludge from WWTPs has changed a lot in the last decades, especially regarding landfilling (20% in 2004, down to <1% in 2022). Most sludges are now used in agriculture after composting (51%), or with direct application (32%), and the remaining part being mostly incinerated (13%). Not all wastewater treatment plants are equipped with a sludge treatment and disposal system: in 2016, 43% of collective wastewater treatment plants in France declared that they had a sludge treatment system, representing around 95% of the total treatment capacity installed in France and the mass of sludge extracted. The volume of sludge produced in France in 2022 was about 1,030,000 t.dw (**Fig. 6**).

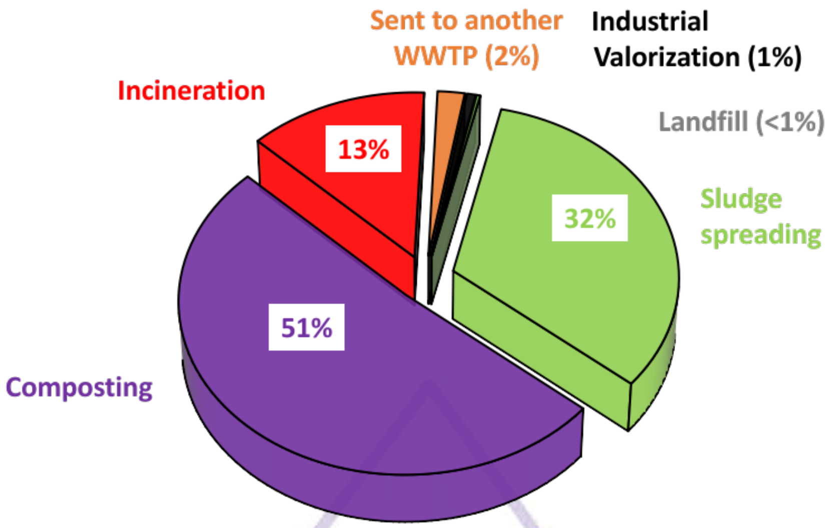


Figure 6. Sludge management in France (2022)

Sludge uses have been regulated since 1998 (Order of January 8, 1998 laying down the technical requirements applicable to the spreading of sludge on agricultural soils in application of Decree no. 97-1133 of December 8, 1997 on the spreading of sludge from wastewater treatment). Agricultural spreading is subject to a multi-stages procedure, with a pre-study to evaluate the feasibility and to define a spreading method, a construction step at the WWTP (thickening method, storage building), a spreading planification stage with agreements prepared between farmers and the authority responsible for agronomic monitoring as well as submission of administrative declaration, and a final stage dedicated to monitoring (agronomic and sludge quality monitoring, annual review of sludge application campaigns and projected annual sludge application program).

The spreading program generally involves a lot of stakeholders: the public authority (WWTP owner), the WWTP manager (public authority or private company), the service provider for monitoring of the sludge application, the transport supplier, the spreading contractor, the landfill contractor, an accredited analysis laboratory and the farmers involved in spreading campaigns. To launch a spreading program, some specific guidelines are available in the regulation and are related to crops (type of crops, their surface), to the soils (agronomic value and levels of contamination before spreading) and to sludges (quantities, agronomic value and contamination).

Recently, there has been an increase in the implementation of methanization, reaching 3% of uses of sludges in the Parisian conurbation in 2022. In France, there were 105 WWTPs (90% of which had a capacity of 60 000 PE or higher) equipped with a methanization facility in 2022. It is estimated that ~430 WWTPs could be capable of methanizing their sludges at the scale of France (**Fig. 7**).

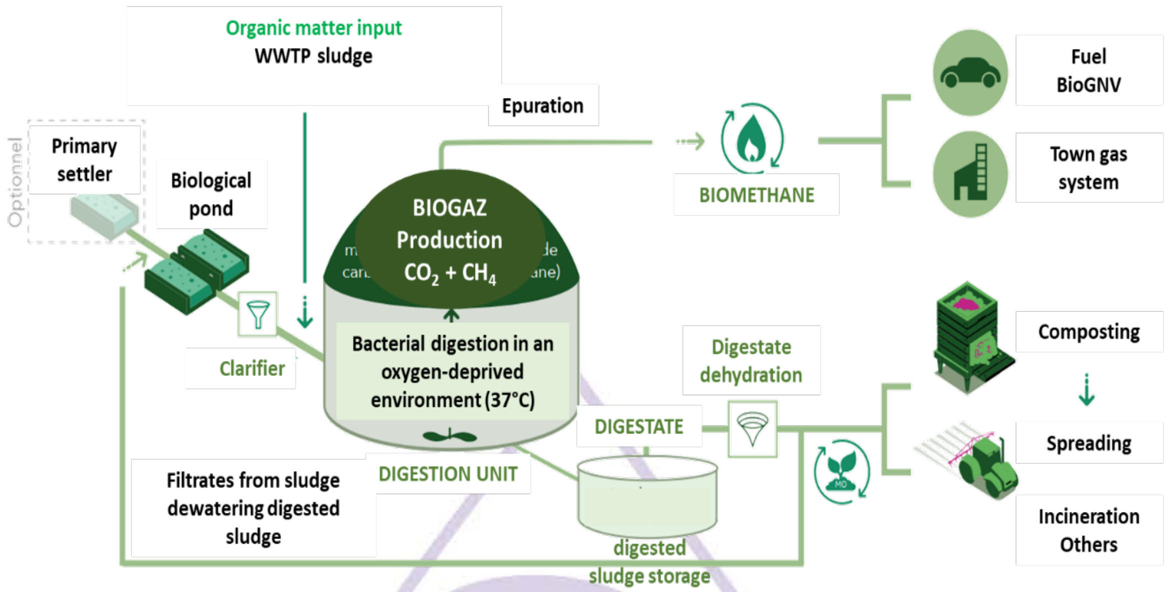


Figure 7. Process layout of a classical biogas recovery facilities (adapted from Suez)

[For a factsheet on biogas production: *Gupta & Khatiwada (2024). Investigating the sustainability of biogas recovery systems in wastewater treatment plants-A circular bioeconomy approach. Renewable and Sustainable Energy Reviews, 199, 114447.***]**

Government plans (e.g., the recent French "Water Plan") demonstrate the goal to develop the reuse of treated wastewater in France, allowing facilitated projects through simplification of administrative requests and no limitations regarding the duration of projects. Public operators of wastewater treatment plants are increasingly aware of the benefits that can be made from biogas production, with short returns on investments made from methanization infrastructures. Experimentations of source-separation of urine made in collaboration between citizens/consumers (clients of small scale and short-distance farming associations) and farmers show the interest of these stakeholders for the direct reuse of urine for agriculture production.

8. CURRENT STATUS OF WASTEWATER AND SEWAGE SLUDGE MANAGEMENT IN THE REPUBLIC OF SERBIA

Currently, there is 40 WWTP built in the Republic of Serbia. Estimation indicates that for 9 WWTPs reconstruction or construction of a new one is required, 26 are in a functional state in the sense that they can be managed with smaller or larger investments, and 5 is not functional. The oldest plants are from the 1990s. In the period 2006-2022, 26 plants were built.

A number of problems have been identified in the operation of wastewater treatment plants (Study: Analysis of the situation in the municipal wastewater management sector and guidelines for further development, 2024, in Serbian). In several agglomerations, the impact of rainwater and groundwater infiltration into the sewage system has been observed, causing higher energy consumption; greater need for maintenance; reduced component life; higher consumption of chemicals and reduced efficiency of the wastewater treatment process.

The impact of industrial users of the sewage system is significant in agglomerations of 10 000-100 000 PE. The magnitude of this negative impact was determined based on the frequency of occurrence and duration of discharges of untreated/insufficiently treated industrial wastewater. The management and location of sludge disposal are inadequate for most WWTPs.

Poor technological performance and deficiencies in the functioning of equipment were identified in 75% of WWTP. Construction problems have a WWTP < 10 000 PE.

The largest number of plants inappropriately dispose of sludge (at the plant location or in unregulated landfills), while a smaller number dispose of it in regional landfills. Sludge generated after wastewater treatment at one plant is incinerated.

Serbian specific implementation plan of the Urban Waste Water Treatment Directive 91/271/EEC related to the treatment of urban wastewater assessed the need for the construction of 359 WWTP (**Table 13)** in 398 agglomerations in the Republic of Serbia. In the coming years, significant investments in wastewater treatment in the Republic of Serbia are planned (**Figure 8**).

Table 13. Categories of planned WWTP in RS

Category 1	Small WWTP	2000-10 000 PE	274
Category 2	Medium WWTP	10 000 -100 000 PE	74
Category 3	Large WWTP	> 100 000 PE	11
		Σ	**359**

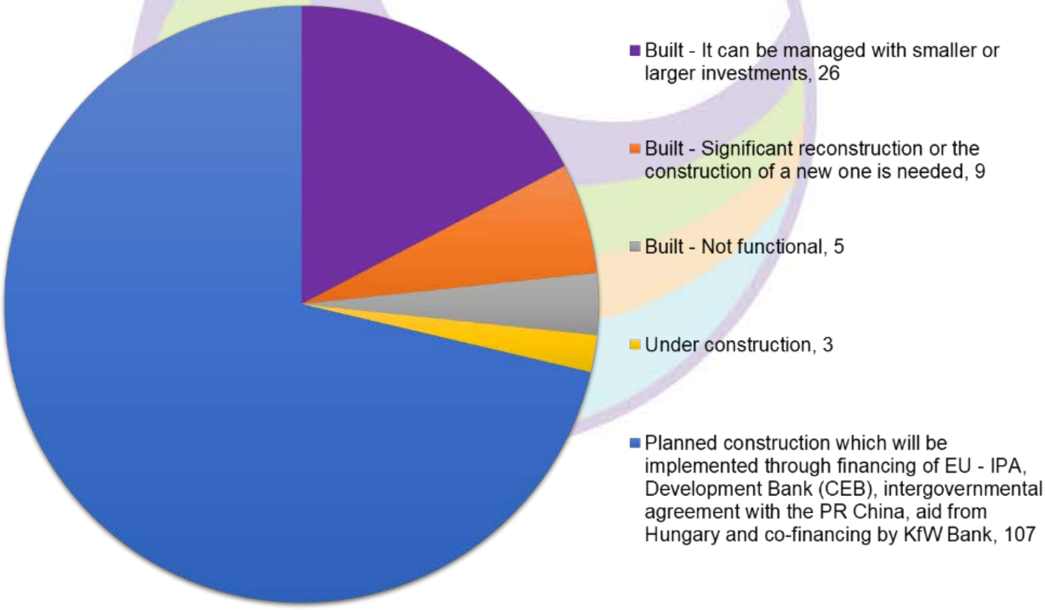


Figure 8. Current situation and foreseen plans for WWTP construction in the Republic of Serbia

Financing of wastewater systems

This sector funded by local authorities, national and provincial funds, subsidies and tariffs collected from sewer system users. The total revenues of Public Utlity Companies in 2022 were around 35.7 billion RSD, and the total costs were around 36.3 billion, which gives a negative balance of -0.6 billion RSD (~ 0.5 million EUR). Taking into account non-repayable funds, the negative balance increases to 2.94 billion RSD (~30 million EUR). This trend has been present for many years (Study: Analysis of the situation in the municipal wastewater management sector and guidelines for further development, 2024, in Serbian).

The average price charged for collection through sewer systems, transportation and treatment of wastewater is 28.2 RSD/m³ (~0.2 euros), with a range of about 1:5 - the minimum tariff was about 5.2 RSD/m³. The tariff of wastewater treatment is ca. 25 RSD/m³. Activities for the maintenance of WWTPs include activities for preventive maintenance, corrective maintenance, repair and inventory management. In most cases, only emergency maintenance is carried out, which has a negative impact on the service life of the sewer and wastewater treatment plant equipment.

