RESEARCH ON WASTEWATER TREATMENT

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In order to have access to an infrastructure with a well-centralized sewage system and to properly treat the water volumes generated, that prioritizes sustainability and the transition to a circular economy, it is essential to establish a clear overview of the current state and technologies available both at the European and national levels. This study provides a European assessment of the collection, treatment, and reuse of wastewater, integrating multiple data sources with focus on Romania. Additionally, key statistics are presented that highlight how each country manages its wastewater. The study identified 7 successful projects in Romania, making a comparison between one WWTP from Romania and one WWTP from Denmark. According to Eurostat, in 2020 more than 40% of the Romanian population was not connected to the public water supply and even more to the wastewater system.

Keywords: wastewater, projects, technologies, EU policy

1. Introduction

The main objectives of this article are to bring awareness to the current state of wastewater management in Europe, highlighting the most recent and significant projects in various countries, comparing them to the situation in Romania, and assessing the progress Romania has made in recent years regarding wastewater treatment, and for this it is necessary to highlight both the importance of wastewater

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treatment, as well as the method and key technologies that most European countries apply.

Sustainability and wastewater treatment are interconnected, playing a crucial role in environmental protection and sustainable development. Effective wastewater treatment is a key aspect of sustainability, influencing the conservation of natural resources, the preservation of biodiversity, and the safeguarding of human health.

In Europe, in the last 2 decades, we have seen a significant improvement on river water quality after implementation of the Urban Wastewater Treatment European Directive (91/271/EEC), and the European Water Framework Directive. [1]

This information is essential for assessing progress towards Sustainable Development Goal (SDG) 6, such as SDG 6.3 that specifically focuses on achieving water quality improvements through halving the proportion of untreated wastewater and promoting safe reuse globally. However, the availability of wastewater data at the continental and global scales is sparse and often outdated or from inconsistent reporting years [2].

As can be seen in table 1, Romania has reached the basic objectives regarding access to drinking water services, with 100% of the population benefiting from them in 2022. However, challenges remain for population using at least basic sanitation services and scarce water consumption embodied in imports, that is why measures should be taken for a more sustainable management.

Romania has a country score of 76.7% and it is ranked 40/167 with a statistical performance index of 84.3 and increasing [3].

Table 1

Performance by indicator in Romania

SDG6 – Clean Water and Sanitation	Value	Year	Rating
Population using at least basic drinking water services (%)	100.0	2022	SDG achieved
Population using at least basic sanitation services (%)	88.3	2022	Challenges remain
Freshwater withdrawal (% of available freshwater resources)	7.4	2021	SDG achieved
Anthropogenic wastewater that receives treatment (%)	25.7	2020	Significant challenges
Scarce water consumption embodied in imports (m3 H2O eq /capita)	1,379.0	2024	Challenges remain

Western European countries often have access to more advanced wastewater treatment technologies. The wastewater treatment infrastructure is very advanced, with full coverage of sewage networks and modern treatment plants.

Romania performed well and started to modernize the technologies it uses, but at a slower rhythm than the other EU member states.

European Case Studies and successful projects:

1. Denmark- Marselisborg Wastewater Treatment Plant (WWTP).
2. Netherlands- Advanced membrane bioreactor technology.
3. Sweden- Nutrient recovery from wastewater and has some of the highest standards for wastewater treatment in the world.
4. Germany- The Emscher – Europe's largest wastewater treatment project.

Romania has made significant progress in wastewater treatment in recent years, largely driven by the need to comply with European Union (EU) environmental regulations and to improve public health and environmental sustainability.

Successful projects and initiatives in wastewater treatment in Romania:

1.Bucharest Wastewater Treatment Plant – Glina (nominated for the award for the best environmental, wastewater treatment project in the world, the project being included on the short list of projects nominated for the 2024 edition of the Global Water Awards).
2.Cluj-Napoca Wastewater Treatment Plant
3.Constanța Wastewater Treatment Plant
4.Integrated Wastewater Treatment Projects in the Danube River Basin
5.Iași Wastewater Treatment Plant
6.Sibiu and Brașov Regional Wastewater Projects
7.Timișoara Wastewater Treatment Plant

Table 2 presents the main laws regarding water management in Romania and the related European directives.

The main reason for this diversity of legislative instruments is related to the flexible nature of European directives and depending on how the Romanian government chooses to implement them.

Also, in table 3 we can see an overview of the situation in Romania in 2023, with only 72.4 % population served out of the total population connected to sewerage services.

Table 2

Main laws on water management

Domain	Romania - National Legislation, Laws, and Regulations	European Union - Directives
Water Management	Water Law no. 107/1996	Water Framework Directive 2000/60/EC
Drinking Water Quality	Ordinance No. 7 of January 18, 2023	Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020
	Government Decision no. 188 of February 28, 2002 (*updated*) for	Directive 91/271/EEC concerning Urban Wastewater Treatment

Urban Wastewater Treatment	the approval of some rules regarding the conditions for discharging waste water into the aquatic environment (updated until March 19, 2007*)	
	Currently being transposed into Romanian legislation.	Directive Of The European Parliament and Of The Council concerning urban wastewater treatment (recast), of 26 October 2022, code 2022/0345 (COD)
Pollution Control	EMERGENCY ORDINANCE no. 152 of November 10, 2005 (*updated*) regarding the prevention and integrated control of pollution (updated to November 19, 2010*)	Directives no. 2003/35/EC and no. 2003/87/EC
Industrial Emissions	Law no. 278/2013 on Industrial Emissions	Directive 2010/75/EU on Industrial Emissions
Protection of Waters Against Pollution by Nitrates	Government Decision no. 964/2000	Directive 91/676/EEC concerning the Protection of Waters Against Pollution Caused by Nitrates from Agricultural Sources
Sustainable Water Use	Order of the Ministry of Finance no. 85/2024 ("OMF 85/2024")	Directive (EU) 2022/2464- Corporate Sustainability Reporting Directive (CSRD)

Table 3

An overview of the situation in Romania 2023

Water and Wastewater Operators Market in Romania	Percentage of the population served out of the total population connected to water services (market share for water services)	Percentage of the population served out of the total population connected to sewerage services (market share for wastewater services)
Regional operators	68.6	72.4
Large operators with mixed capital	13.7	19.1
Other operators organized as private or mixed capital companies	2.1	1.5
Other operators organized as municipal services or public capital companies	15.6	7.1

The sewage system in Romania is in a variable state, with significant differences between urban and rural areas, with a number of 1,154 sewage treatment plants and 874 treatment plants.

Currently, the connection rate to water services is around 74% and to sewerage services around 59%, being the lowest among EU countries - both for drinking water and for sewage [4].

Romania is comparable to the other EU states in terms of the connection rate to the water supply infrastructure in the urban environment, 94.9%, compared to 96-100% in the other EU states. On the other hand, in the rural areas the connection rate is only 30.8%, below the EU average [5].

The 26 523 waste-water treatment plants in Europe process wastewater from 447 million inhabitants and from small industries that discharge into public sewers. This wastewater includes pharmaceutical residues, pesticides, nutrients, organic matter, microplastics and hazardous substances [6].

The share of the population connected to at least one secondary wastewater treatment plant even rose to 95% and above in six Member States (Denmark, Germany, Greece, the Netherlands, Austria and Sweden), as well as in Switzerland and the United Kingdom. At the other end of the range, less than one in two households were connected to at least secondary urban wastewater treatment plants only in Malta and Croatia, while the same was true in Iceland, Albania, Serbia and Bosnia and Herzegovina [7].

As it is shown in table 4, we can observe from this point of view that Romania had an increase of 5.83 % from 2018 to 2022 in terms of population connected to at least secondary wastewater treatment.