Public Utlity Companies estimated minimum tariffs to fully cover costs (taking into account amortization), 38 DIN/m³, while wastewater treatment would require ca. 43 DIN/m³. This means a price increase of around 35%. The costs are certainly significantly influenced by the changes resulting from the energy crisis and increase in prices chemicals, equipment and other costs.

Employment in wastewater sector

The number of employees in public utility companies in 2022 was 18 989. In the sewerage sector, about 10% of the total number of employees.

The problem in municipal wastewater management is not only financial but also personnel-related especially in WWTP size 2 000-10 000 PE. Lack of experts in various specific professions, necessary for a comprehensive, high-quality and long-term sustainable approach to the management and maintenance of this system.

Existing problems with job abandonment in the municipal wastewater sector can primarily be linked to the market price of labor.

Public Utilities Companies face the problems of dysfunctional political economy (term taken from: Water Utility Turnaround Framework, World Bank group, 2018). In such settings, water utilities operate for purposes other than serving customers, helping government authorities secure votes by providing jobs. Influence on decision-making in these companies leads to poor performance in serving customers and inefficient operation of the utilities.

It can be concluded that the management of existing WWTPs in the Republic of Serbia has a number of challenges in every sense, financial, technical, staff, organizational.

Sewage sludge management plan

In the Sludge Management Program wastewater treatment technologies and methods of sludge treatment and disposal are given according to the expected capacity of the waste water treatment plant (**Table 14 a & b**).

Table 14a. An overview of the planned wastewater treatment and sludge digestion technologies in the Republic of Serbia

Wastewater treatment plants	Planned number of plants	Anticipated technology	Maximum specific sludge production (aerobic or anaerobically stabilized) g SM/PE day	Sludge digestion	
Small wastewater treatment plants 2 000 - 10 000 PE	274	Conventional extended aeration process, sequential batch reactor (SBR) with extended aeration, or biodisc with primary clarifier and separate anaerobic digestion under psychrophilic conditions (12-15°C).	55	Extended aeration with simultaneous sludge stabilization or separate aerobic stabilization.	
Medium-sized plants, 10 000 - 100 000 PE	74	Activated sludge process with biological nutrient removal and, depending on capacity, aerobic or anaerobic sludge stabilization.	52,5	≤ 50 000	Single-stage anaerobic digestion with cogeneration wherever cost-effective.
				≤ 100 000	One-stage anaerobic digestion with cogeneration.
Plants above capacity 100 000 PE	11	Conventional activated sludge process with biological removal of nutrients and anaerobic sludge digestion.	45	≤ 150 000	Single-stage anaerobic digestion with sludge disintegration and combined heat and power generation and cooling (CHP) device.
				≤ 250 000	Highly efficient anaerobic digestion with sludge disintegration and CHP (cooling, heating and electricity).
Capacity plants 1 500 000 PE	WWTP „Veliko Selo"	A technologically modern solution, based on the principles of optimizing biogas production (mesophilic anaerobic digestion of thickened sludge (gravitationally thickened primary and mechanically thickened surplus activated sludge), hydrothermal carbonization process).	32	≥ 250 000	Highly efficient anaerobic digestion with sludge disintegration and CHP (cooling, heating and electricity).

Table 14b. Overview of additional sludge treatment and options for its final disposal in the Republic of Serbia

Wastewater treatment plants	Additional sludge treatment	Disposal in sludge treatment centers/Regional sludge management centers	Final disposal
Small wastewater treatment plants 2 000 - 10 000 PE	Humification in reed fields; Storage for service dewatering.	Hummus after 10 years. Mud cake	Application to land. Transport to the sludge treatment center.
Medium-sized plants, 10 000 - 100 000 PE	Sludge dewatering; solar drying.	Transport of granules or sludge cake	Application to land. Disposal in monodeposits Transport to the sludge treatment center.
	Solar drying or thermal drying; Sludge dewatering.	Transport of granules or sludge cake	Disposal at mono-landfills Transport to the sludge treatment center.
Plants above capacity 100 000 PE	Solar drying or thermal drying; Sludge dewatering.	Transport of granules or sludge cake	Disposal at mono-landfills or transport to the Regional Sludge Management Center for incineration (mono-incineration).
	Thermal drying.	Transport of granules	Disposal in mono-landfills or transport to the regional sludge management center for mono-incineration.
Capacity plants 1 500 000 PE	Monoincineration	Transport of granules	Disposal in monodeposits

Sludge Management Program emphasizes as a general goal "the establishment of a safe, sustainable and cost-effective sludge management system from wastewater treatment plants in accordance with the principles of circular economy" without projection of the content of useful components (eg nutrients) and the need for agricultural crops.

Considering that using sludge as fertilizer is still a most cost-effective management option, in this project a step was taken further in order to estimate the amount of nutrients in the sludge assuming it will be used for agricultural purposes (see chapter Proposed methodological framework for the application of the principle of circular economy in the wastewater sector (Republic of Serbia)).

From the aspect of resource recovery, the option according to the Program is the formation of struvite (magnesium ammonium phosphate, $NH_4MgPO_4 \cdot 6H_2O$) from this flow. Process of struvite crystallization requires higher investment and operating costs. Therefore, it is necessary to assess for the plants which capacity (according to literature ≥ 100 000 PE), and the quality of the concentrate in terms of nitrogen and phosphorus concentrations, this possibility is profitable. Also, the efficiency of phosphorus recovery through struvite is much lower than 90% at a large plant, so optimization of the process is necessary.

As one of the additional sludge treatments for small plants, the Program specifies humification in reed fields. This type of sludge treatment is favored worldwide in order to reduce the costs of sludge dewatering both from the technical aspect and from the aspect of the use of chemicals. It must be emphasized that the knowledge and careful maintenance of such systems is of key importance. Vegetation must be regularly maintained in order to prevent spontaneous rotting and loss of treatment efficiency, which can lead to neglect of the system and potential microbiological risks. Humification has been shown to be beneficial in terms of removing toxic organic substances that are mineralized during this period. From the aspect of reducing the metal content, the aspect of phytoremediation is also considered. However, the risk of increased metal content is not significant , if sludge originating only from the population's wastewater is treated in this way, which is the most common case in settlements in the Republic of Serbia for which this method of sludge disposal is provided. From the perspective of the circular economy, given that the period of exploitation of the reed field is 10 years, it is concluded that nutrients will be "trapped" in this period, that is, unavailable for application to agricultural land, at the same time with the risk of reducing their content in this period. It is necessary to do a cost-benefit analysis in order to adequately evaluate the decision for such solutions (author's note).

Sludge incineration results in a reduction of the total mass of dry sludge by 93% primarily at the expense of organic matter. There is also a loss of nitrogen to the atmosphere of 94% through the formation of various nitrogen oxides during heat treatment. At the WWTP level, this option may require additional moisture reduction in the sludge to make it an adequate material for incineration. High temperatures determine the decomposition of organic pollutants, and metals will remain in the sludge ash and their concentration will occur due to the reduction of the sludge mass. As highlighted earlier in the text, according to data from different countries, this is currently the most expensive sludge management option. What is not mentioned in the Program is the need for the application of technologies for the recovery of phosphorus from ash, which requires additional investments. These technologies are still under development, with the efficiency of phosphorus recovery up to 90% and primarily include leaching with acids. Phosphorus can be recovered from ash in the form of phosphoric acid, struvite, calcium phosphate and related products.

Perception of agricultural sludge users

Farmers' attitudes are an important and necessary prerequisite for valorisation of sewage sludge in agriculture. As part of the SmartWaterTwin project, a survey of farmers in the Republic of Serbia was carried out on current information and attitudes when it comes to the application of sludge for agricultural purposes.

Survey distributed using the Google Form tool. A total of 81 farmers participated in the survey. The majority of farmers are members of the "Serbian Association of Young Farmers" and deals with cultivation and production of plants on arable land in the territory of AP Vojvodina, while a smaller number of them are located in Central and Eastern Serbia. Answers to some of the important questions are given in this section.
According to the responses, mineral fertilizer is used to the greatest extent, while manure or a combination of synthetic mineral fertilizers and manure is used significantly less (20% of respondents). Very few farmers have knowledge that sewage sludge can be used as a fertilizer (**Figure 9**).

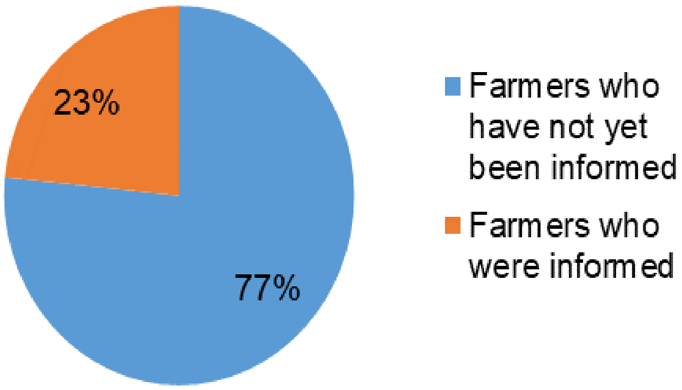


Figure 9. Farmers' awareness of the possibilities of using sludge for agriculture purposes

To the question of whether farmers would be ready to spread sewage sludge on their land, 45 of them answered with "maybe". Of the remaining number, 28 respondents answered this question with "yes", and the remaining 8 with "no" (**Figure 10**). The results of the survey indicate that 90% of the surveyed farmers are potential users of the treated sludge that is created after the treatment of municipal wastewater for the purpose of fertilization.

Figure 10. Farmers' willingness to use treated sewage sludge as fertilizer

The main factor that would motivate farmers to use sludge is better yields (**Figure 11**). The cited reasons for reluctance to use sludge from municipal wastewater treatment plants as fertilizer include mistrust in the quality of this type of fertilizer, doubts about the yield, unsuitable type of soil, lack of mechanization and concerns about transporting fertilizer to the arable land.

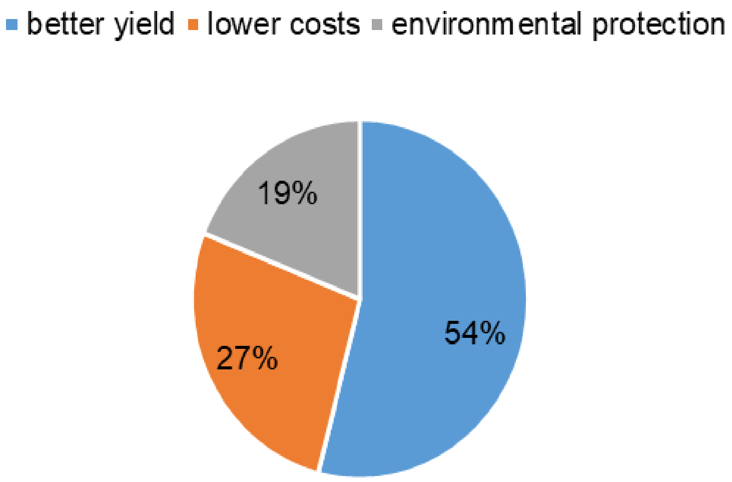


Figure 11. Factors motivating farmers to use sewage sludge as fertilizer

The support instruments that farmers expect for making a decision on the use of treated sewage sludge are education, information on costs and subsidies, detailed explanations on the method of use and composition of sludge, results of analysis on the effects on yield and soil quality. Farmers are interested in detailed studies and examples of use, as well as in scientific and practical education that would allow them to better understand the potential of sewage sludge and make final decision. In addition, some farmers are interested in local demonstration projects. This information are considered important for formal and informal institutions in sludge management process and establishing ways of its valorisation.