Table 4

Population connected to at least secondary wastewater treatment (2018-2022)

Belgium	84.34	84.25	83.58	84.03	84.04	**Romania**	48.10	49.40	51.80	52.60	53.94
Bulgaria	63.72	64.51	65.05	65.30	:	**Slovenia**	68.95	69.52	69.32	67.61	68.45
Czechia	82.30	82.60	83.40	84.70	84.90	**Slovakia**	65.70	68.10	68.80	69.90	70.60
Denmark	97.10	97.50	97.70	97.80	97.93	**Finland**	85.00	85.00	85.00	85.00	85.00
Germany	96.20	96.32	:	:	:	**Sweden**	96.00	96.00	96.00	96.00	:
Estonia	83.00	83.00	83.00	82.00	82.00	**Iceland**	:	:	:	:	:
Ireland	62.66	63.09	63.63	64.30	64.72	**Norway**	66.86	66.15	67.00	67.88	70.93
Greece	94.80	94.20	94.70	94.70	94.90	**Switzerland**	:	98.00	:	:	:
Spain	88.21	87.57	86.93	86.93	:	**United Kingdom**	:	:	:	:	:
France	80.19	80.02	79.85	79.68	79.56	**Bosnia and Herzegovina**	29.00	29.60	:	:	:
Croatia	36.90	36.90	36.90	31.39	:	**Albania**	33.60	31.80	30.90	21.63	22.91
Italy	:	:	:	:	:	**Serbia**	12.87	13.14	13.77	14.67	15.16

Cyprus	82.65	83.07	83.48	:	:	**Türkiye**	60.79	61.03	61.12	60.75	61.18
Latvia	75.44	77.52	76.97	76.48	77.20	**Kosovo***	:	:	:	:	:
Lithuania	75.80	76.55	76.58	76.94	76.03	**Austria**	99.78	99.78	99.10	99.10	99.15
Luxem-bourg	:	:	:	:	:	**Poland**	74.00	74.44	74.78	75.20	75.68
Hungary	80.36	80.26	80.91	81.90	81.73	**Portugal**	:	:	:	:	:
Malta	0.00	0.00	6.54	7.40	7.41	**Netherlands**	99.50	99.50	99.55	99.60	99.65

Special value

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Available flags:

d	definition differs (see metadata)
e	estimated
s	Eurostat estimate

Population connected to at least secondary wastewater treatment
Source: EurostatOnline data code:sdg_06_20
DOI:10.2908/sdg_06_20

Industrial pollutant releases to water in Europe

Industrial releases to Europe's water bodies of pollutants damaging to human health and the environment declined overall between 2010 and 2022. Emissions of nitrogen, which cause eutrophication, declined to a lesser extent.

The table show the top five emission reduction changes in pollutant releases into water in EU-27 Member States from 2010 to 2022 [8].

There was a significant decrease of 72% in the heavy metals Cd^{2+},Hg^{2+},Ni^{2+}, Pb^{2+}, indicating progress in the control of these pollutants. Total nitrogen emissions decreased by 19%, phosphorus emissions fell by 26%, which can help reduce the risk of eutrophication. Total organic carbon emissions increased by 6%, which may indicate an increase in organic matter in wastewater, possibly due to industrial or agricultural activities.

Table 5

Cd^{2+},Hg^{2+},Ni^{2+}, Pb^{2+}			Total N			TOC			Total P		
2010	2022		2010	2022		2010	2022		2010	2022	
17557	4971	-72%	8761900	7136400	-19%	17082900	18177900	6%	880400	651040	-26%