9. INNOVATION AND RESEARCH

Research, innovation and knowledge development for the transition to a circular economy in the Republic of Serbia

The analysis of the scientific contribution to the introduction of CE in the Republic of Serbia was carried out by reviewing the results on the Serbian eScience portal (https://enauka.gov.rs). It should be emphasized that this is a rough analysis, bearing in mind that not whole publications either abstract are available in the database. Searching is possible using keywords in the title of the results. The keywords “circular economy” were used in the first phase of the search results. This database contains a total of 783 306 results published in the period 2000-2026, of which 2 567 there are the given keywords in the title. The largest number are scientific articles (1139), conference papers (779), text books (202) and monographs/part of monographs (270). In the second stage, single words were considered in the title. Most of the results in the first decade analysing period relate to the economy and economic development in general. An increasing in interest in the subject area was found between 2010 and 2019 when in addition to “circular economy” the terms “sustainable economy”, “regenerative economy”, “sustainable development”, “environmental protection”, “green economy”, “green chemistry”, “systems thinking” appear. In the last five years, review papers on the application of the circular economy in wastewater treatment and possibilities for collecting and reusing wastewater have been published. Also, there were published articles with the following terms in titles: technological solutions in the concept of sustainable cities, nutrient flows in a wastewater treatment plant and possibilities for their recovery, electrochemical treatments in a circular economy, implementation of a zero waste strategy - use of sludge from wastewater treatment plants in construction materials. Most of the articles were published in Serbian. It is evident that the articles from waste management in the context of a circular economy are predominant compared to wastewater management which is currently in relation to funding in this area.

The project SmartWaterTwin contributed to the internationalization of science and innovation through numerous publications that are presented in table 15. Within the project, one auxiliary book was published for teaching purposes at universities in Republic of Serbia, through existing and newly formed courses.

Table 15. Overview of publications developed through SmartWaterTwin project

Type of publication	No. of publication	Status of publication
Auxiliary book for teaching - University level	1	Published
Manuscript in the top international journal	5	2-Published 2-Submitted 1-In preparation
Manuscript in the prominent international journal	2	2-Submitted
Manuscript in the national journal	2	Published
Invited lecture on an international conference – abstract	2	Published
Proceeding from the international conference - whole manuscript	1	Published
Proceeding from the international conference - abstract	13	Published
Invited lecture from a national conference - whole manuscript	2	Published
Proceeding from the national conference – whole manuscript	10	Published
Proceeding from the national conference – abstract	1	Published
Dissemination and communication presentation on national event Water Forum	6	Published
Publications are available on https://smartwatertwin.pmf.uns.ac.rs/knowledge-hub/publications/		

In the period 2022-2024, the Serbian Ministry of Environmental Protection and the Ministry of Education conducted a campaign aimed at introducing the circular economy into study programs at undergraduate and master's academic or vocational studies during actual campaign. This was an ambitious and not entirely realistic plan of encouraging higher education institutions as key stakeholders in the transition process towards CE. One of the reasons is that the study programs are accredited for a period of seven years and the introduction of new concepts and content into the curricula is a more demanding and long-term process. An analysis of study programs at universities in the Republic of Serbia suggests that there is currently no holistic approach that would enable the transition from a linear to a circular economy. Most courses focus on individual issue-related topics such as economic, environmental, technological or business. One specific study module "Circular Economy - Principles and Concepts" is being realized within the master's academic studies at the Faculty of Organizational Sciences, University of Belgrade (https://ekonomija.fon.bg.ac.rs/cirkularna-ekonomija/). At University of Kragujevac there is the possibility of attending short study program "Cirular economy consultant" which includes economic sciences and mechanical engineering as two scientific/professional fields and provides professional practice in companies and acquiring specific competences besides theoretical knowledge (https://www.kg.ac.rs/vest.php?vest=4864). This type of course is suitable for long-life learning considering to allow development of professionals and upgrade knowledge necessery to apply CE in industrial sector. The accreditation of the program preceded the establishment of the Regional Center for Circular Economy in Kragujevac, whose goal is to promote the principles of the circular economy and strengthen the capacities of key actors from the territory of the city of Kragujevac and the Region Šumadije i Zapadne Srbije.

However, it seems that universities still don't achieve a significant social impact as indicated by the statistics of implemented and development projects. Contribution to a sustainable economic system and environmental protection is visible through a specific niches of research and related innovations through the implementation of projects with other stakeholders. Faculties and research institutes, in cooperation with the business entities have implemented projects in the development and implementation of innovative solutions for more efficient use of natural resources and reuse and recycling of materials and products. Most of the projects aimed at the beneficial use of biowaste, producing innovative bioproducts, use of renewable energy sources and other inovations that contribute to climate change mitigation. Public utility companies have shown interest in projects of composting "green" waste and using waste as biomass for energy production. The projects were financed by the allocation of circular vouchers within the project “Reducing the carbon footprint of local communities by applying the principles of circular economy in the Republic of Serbia – Circular Communities” (Ministry of Environmental Protection in partnership with UNDP and Global Environmental Fund (GEF)).

Industrial wastewater was the focus of certain number of projects funded through the "Green Program of Science and Industry Cooperation" of the Science Fund of the Republic of Serbia. The projects promoted the zero waste concept and the use of materials obtained from metal and food industry waste in wastewater treatment.

Serbia ranks 52nd among the 133 world economies featured in the Global Innovation Index 2024 (https://www.wipo.int/gii-ranking/en/serbia) with strong performance in Domestic industry diversification (11th), ICT services exports (12th), Scientific and technical articles (13th) and Cultural and creative services exports (14th) in Europe (Global Innovation Index Database, WIPO, 2024). According to the summary innovation index, the Republic of Serbia is seen as a *moderate innovator* compared to the European Union countries, but the data indicate fast and at the same time low growth and development of the innovation ecosystem (https://ec.europa.eu/docsroom/documents/41898*).* The low and rapidly growing value of the index is contributed by significant structural differences between the Republic of Serbia and the European Union member states. The key difference is in the financing structure with a particularly low share of the business and less innovation outputs relative to its level of innovation investments. The Strategy for Scientific and Technological Development of the Republic of Serbia for the period from 2021 to 2025, "The Power of Knowledge", recognizes this shortcoming as well as the need to introduce incentive measures for the economy to invest in science and research.

In the future period it is necessary to align the educational, scientific research and innovation system with the needs of the economy and society in the Republic of Serbia more effectively. This is one of the prerequisites for implementing the circular economy model in the wastewater sector.

PFAS in the focus of development of emerging technologies in European countries

A lot of focus in terms of emerging water and wastewater treatment technologies is currently on the destruction methods for per- and polyfluoroalkyl substances (PFAS). PFAS are known as “forever chemicals” due to their extreme persistency in the environment. The annual health-related costs of PFAS pollution in Europe are estimated at € 52-84 bn. These costs are not paid by the polluting industries but weigh indirectly on ordinary people and health care providers. The cost of remediation of all PFAS-polluted water sources is unknown; Nordic Council estimates are between € 17-171 bn. To reduce the concentrations of PFAS in water, water treatment plants typically resort to non-destructive technologies such as reverse osmosis (RO), granular activated carbon (GAC), and ion exchange resins (IXR) that can remove long-chain PFAS. However, these technologies result in a concentrated PFAS-laden stream or residual that needs to be further treated. Existing advanced oxidation processes (AOPs) based solely on ozone and/or hydroxyl radical (•OH) (e.g., UV/H2O2) cannot degrade PFAS. Removal and destruction of PFAS in the context of industrial wastewater treatment is even more challenging, as the use of RO, GAC, IXR is often not operationally feasible (e.g., due to membrane fouling). For example, due to a lack of treatment options, PFAS-laden wastewater in the semiconductor industry is currently incinerated, resulting in enormous environmental footprint in terms of energy consumption and resulting perfluorinated gaseous byproducts. Given that the semiconductor industry will not be able to phase out PFAS used in photolithography in the foreseeable future, new treatment options are urgently needed. To date, there are no technologies capable of degrading PFAS at reasonable operational costs, and the energy expenditure tends to be >100 kWh/m3. Moreover, there are no technologies that can deal efficiently with short-chain PFAS (≤C6). The approach currently explored in the industry is based on supercritical water oxidation (SCWO), hydrothermal alkaline treatment (HALT) and plasma, however their energy consumption is ~1,000 kWh/m3 and ~100 kWh/m3, respectively. These processes suffer from other, inherent drawbacks, as e.g., they cannot be operated in continuous mode (SCWO, HALT) or treat larger volumes of waste (plasma). SCWO and HALT operate at high temperatures (≥370°C) and pressures (>20 MPa), whereas plasma-based water treatment is difficult to upscale, e.g., due to the limited depth of plasma penetration.

Previous research and achieved levels of technological development, as well as the identified needs of society, have led to the improvement of WWTPs. Best practice in wastewater sector in the frame of circualr economy in EU countries (France and Spain) and Republic of Serbia are part of ANNEX 1.

10. PROPOSED METHODOLOGICAL FRAMEWORK FOR THE APPLICATION OF THE PRINCIPLE OF CIRCULAR ECONOMY IN THE WASTEWATER SECTOR (REPUBLIC OF SERBIA)

Clear national policy objectives in the Republic of Serbia is one of the key factors that can encourage the development of circular economy model in wastewater sector. Policy should be defined to address specific issues and engaged different stakeholders in river basin.

Core institutions and stakeholders for circular economy implementation in wastewater sector in the Republic of Serbia are:

- RS Government Ministries and Provincial secretariats
- Public Policy Secretariat of the Government of the Republic of Serbia
- Administrative districts and local self-government

- Companies in the provision of communal services
- The Science Fund and the Fund for Innovation Activities
- Universities, research institutes and centres
- Professional associations with activities in the field of wastewater treatment and environmental protection, Farmers' associations, NGOs

Wastewater reuse

In this moment it is difficult to give accurate predictions about potential of replacing part of the water extracted from natural resources with treated wastewater considering that the WWTP systems is under construction. However, potential of urban wastewater reclamation for contributing to sustainable water management can be significant. A tentative prediction based on theoretical data, standards and the projected capacity of 6 623 183 PE indicates that ca. 1.3 million m^3 of total reclaimed wastewater per day, that will be available at the WWTP, exits as a potential resource.

For example, amount of treated wastewater would satisfy 80% of the estimated additional amounts of water that will be needed to irrigate agricultural land until 2034.Taking into account the suitability of irrigation methods with treated wastewater, the needs of the total land with orchards and vineyards irrigated by drip irrigation would certainly be met for now and in the case of entire crop land being irrigated (**Figure 16.:** largest areas of land with orchards are in the Region Šumadija i Zapadna Srbija and vineyards are in the Region Južna i Istočna Srbija). Subsurface drip irrigation can minimize pathogen exposure in the soil and reduce farmers' concerns.

Considering the size of the WWTP, in smaller settlements of 2 000-10 000 PE produced treated wastewater, would exceed the current and future irrigation needs (for example, a settlement of 3 500 PE produces 317 000 m^3/year of wastewater, which would satisfy the needs for irrigation 10 ha of crop land). The largest number of plants planned to be built are in this group so their potential as alternative water sources is significant. In addition, this WWTPs does not require stricter wastewater treatment than secondary and this partially treated wastewater with nutrients (phosphorous and nitrogen) can be very valuable for farmers. However, in order to obtain reliable data on available nutrients, it is necessary in the phase of planning process to take into account the age of the population. According to literature, it is assume that children and teenagers excrete 50% less urine and 30% less faeces than adults.

Code of Good Agricultural Practice is necessary to provides guidance to ensure the protection of public health and the environment and national regulations need to be harmonized and a single legal act should be adopted to regulate the wastewater reuse.

Another important potential user of treated wastewater is the industrial sector, primarily thermal power plants for cooling purposes. Replacement of part of the surface water volume as a resource with treated wastewater in cooling towers would helps conserve and expand available water supplies especially considering the high water consumption in this sector in the Republic of Serbia. The treated wastewater used for this purpose would have to meet quality criteria without causing problems such as sedimentation, corrosion and biological growth.

Data on water consumption in cities for green spaces and cleaning streets is not publicly available and it was not possible to make a projection of water savings using treated wastewater. As some cities continue to grow (Beograd, Novi Sad, Novi Pazar) as a result of internal migrations wastewater should be considered a valuable resource from which energy and nutrients can be extracted as planned by the Sludge Management Program but also as an additional source of water. Of particular concern was climate change coupled with low water level of some rivers and water mismanagement which are caused water scarcity in the summer 2025 in the Republic of Serbia. A state of emergency has been declared in several cities.

Bearing in mind that in some parts of the Serbia such as Region Južne i Istočne Srbije with the largest number of small settlements centralized sewerage is still not available, it is necessary to find alternative solutions for the treatment of wastewater. One of the possible solutions is managing both greywater and blackwater at household level. Source segregation enabling reuse of greywater and the nutrients present in black water. This localized approach can significantly reduces the cost and environmental footprint. However, selection of the most effective solution depends on settlement's size, layout, available water resources and other needs (eg. agriculture needs). Resource recovery at the source is also an option to consider. Most of the nutrients are in the urine, especially N, with a higher P to K ratio than most commercial fertilizers. According to estimates, the urine excreted by one person/year is sufficient to satisfy the needs for nitrogen fertilization of 300-400 m^2 of crops and the needs for phosphorus fertilization of 600 m^2 of crops for one growing season. The fertilization needs of 1 ha would be met by a small settlement of 20 inhabitants, which is a smaller number than the average number of inhabitants in some parts of this Region.

Planning the wastewater reuse requires consideration of technical design and location of the WWTP in relation to users. Wastewater reuse is a new concept in urban planning and it is difficult to consider new infrastructure in an existing one. There is little space to build another pipeline specifically designed for this water, and subsequent installations and repairs are expensive and impractical. The life cycle impact of such actions calls into question the sustainability of such a solution. However, it is not impossible, especially in water-scarce regions, where such solutions very quickly prove to be acceptable options even when planning the construction of a new WWTP.

From a topographic perspective, WWTPs are built or are being built in low-lying areas so that wastewater can be easily delivered to users, i.e. by gravity. If reclaimed water were to be returned to users in the opposite direction, it would mean that it would have to be pumped to higher heights, which brings additional costs that should be taken into account in the techno-economic analysis.

Wastewater management and circular model in this sector should be part of the broader management process within the River Basin Management Plan. The ecological potential/status of water bodies, i.e. the ecological minimum, needs to be taken into account. If the risk is assessed to be high (e.g. smaller water bodies during the dry season), wastewater reuse may be considered an inadequate solution.

Also, disproportion in the wealth of land resources and the quality of water resources requires the determination of WEI (Water Exploitation Index) at the level on basins and water areas in the Republic of Serbia.

Proposed methodological framework for the application of measures for wastewater reuse in the Republic of Serbia in accordance with the future WWTPs construction plans is shown in **Figure 12**.

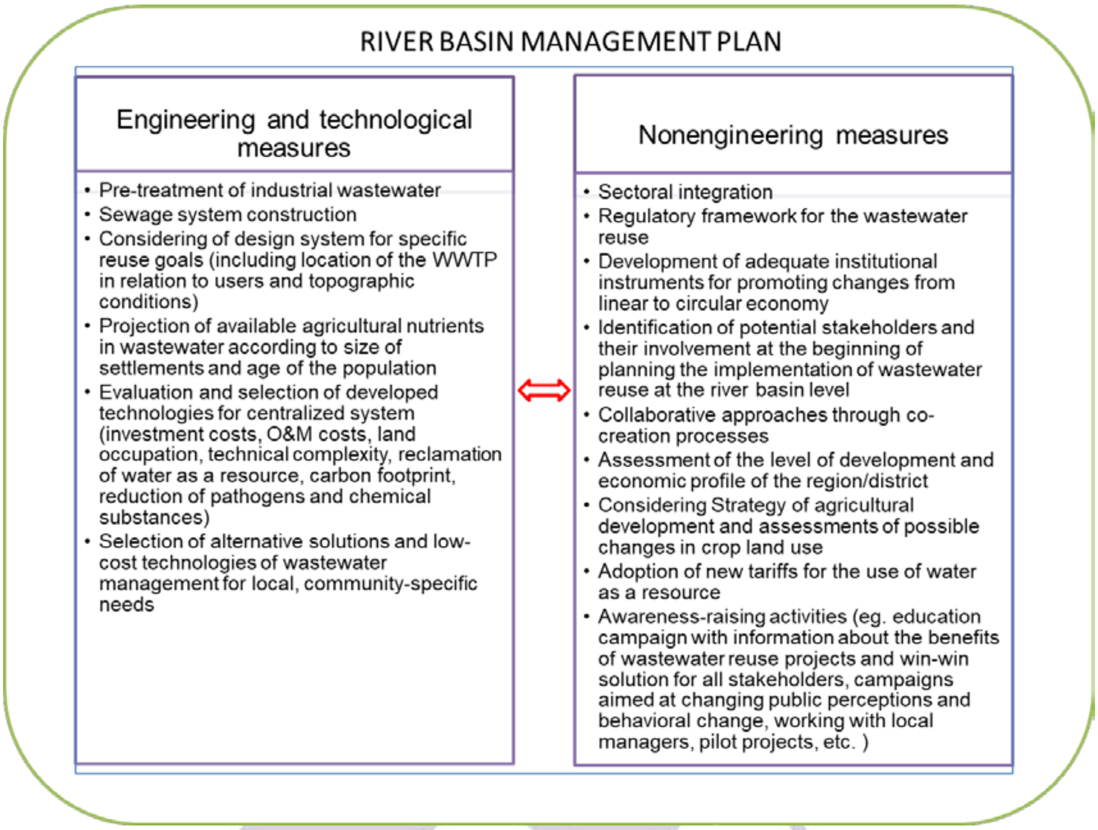


Figure 12. Proposed methodological framework for wastewater reuse in the Republic of Serbia

Projection of use sludge in agriculture in the Republic of Serbia

The following section provides a projection and proposed roadmap for decision-making on the use of sludge for agricultural purposes for existing WWTPs and and WWTPs whose construction is planned.

According to the literature data on the mass of nitrogen and phosphorus per person equivalent coming to the WWTP, a mass balance of nutrients was made according to the main selected technologies and for the WWTS listed in the Sludge Management Program for which there is a possibility of applying sludge as fertilizer (**Figures 13 and 14**).

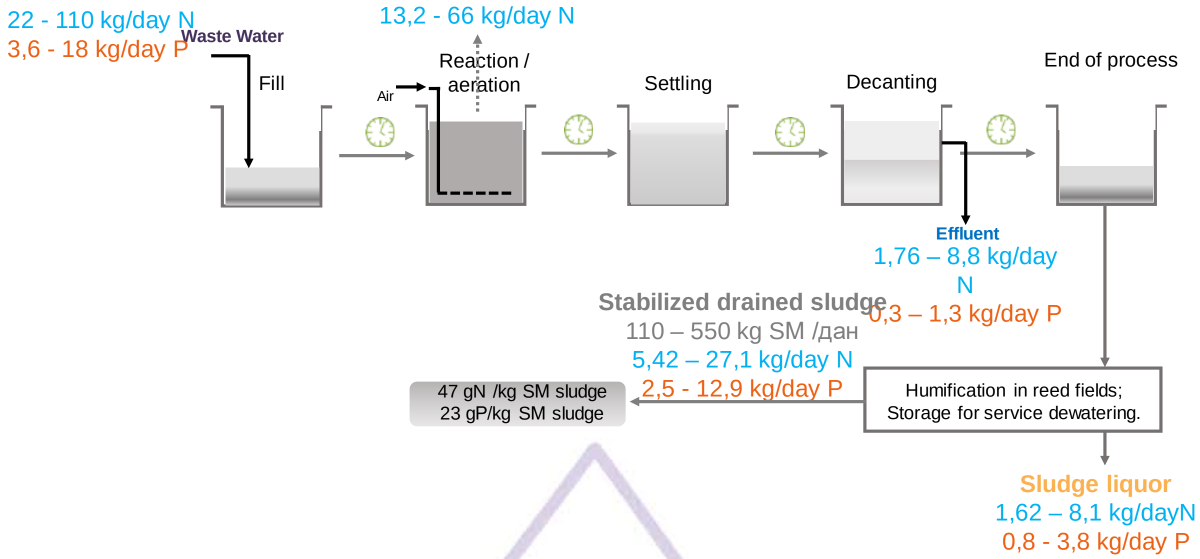


Figure 13. Mass balance of phosphorus and nitrogen for plants with a capacity of 2,000 - 10,000 PE

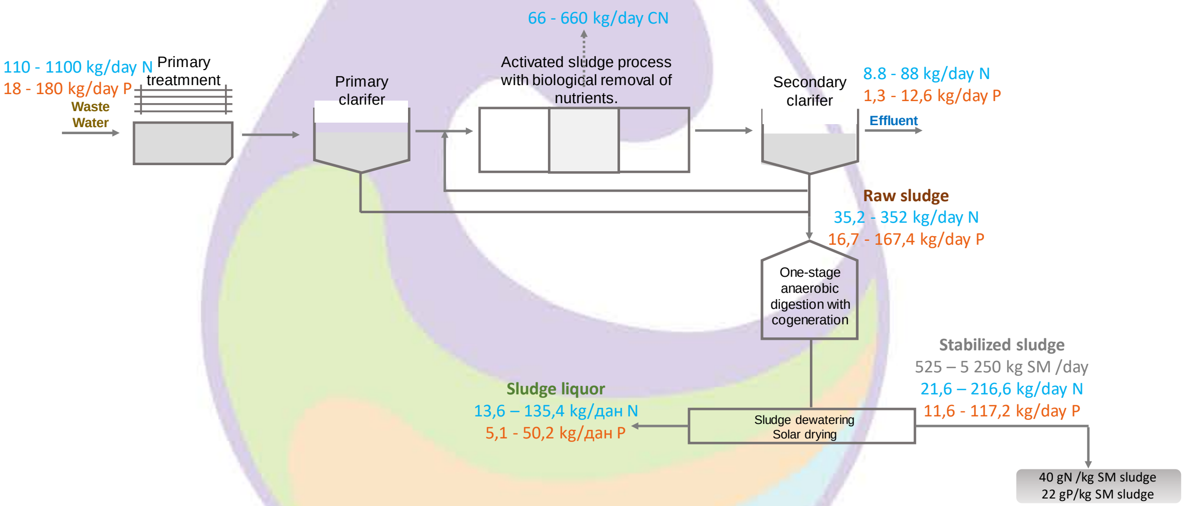


Figure 14. Mass balance of phosphorus and nitrogen for plants with a capacity of 10,000 - 100,000 PE

The amount of nutrients that will be found in the stabilized sludge in a certain extent depends on the method of stabilization of the sludge, i.e. whether it is aerobic or anaerobic. According to the plan, the largest number of PE will be covered by anaerobic treatment.

Stabilized sludge contains 1-6% nitrogen and phosphorus per unit of dry mass (Metcalf & Eddy, 2014). In accordance with these data, **Figure 15** shows, in addition to the predicted production of dry matter of the sludge, the potential content of nitrogen and phosphorus (calculated according to the mean value of the percentage of nutrient content in the sludge). Based on these predictions 4 732 t of nitrogen and 4 664 t of phosphorus would be available through treated sludge in one year.

The percentage of phosphorus in the sludge can be further increased with the inclusion of chemical precipitation, where the usual practice is the addition of primarily ferric chloride or other salts. In the technological scheme, addition can be made in several locations. This procedure is usually performed if the percentage of phosphorus removal in the water line by biological means is not efficient enough.