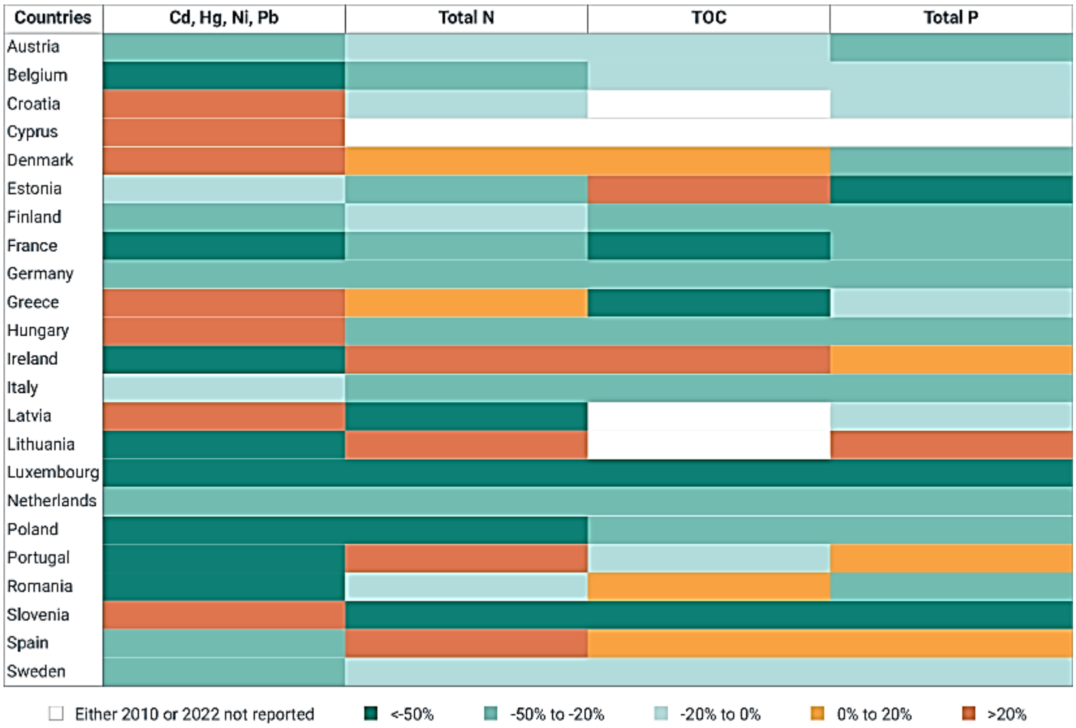

Fig. 1 Water pollutant releases changes from 2010 to 2022 for the EU Member States

Through a review of the sector performed in 2017 by Water Reuse Europe, 787 schemes practicing reuse were identified, distributed across 16 countries, 437 more than identified by the previous review of the water reuse sector in Europe performed in 2006 [9].

A map of Europe is illustrated in Fig. 2, with different uses of reclaimed water in various European countries, divided into categories. Each colored circle in each country represents the proportion of recycled water used for different purposes. As we can see, agricultural and industrial uses are the most popular.

Table 6

Urban Wastewater Treatment for Romania [8]

Year	2020	No treatment %	2.47
Generated load (p.e)	19,831,511.00	No. of connected plants	673
Collected load (p.e.)	12,756,522.70	Stringent treatment (no of plants)	206
Collected %	64.32	Secondary treatment (no of plants.)	440
Treated in Individual appropriate systems %	1.43	Primary treatment (no of plants)	27
Rate raw %	34.25	Secondary treatment %	6.34
Stringent treatment %	52.03	Primary treatment %	3.49