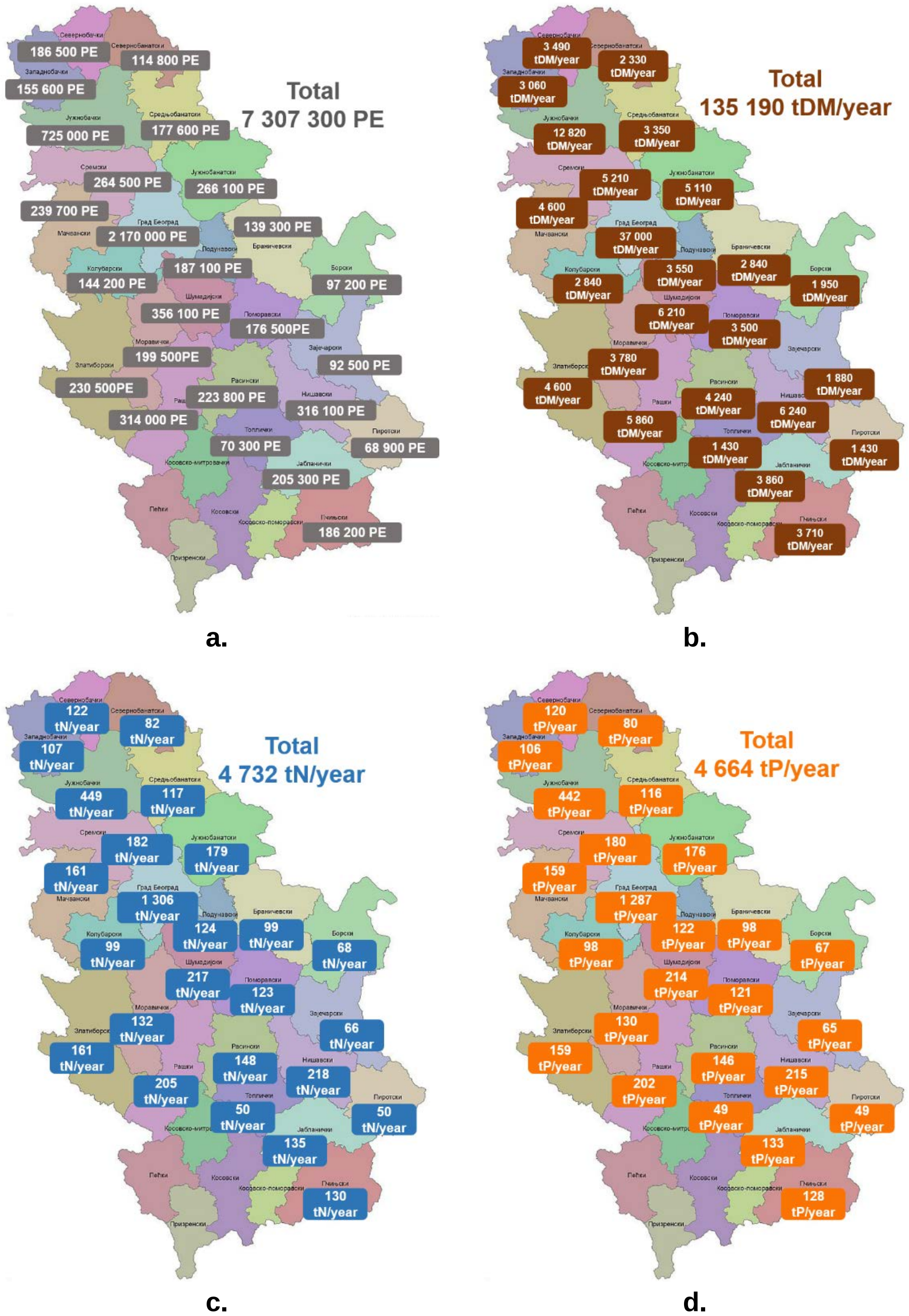


Figure 15. Projected capacity (a), annual production of sludge dry matter (b), annual average expected amounts of N (c) and P (d) per administrative district

The estimated values given in **Figure 16** are important for considering the possibilities and needs of applying sludge for agricultural purposes and were not estimated in the Sludge Program nor in any similar document. Bearing in mind the heterogeneity in land use in the Republic of Serbia, the data were processed by region.

Slightly more than 10% of land belongs to orchards, vineyard and fodder - 427 103 ha in total (**Figure 17**), that may be eligible for sludge spreading according to The Regulation on the manner and procedure of sludge management from municipal wastewater treatment plants ("Official Gazette of the RS", 103/2023), Article 8.

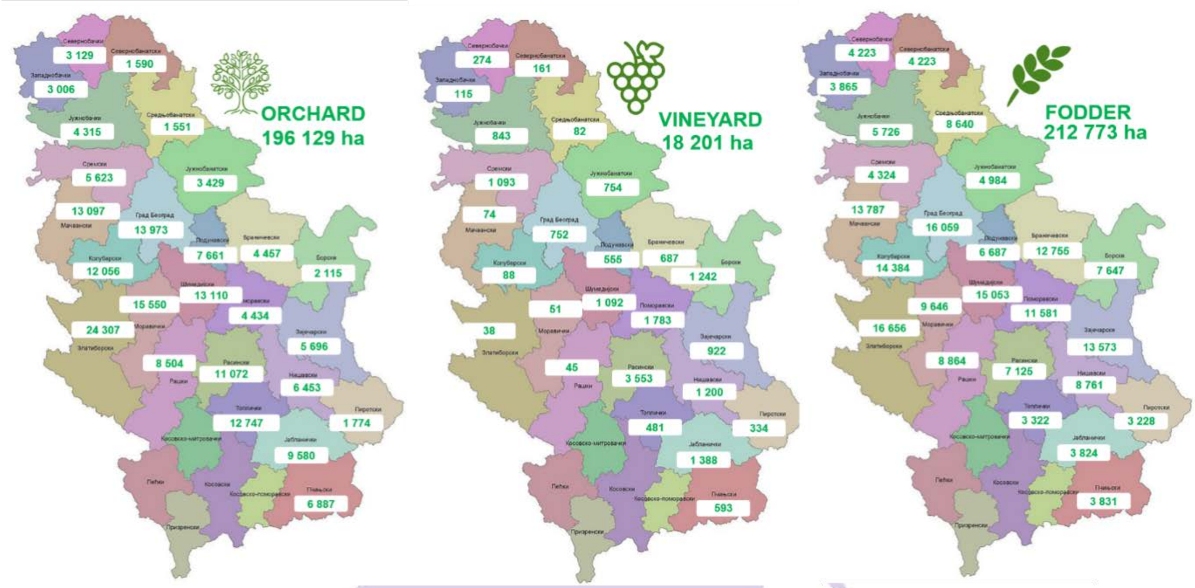


Figure 16. Surface of orchard, vineyard and fodder in the Republic of Serbia

In the mentioned document in Article 12, it is stated that it is allowed to apply 1.2t sludge DM/ha year. Regarding this amount, and according to eligible agricultural areas, it is estimated that 512 524 tDM/year of sludge can be applied (**Figure 13**).

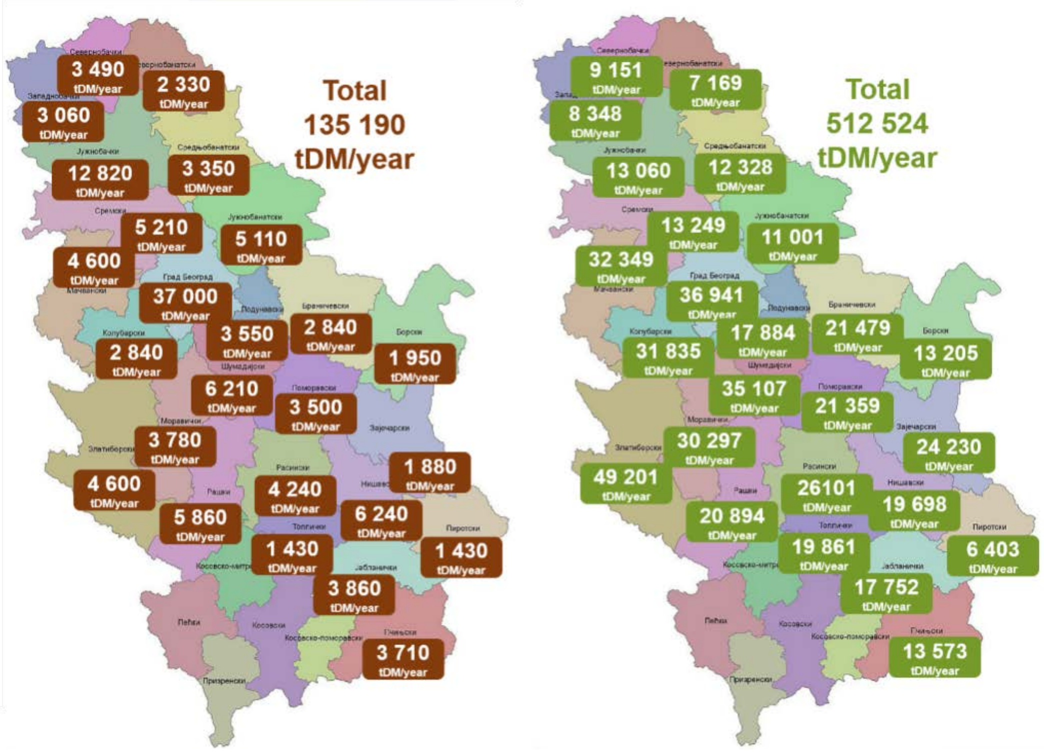


Figure 17. Amounts of predicted sludge production and amounts that can be spread on agricultural land in one year period per administrative district

After determining the need of plant crops for nitrogen and phosphorus (in this way, the immediate use of organic matter of sludge is achieved along with nitrogen and phosphorus), the potential for using sludge for these purposes can be assessed, i.e. to what extent given needs would be met. This is further very important information for WWTP, current and future sludge owners (Utility Company). Concerns arise from the possibility of the presence of various difficult-to-degrade and potentially toxic organic components as well as toxic metals. But these risks should be viewed rationally in relation to the characteristics of the wastewater entering the plant, as well as through the efficiency and type of applied technologies in the water line, which is closely related to the quality of the separated sludge. By applying measures at the source and optimizing the operation of the WWTP, these risks can be reduced to a minimum.

According to the material balance of nutrients, a significant amount of them will be in the water created after sludge dewatering. Common practice is to return these flows to the plant inlet.

Based on this data it can be concluded that the needs for sludge as a fertilizer are far exceeding the produced amounts in each administrative district. This also mean that transport requirement will be minimal and possible within each administrative district.

If, in addition to transport, other important criteria are taken into account in the multi-criteria analysis (sludge production assessment, application site identification, soil properties and topography, nutrient requirements, local climate and other important criteria), it is possible to make a decision at the local level.

Figure 18 shows the proposed framework and implementation roadmap for the application of treated and/or composted sludge for agricultural purposes in the Republic of Serbia as one of the typical examples of the circular cycle in wastewater sector.

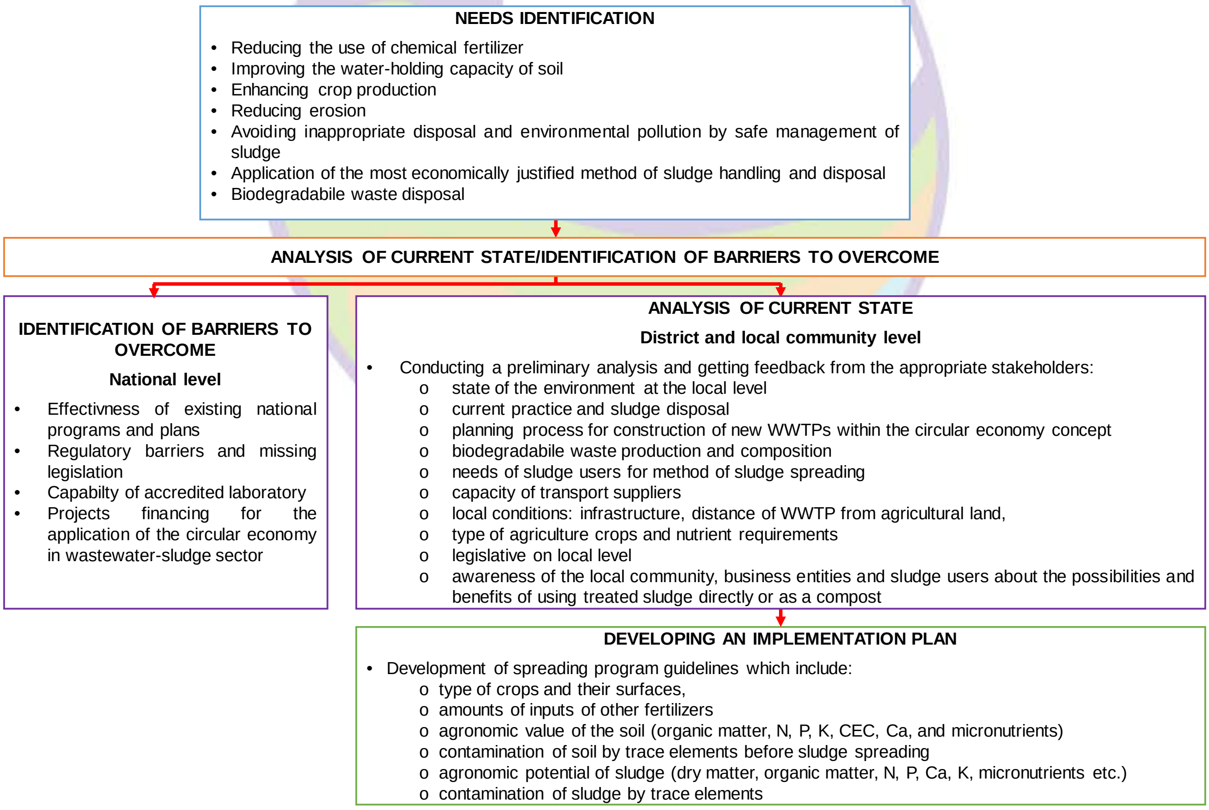


Figure 18. Proposed roadmap for decision-making on the use of sludge for agricultural purposes

11. ANNEX: BEST PRACTICES IN WASTEWATER SECTOR IN THE FRAME OF CIRCULAR ECONOMY

BEST PRACTICES IN EU COUNTRIES

Box 1
CASE STUDY: Indirect potable water reuse in Barcelona, Spain

Close to the city of Barcelona (NE Spain), a pilot test was carried out in the Llobregat River aiming to provide a useful procedure to cope with severe droughts through indirect water reuse. Reclaimed water was used to restore the minimum flow of the lower Llobregat River, ensuring a suitable water supply downstream for Barcelona. To assess chemical and microbiological threats throughout the water treatment train, the river and the final drinking water, a monitoring campaign was performed including 376 micropollutants and common microbiological indicators. The effects of water disinfection were studied by chlorinating reclaimed water prior to its discharge into the river.
Data showed that 10 micropollutants (bromodichloromethane, dibromochloromethane, chloroform, EDDP, diclofenac, iopamidol, ioprimid, lamotrigine, ofloxacin and valsartan) posed a potential risk to aquatic life, whereas one solvent (1,4-dioxane) could affect human health. The chlorination of reclaimed water mitigated the occurrence of pharmaceuticals but, conversely, the concentration of halogenated disinfection by-products increased. From a microbiological perspective, the microbial load decreased along wastewater treatments and, later, along drinking water treatment, ultimately reaching undetectable values in final potable water. Non-chlorinated reclaimed water showed a lower log reduction of *E. coli* and coliphages than chlorinated water. However, the effect of disinfection vanished once reclaimed water was discharged into the river, as the basal concentration of microorganisms in the Llobregat River was comparable to that of non-chlorinated reclaimed water. Overall, our study indicates that indirect water reuse can be a valid alternative source of drinking water in densely populated areas such as Barcelona (Catalonia - NE Spain). A suitable monitoring procedure is presented to assess the related risks to human health and the aquatic ecosystem.

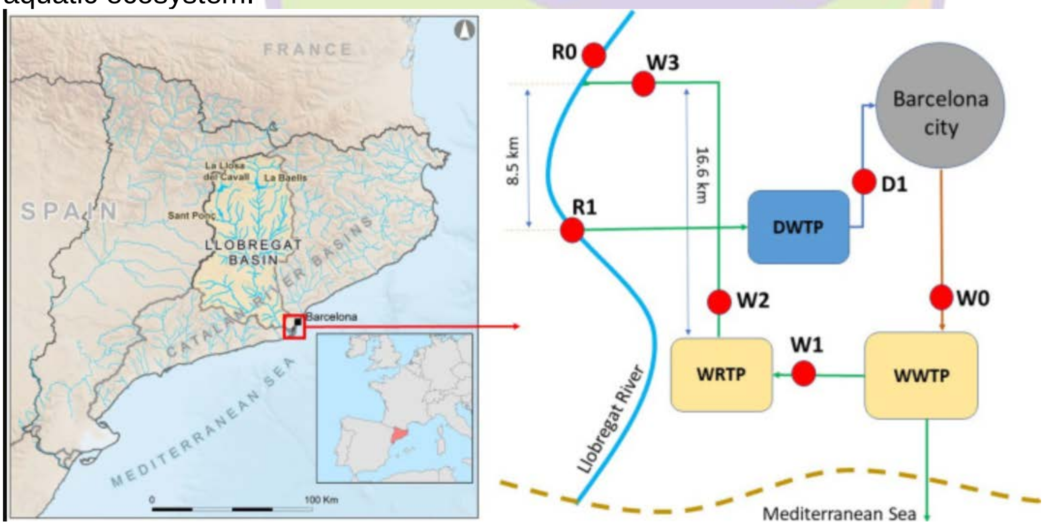
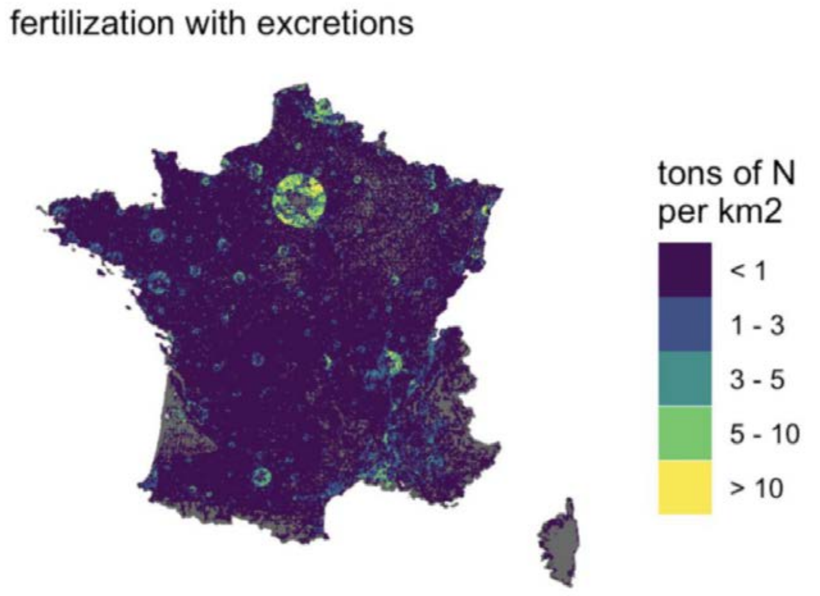


Figure Box 1. Location of the Llobregat River basin and Barcelona. Location of the monitoring sampling sites of the pilot test carried out to increase water flow in the lower Llobregat River through indirect water reuse. Barcelona's urban wastewater treatment plant (WWTP), the water reuse treatment plant (WRTP), and the drinking water treatment plant (DWTP) are also shown. Site W0 is located at the WWTP influent; W1 is at the WWTP effluent; W2 site is located at the WRTP effluent just before the chlorination facility; W3 is located at the water reuse discharge to the river; R0 and R1 are sites located in the river, R0 is upstream and R1 is downstream from the water reuse discharge; and D1 site is located at the DWTP output to Barcelona's potable water supply network.

Box 2

CASE STUDY: Source-separation in France

Since the European Framework Directive of 21 may 1991 (91/271/CEE) related to wastewater treatment, many WWTPs have been built in France and areas have been defined as sensitive to eutrophication from nitrogen or phosphorus. As of 2020, most regions of France are classified as sensitive areas, either for nitrogen or phosphorus, especially the northern water basins. Around 80% of WWTPs with treatment capacity > 2000 p.eq. have good performances of treatment, while 20% do not comply with treatment efficiency regulations for carbon and/or nitrogen and phosphorus removal. At the national level, the removal of nitrogen is 70% on average (around 80% in northern basins totally sensitive areas, and around 60% in other basins).
Globally, only 10% of nitrogen entering the French sanitation system is recycled in agriculture through composting/spreading. Since most fertilizers are imported in France and that a large quantity of agricultural products is exported, it is estimated that a full recycling of nitrogen excreted by the french population would only account for 15% of the needs in fertilizers (Starck 2024). Most of nitrogen excretions could however be spread at a distance lower than 10 km from their source (i.e., the cities), considering the spatial distribution of agricultural parcels (figure below).



Several projects are dedicated to urine recovery at the source for agricultural use, and several realizations have been made. Some examples of short-distance uses include a collective housing in the Brittany region, with stocked urine collected and used by an agricultural high school nearby. In a more urban context, some agricultural non-profit organizations providing farm products start to collect urine from their consumers to grow their crops in a short-distance circular framework (e.g., Châtillon, 2024).
Other examples include longer-distance chains, with processes employed to concentrate urine before their use. The European Spatial Agency (ESA) has such process since 2023 in their Paris building, based on the Vuna Nexus process based on nitrification and distillation to get a concentrated product that can be transported more easily.

Box 3

CASE STUDY: Methanization in France

Units for biogas production are increasingly being developed in France to generate biogas from wastewater treatment plant (WWTP) sludge. A large-scale example of methanization is implemented at the Seine Valenton WWTP, operated by SIAAP (treatment capacity of 600,000 m³/day - equivalent to 2.5 million inhabitants).

Since the 2010s, the plant has been equipped with digesters that produce biomethane, 80% of which is reused on-site. Projects have been carried out to utilize the remaining 20% to produce liquid fuel (using the CryoPur process, which separates CH_4 and CO_2) for trucks. Additionally, the Cométha project aimed to treat solid and liquid waste rich in organic matter, supplementing the plant's sludge (e.g., the wet fraction of household waste and equine manure from stables), in partnership with a household waste treatment and recovery operator (Syctom).

As part of this project, a pilot treatment unit was installed by the consortium John Cockerill - Sources, combining methanization and a pyrolysis reactor for digestate. A first thermophilic reactor (55°C) and a second mesophilic reactor (37°C) enable liquid-phase methanization. The remaining liquid effluent is recovered to produce ammonium sulfate via stripping, which can then be used in agriculture. The remaining digestate is dehydrated, dried at low temperatures, and then treated by pyrolysis at 900°C, generating ash with minimal smoke emissions.

At the end of 2024, a new biomethane production unit was inaugurated in collaboration with Veolia, enabling the production of 1,300 Nm³/h, equivalent to 45 GWh of energy injected into the gas grid. This production corresponds to the annual energy consumption of 10,000 homes, saving approximately 9,000 tons of CO_2 equivalent emissions from natural gas and generating around €1.9 million in revenue.

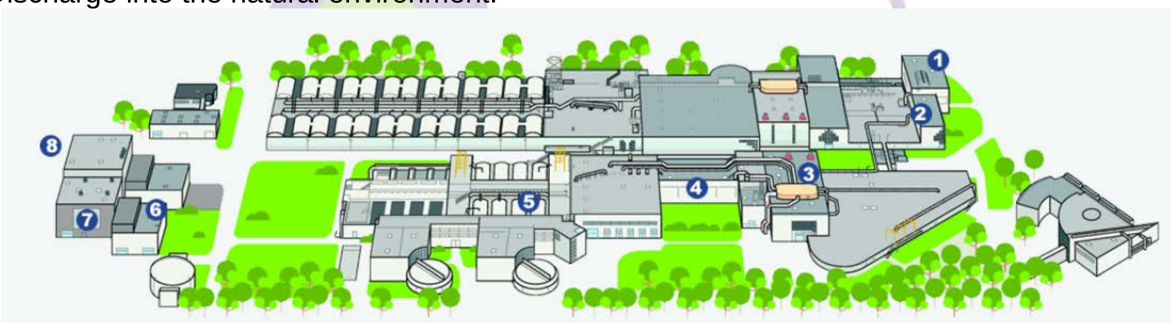
Another example of methanization implemented in an existing WWTP is the Saint-Thibault-des-Vignes WWTP (350,000 person equivalent) operated by the Syndicat Intercommunal d'Assainissement de Marne-la-Vallée (SIAM). Two digesters, with a combined usable capacity of 7,800 m³, were constructed by the SAUR Group. Annually, 6,700 tons of sludge and grease will be treated in these digesters, generating enough carbon-free energy to supply 4,000 households in the region.

Box 4

CASE STUDY: Saint-Thibault-des-Vignes WWTP in France

The Saint-Thibault-des-Vignes plant is a wastewater treatment plant that incorporates circular economy concepts for both the water and sludge lines. The plant is part of an 8.6-hectare site. Wastewater from 230,000 residents (from 31 municipalities) and more than 20,000 businesses is collected and sent to the plant, which treats 41,590 m^3/day (i.e., 350,000 population-equivalent), or around 15,000,000 m^3/year.

The figure below describes the main treatment stages of the Saint-Thibault-des-Vignes WWTP: 1. Screening and pumping, 2. Sand and oil removal, 3. Deodorisation, 4. Primary settling, 5. Biological treatment, 6. Sludge dewatering, 7. Sludge incineration furnace, 8. Discharge into the natural environment.



In recent years, however, the WWTP operator has decided to make a major transformation. Moving from a linear to a circular economy, the WWTP has become a treated water recycling plant, producing energy, raw materials and high-quality recycled water for watering green spaces, for example.

Circular economy at Saint-Thibault-des-Vignes WWTP

Biogas production. A biogas reactor has been built in 2023 to produce energy and biogas (CH_4) from sludge. It was an expensive project (20 million €), but one that Siam expects will soon pay for itself. The biogas produced (2 million Nm^3/year of CH_4) will be sold to GRDF (leading natural gas distribution operator in France) or any other distributor. The biogas plant will produce energy to heat almost 4,000 housing equivalents. This would generate revenue of 2 million €/year, according to Siam's budget.

CO_2 valorisation. The production of CH_4 is also accompanied by the production of CO_2. At the Saint-Thibault-des-Vignes WWTP, the BIO-CO2 project is investigating the possibility of recovering this CO_2, which represents a resource of 2,500 t/year, in the agri-food sector, provided that the required quality is achieved. One possibility is to produce a CO_2 that could be resold to a soft drinks producer, a major consumer of CO_2.

Treated wastewater reuse. A micropollutant elimination system using CarboPlus® technology (from SAUR) is currently under construction. Coupled with the elimination of bacteria and viruses using ultrafiltration membranes, this system will produce recycled wastewater for use at the plant and for watering, which will be made available via a dedicated terminal. The effectiveness of this technology is monitored by a 130,000m3 pilot plant.

Other projects under review. A whole series of other projects linked to energy transition are currently under study, such as: the recovery of CO_2 emitted by the incineration furnace, the deployment of photovoltaic panels on the plant to produce electricity, the development of a heat network on the Saint-Thibault-des-Vignes sewer network to recover calories that could be used to heat public facilities, the recovery of waste heat from the wastewater treatment plant, the recovery of materials produced by digestate....

Education and public awareness campaigns.

The operators of the Saint-Thibault-des-Vignes WWTP attach great importance to education and public awareness campaigns. With this in mind, they have developed three trails: a biodiversity trail, a water trail and an energy trail. The latter includes an escape game. The *Syndicat intercommunal d'assainissement de Marne-la-Vallée* (SIAM), owner of the Saint-Thibault-des-Vignes WWTP, as an educational relay for the Agence de l'eau Seine-Normandie, plays an active role in raising awareness of water management among schoolchildren in its area.

BEST PRACTICES IN THE REPUBLIC OF SERBIA

Box 5

CASE STUDY: WWTP Kruševac

Reconstructed in 2020 with predicted capacity of 90 000 PE. Technology process consists of: primary treatment with coarse screens, an inlet pumping station and a pumping station for atmospheric water that directly pumps rainwater into the recipient, 2 fine screens and 2 lines of longitudinal aerated grit chambers with grease removal, 2 longitudinal primary clarifiers. Biological treatment is carried out in 2 lines with aerobic and anoxic phase and longitudinal U-type reactors at the tertiary treatment level (biological nitrogen and phosphorus removal), 2 final circular clarifiers and appropriate pumping stations for return and excess sludge. The plant does not have effluent disinfection, although UV lamps are predicted, and it has a unit for chemical precipitation of phosphorus. The sludge line consists of a primary and excess sludge thickener, one anaerobic digester with mesophilic digestion, a biogas tank, one on-site cogeneration unit and other supporting equipment and facilities. Sludge dewatering on 2 belt filter presses with temporary and emergency storage. After dewatering, the sludge is dried in a solar drying facility. The plant has a system for removing and treating unpleasant odors.

Advancement:

Odor control: It is located in the primary part of the treatment. For odour preventing (mostly originating from H_2S) evaporated salt NaCl for water softening, 25% v/v NaOH i 50% v/v H_2O_2.

RTC (Real Time Control): Separation of aeration zones provides working flexibility and the choice of controlled aeration with the help of RTC, enables moderate energy consumption for four working blowers which are used for entering of ambient for the needs of the oxidation process. Air flow control is performed on the basis of feedback on dissolved oxygen concentrations in nitrification zones of the bioreactor. RTC cost optimization (30% electricity savings), since the blowers are the largest consumers of electricity at the plant.

Solar sludge drying: Sludge is dried in glass greenhouses consisting of 5 drying lines. Each hall has 1080 m^2 surface and the maximum height of sludge is 0.3 m. There is a device for turning over the sludge (agitator), converting it over time in neutral odourless sludge. Dry matter content of solar dried sludge is 60-95% (in summer months higher percentages are reached). Storage space is 984 m^2 providing retention time of 100 days.

CHP unit: Capacity 851kW of input power and output power of 413 kW thermal and 330 kW electrical. Share of gained power is 37% of total consumed one on the plant over 4 years.

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THE POTENTIAL OF USING WASTEWATER AND SLUDGE AS A RESOURCE BASE IN THE REPUBLIC OF SERBIA

-FACTSHEET FOR DECISION MAKERS-

CURRENT STATE | **PROJECTIONS AND POSSIBILITIES**

THE POTENTIAL OF USING TREATED WASTEWATER

Own specific availability of surface water **1500 m³/inhabitant·day.**

According to the UN Global Water Security Assessment, Serbia is considered as **water-insecure, facing potential water crisis.**

Area of land that is irrigated for registered farms is around **269 000 ha with 67–69·10^6 m³ water - groundwater (51%) and surface water (25%).**
For all users, registered and unregistered, **water consumption for irrigation is more than 6 times higher.**

Currently, there is no widespread practice of using reclaimed wastewater for purposes such as irrigation or industrial processes, and it is not supported by legislation.

In the future, water resources in the RS are under great pressure due to **climate change, insufficiently developed infrastructure and high levels of pollution.**

By 2034, **irrigated areas will increase** up to 350,000 ha.

For the projected capacity of 6,623,183 PE of treated water from agglomerations in the Republic of Serbia about **1.3 ·10^6 m³ of reclaimed wastewater would be available as a potential resource.**

CURRENT STATE

PROJECTIONS AND POSSIBILITIES

AGRICULTURAL AREAS

Area of available land of agricultural holdings – 3 947 257 ha

- Area of used agricultural land – **3 336 785 ha**

The total agricultural area to which the treated sludge could be applied is 427 103 ha

Areas under:

- fodder - 212 773 ha
- orchards - 196 129 ha
- vineyard - 18 201 ha

SLUDGE PRODUCTION AND APPLICATION

Current sludge production at WWTP
15 000 tDM/year

The maximum expected amount of sludge after the construction of the planned WWTP
135 190 tDM/year

A total of 512 525 tDM/year of treated sludge can be applied annually on agricultural land (1.2 tDM/ha year)

Quantities of treated sludge that can be used on areas under:

- fodder - 255 328 tDM/year
- orchards - 235 355 tDM/year
- vineyard - 21 841 tDM/year

SOIL FERTILITY AND SLUDGE AS A SOURCE OF ORGANIC MATTER AND NUTRIENTS

The average content of **organic carbon in the soil is 1.82% - the category of low content.**

The content of readily available phosphorus in the soil of arable land, gardens, orchards, meadows and pastures in the class of very low and low content in central Serbia
P_2O_5 <5mg/100g and 5-10mg/100g

Exceeding the content of Cu, Zn, Ni, Co, Cd, As in the soil of certain regions of the Republic of Serbia may be a consequence of long-term use of mineral fertilizers, especially cost-effective diammonium phosphate.

An average of **250 kg/t of organic carbon will be available through the sludge.**

Based on the average values of the content of N and P in the sludge, after the construction of the planned WWTP, the following would be available through the sludge within a year:

4 732 tN/year
4 664 tP/year

The required amounts of treated sludge that could be used on agricultural land exceed almost 4 times the future produced amount of sludge (when all plants are built).

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POTENCIJAL KORIŠĆENJA OTPADNE VODE I MULJA KAO RESURSNIH BAZA U REPUBLICI SRBIJI

-INFORMATIVNI LIST ZA DONOSIOCE ODLUKA-

SADAŠNJE STANJE

PROJEKCIJE I MOGUĆNOSTI

POTENCIJAL UPOTREBE PREČIŠĆENE OTPADNE VODE

Sopstvena specifična raspoloživost površinskih voda **1500 m³/stanovnik·dan.**
Prema proceni globalne bezbednosti vode UN, Srbija se **smatra nesigurnom u pogledu vode i suoča se sa potencijalnom krizom vode.**

Površina zemljišta koje se navodnjava za registrovana poljoprivredna gazdinstva je oko **269 000 ha sa 67–69·10^6 m³ vode - podzemne vode (51%) i površinske vode (25%).**
Za sve korisnike, registrovane i neregistrovane, **potrošnja vode za navodnjavanje je viša i do 6 puta**.

Trenutno ne postoji široko rasprostranjena praksa upotrebe prečišćene otpadne vode u svrhe poput navodnjavanja ili industrijskih procesa i nije podržana zakonodavstvom.

Vodni resursi u RS u budućnosti su pod velikim pritiskom usled **klimatskih promena, nedovoljno razvijene infrastrukture i visokog nivoa zagađenja**.

Do 2034. godine, **površine za navodnjavanje povećaće se** za 250.000–350.000 ha.

Za projektovani kapacitet od 6 623 183 ES prečišćene vode iz aglomeracija u Republici Srbiji oko **1,3 ·10^6 m³ prečišćene otpadne vode bi bilo dostupno kao potencijalni resurs.**

SADAŠNJE STANJE | **PROJEKCIJE I MOGUĆNOSTI**

POLJOPRIVREDNE POVRŠINE

Površina raspoloživog zemljišta poljoprivrednih gazdinstava – 3 947 257 ha

- Površina korišćenog poljoprivrednog zemljišta – **3 336 785 ha**

Ukupna poljoprivredna površina na koju bi se mogao primenjivati tretiran mulj iznosi 427 103 ha

Površine pod:

- krmnim biljem - 212 773 ha
- voćnjacima - 196 129 ha
- vinogradom - 18 201 ha

PRODUKCIJA MULJA I PRIMENA

Trenutna proizvodnja mulja na PPOV **15 000 tSM/god**

Maksimalne predviđene količine mulja po izgradnji planiranih PPOV **135 190 tSM/god**

Ukupno 512 525 tSM/god tretiranog mulja se može godišnje primeniti na poljoprivrednim površinama (1,2 tSM/ha god)

Količine tretiranog mulja koje se mogu koristiti na površinama pod:

- krmnim biljem - 255 328 tSM/god
- voćnjacima - 235 355 tSM/god
- vinogradom - 21 841 tSM/god

PLODNOST ZEMLJIŠTA I MULJ KAO IZVOR ORGANSKE MATERIJE I NUTRIJENATA

Prosečan sadržaj **organskog ugljenika u zemljištu iznosi 1,82% - kategorija niskog sadržaja.**

Sadržaj lakopristupačnog fosfora u zemljištu oranica, bašti, voćnjaka, livada i pašnjaka u klasi vrlo niskog i niskog sadržaja u centralnoj Srbiji
P_2O_5 <5mg/100g i 5-10mg/100g

Prekoračenje sadržaja Cu, Zn, Ni, Co, Cd, As u zemljištu pojedinih regiona Republike Srbije može biti posledica dugotrajnog korišćenja mineralnih đubriva, posebno ekonomičnog diamonijum-fosfata.

Kroz mulj će u proseku biti **dostupno 250 kg/t organskog ugljenika.**

Na osnovu prosečnih vrednosti sadržaja N i P u mulju, po izgradnji planiranih PPOV, kroz mulj bi u toku godinu dana bilo na raspolaganju:

4 732 tN/god
4 664 tP/god

Potrebne količine tretiranog mulja koji bi se mogao koristiti na poljoprivrednom zemljištu prevazilaze skoro 4 puta buduću produkovanu količinu mulja (kada se izgrade sva postrojenja).

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SEWAGE SLUDGE POTENTIAL IN AGRICULTURE

-FACTSHEET FOR FARMERS-

WAHT IS SEWAGE SLUDGE AND ITS ADVENTAGES

- **Sewage sludge** is the semi-solid, organic by-product generated during the treatment of municipal or industrial wastewater in a wastewater treatment plant (WWTP).

N 3.3 % | **P** 2.3 % | **K** 0.3 %

- **Organic matter contribution**: Rich in organic matter, improves soil structure, aeration, and water retention.
- **Enhances soil fertility**: Increase of organic matter content, promoting microbial activity, and improving soil aeration and moisture retention.

SEWAGE SLUDGE CHARACTERISTIC

Parameter	Aerobically digested sludge	Anaerobically digested sludge
Remaining organic matter (as % of dry sludge)	60–70%	40–50%
Total nitrogen (% of dry sludge)	3.5–5.0%	2.5–4.0%
Organic nitrogen (% of total N)	60–80%	30–50%
Ammonium-N (% of total N)	10–20%	40–70%
Total phosphorus (% of dry sludge)	2–4.5%	2–4.5%
Organic P (% of total P)	40–60%	20–40%
Inorganic P (% of total P, as orthophosphate)	40–60%	60–80%
C/N ratio*	10–15**	6–10***

*For general soil fertility, C/N ratio of 10-20 is ideal
**Closer to soil requirements
***Lower due to carbon loss, which may cause faster nitrogen mineralization – improvement trough mixing with higher carbon materials (e.g., straw, wood chips, compost).

ESTIMATED REDUCTION IN MINERAL FERTILIZER USE

Nutrient	Potential reduction (%)	Key factors	Comment
Nitrogen (N)	30–70	Organic N mineralization rate, sludge stabilization type, application timing.	Organic nitrogen in sludge mineralizes slowly, with 30–50% becoming available in the first year. The remaining nitrogen releases gradually over time. Higher replacement rates are possible if sludge has high ammonium (NH_4^+) content (e.g., anaerobic sludge).
Phosphorus (P)	50–100	Soil P levels, sludge P availability, crop uptake.	Phosphorus in sludge is more stable and binds to soil, making it less prone to leaching compared to synthetic P fertilizers. Long-term sludge application can build up soil P levels, reducing the need for additional phosphate fertilizers.
Potassium (K)	0-20	Sludge has low K content, additional K may be needed.	Farmers may still need to apply potash-based fertilizers depending on crop requirements.
Not a direct fertilizer replacement - sewage sludge improves soil organic matter, structure, and microbial activity, enhancing nutrient retention and reducing leaching losses. This indirectly improves nutrient use efficiency, meaning less synthetic fertilizer is wasted. **UNLIKE MINERAL FERTILIZERS SEWAGE SLUDGE CAN PROVIDE THE NECESSARY ORGANIC MATTER.**			

FINANCIAL CONSIDERATIONS

Reduction in mineral fertilizer purchase cost

Potential costs for sewage sludge transport

Annual costs for soil analysis

OBLIGATIONS WHEN USING SEWAGE SLUDGE ON AGRICULTURAL LAND

Obligations are defined in *Regulation on the method and procedure of sludge management from municipal wastewater treatment plants ("Official Gazette of RS", No. 103/2023)*

- Performing soil analysis before the first use of the sludge.
- Performing a soil analysis when using sludge at least once a year.
- Soil analysis is performed based on prescribed parameters and reference methods in a laboratory accredited in accordance with soil regulations (pH value, the content of heavy metals in the dry matter of the soil: Cd, Cu, Ni, Pb, Zn, Cr and Hg)
- Obligation to keep copies of the Report on the results of soil analysis at least two years.
- Obligation to keep copies of the Report on the results of the soil analysis before the first use of the sludge permanently.
- Bearing the expenses of soil analysis.
- 1 composite sample per 5 ha (for regular monitoring)
- Obligation to prepare an Annual Report on the use of sludge in agriculture and submit it by to the Environmental Protection Agency RS, by March 31 of the current year for the previous calendar year.
- It is allowed to use a maximum of 1.2 t of dry sludge matter per hectare of land per year.

Available per allowed land use of 1.2 tDM/year per ha

C_{org}	N	P	K
400 kg	40 kg	28 kg	3.6 kg

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POTENCIJAL PRIMENE MULJA U POLJOPRIVREDI

-INFORMATIVNI LIST ZA POLJOPRIVREDNIKE-

ŠTA JE MULJ IZ PPOV I KOJE SU NJEGOVE PREDNOSTI

- **Mulj** je polučvrsti, organski nusproizvod koji nastaje tokom tretmana komunalnih ili industrijskih otpadnih voda u postrojenjima za prečišćavanje otpadnih voda (PPOV).

N 3.3 % | **P** 2.3 % | **K** 0.3 %

- **Doprinos organskoj materiji:** Bogat organskom materijom, poboljšava strukturu zemljišta, aeraciju i zadržavanje vode.
- **Poboljšava plodnost zemljišta:** Povećava sadržaj organske materije, podstiče mikrobnu aktivnost i poboljšava aeraciju zemljišta i zadržavanje vlage.

KARAKTERISTIKE MULJA

Parametar	Aerobno stabilizovan mulj	Anaerobno stabilizovan mulj
Preostala organska materija (kao % suvog mulja)	60–70%	40–50%
Ukupan azot (% suvog mulja)	3.5–5.0%	2.5–4.0%
Organski azot (% ukupnog N)	60–80%	30–50%
Amonijačni-N (% ukupnog N)	10–20%	40–70%
Ukupan fosfor (% suvog mulja)	2–4.5%	2–4.5%
Organski P (% ukupnog P)	40–60%	20–40%
Neorganski P (% ukupnog P, kao ortofosfat)	40–60%	60–80%
C/N odnos*	10–15**	6–10***

*Uobičajeno za plodnost zemljišta idealan je odnos C/N od 10-20
**Bliže zahtevima zemljišta
***Niže zbog gubitka ugljenika, što može prouzrokovati bržu mineralizaciju azota – poboljšanje mešanjem sa materijalima sa višim sadržajem ugljenika (npr. slama, drvna sečka, kompost).

PROCENJENO SMANJENJE UPOTREBE MINERALNIH ĐUBRIVA

Nutrijent	Potencijalno smanjenje (%)	Ključni aspekti	Komentar
Azot (N)	30–70	Brzina mineralizacije organskog azota, vrsta stabilizacije mulja, vreme primene.	Organski azot u mulju se sporo mineralizuje, pri čemu 30–50% postaje dostupno u prvoj godini. Preostali azot se postepeno oslobađa tokom vremena. Veće stope zamene su moguće ako mulj ima visok sadržaj amonijačnog azota (NH_4^+) (npr. anaerobni mulj).
Fosfor (P)	50–100	Nivoi fosfora u zemljištu, dostupnost fosfora u mulju, usvajanje od strane useva.	Fosfor u mulju je stabilniji i vezuje se za zemljište, što ga čini manje sklonim ispiranju u poređenju sa mineralnim fosfornim đubrivima. Dugoročna primena mulja može povećati nivo fosfora u zemljištu, smanjujući potrebu za dodatnim fosfatnim đubrivima.
Kalijum (K)	0-20	Mulj ima nizak sadržaj kalijuma, može biti potreban dodatak K.	Poljoprivrednici će možda i dalje morati da primenjuju đubriva na bazi potaše u zavisnosti od potreba useva.
Nije direktna zamena za đubrivo - PPOV mulj poboljšava organsku materiju u zemljištu, strukturu i mikrobiološku aktivnost, poboljšavajući zadržavanje hranljivih materija smanjujući gubitke ispiranjem. Ovo indirektno poboljšava efikasnost korišćenja nutrijenata, što znači da se manje mineralnog đubriva uzaludno troši. **ZA RAZLIKU OD MINERALNIH ĐUBRIVA, PPOV MULJ MOŽE OBEZBEDITI NEOPHODNU ORGANSKU MATERIJU.**			

FINANSIJSKA RAZMATRANJA

- Smanjenje troškova kupovine mineralnih đubriva
- Potencijalni troškovi transporta mulja
- Godišnji troškovi za analizu zemljišta

OBAVEZE PRI KORIŠĆENJU KANALIZACIONOG MULJA NA POLJOPRIVREDNOM ZEMLJIŠTU

Obaveze su definisane u *Uredbi o načinu i postupku upravljanja muljem iz postrojenja za prečišćavanje otpadnih voda ("Sl. glasnik RS", br. 103/2023)*

- Obavezna analiza zemljišta pre prve upotrebe mulja.
- Vršenje analize zemljišta pri korišćenju mulja najmanje jednom godišnje.
- Analiza zemljišta se vrši na osnovu propisanih parametara i referentnih metoda u laboratoriji akreditovanoj u skladu sa propisima o zemljištu (pH vrednost, sadržaj teških metala u suvoj materiji zemljišta: Cd, Cu, Ni, Pb, Zn, Cr i Hg)
- Obaveza čuvanja kopija Izveštaja o rezultatima analize zemljišta najmanje dve godine.
- Obaveza trajnog čuvanja kopija Izveštaja o rezultatima analize zemljišta pre prve upotrebe mulja.
- Snositi troškove analize zemljišta.
- 1 kompozitni uzorak na 5 hektara (za redovno praćenje)
- Obaveza izrade godišnjeg izveštaja o korišćenju mulja u poljoprivredi i njegovog dostavljanja Agenciji za zaštitu životne sredine RS, do 31. marta tekuće godine za prethodnu kalendarsku godinu.
- Dozvoljeno je koristiti najviše 1,2 t suve materije mulja po hektaru zemljišta godišnje.

Dostupno po dozvoljenoj upotrebi na zemljištu od 1,2 t SM/god po hektaru

C_{org}	N	P	K
400 kg	40 kg	28 kg	3.6 kg

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