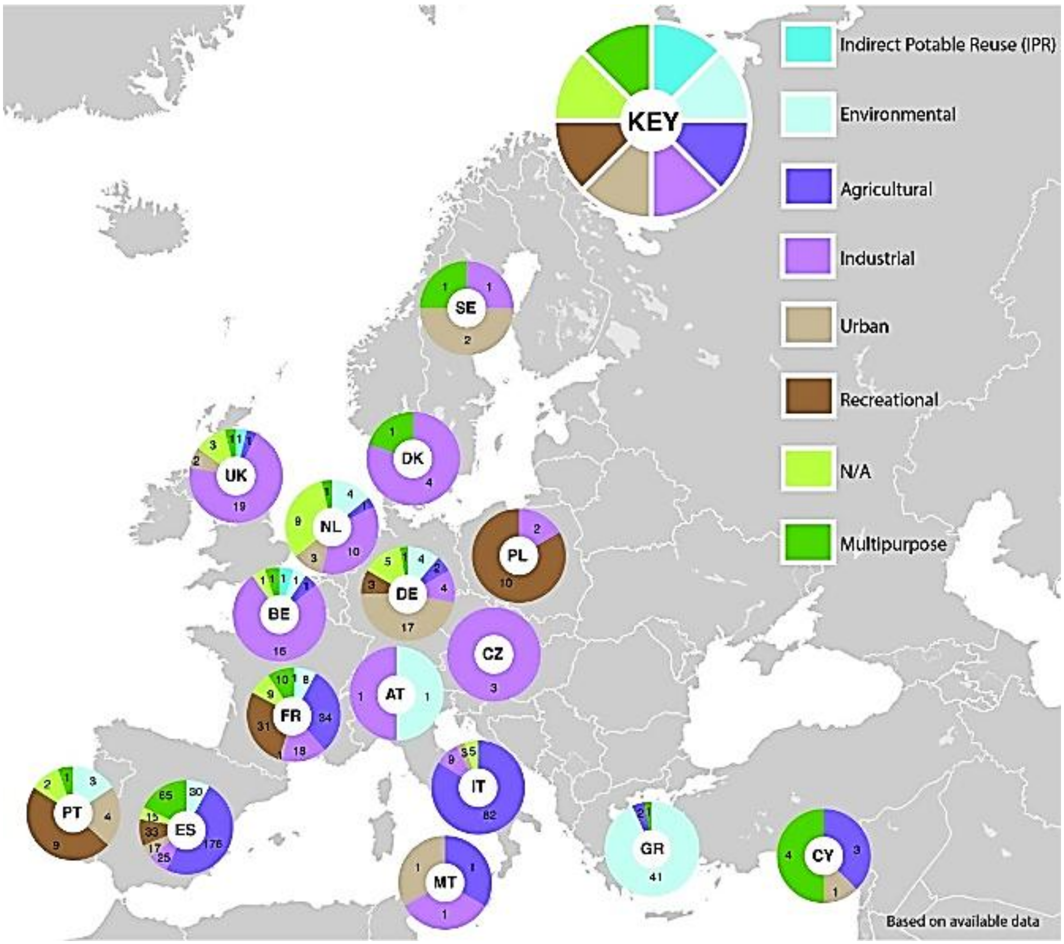

Fig. 2 Sectoral water reuse in Europe

2. Case study

An analysis was made of the statistics taken from specialized literature, from Eurostat online database and from the annual reports issued by National Agencies and the European Environment Agency.

Flows of the Glina WWTP and Marselisborg WWTP were presented. In this paper we bring more knowledge regarding the situation of wastewater in Europe and the differences between technologies, demonstrating the importance for Romania to align with.

To illustrate the advancements and differences between wastewater treatment facilities in Europe, we'll compare the Glina Wastewater Treatment Plant in Bucharest, Romania, with the Marselisborg Wastewater Treatment Plant in Aarhus, Denmark.

Glina WWTP (Romania)

The Glina WWTP has a significant capacity, treating up to 12 cubic meters per second, which translates to over 1 million cubic meters of wastewater per day. It serves around 2.4 million inhabitants in Bucharest and the surrounding Ilfov County [10].

The plant represents a significant investment, with financing from the World Bank, the European Investment Bank, and the Romanian government. The project's cost was around €130 million, underscoring its importance for regional environmental health [11]. The technological scheme of SEAU Glina is presented in Fig. 3 and Fig. 4.

In 2023, the Glina Wastewater Treatment Plant reached a level of energy autonomy of 69.98%. SEAU Glina will ensure the complete purification of an average hourly flow of wastewater of 8.27 m3/s [12].

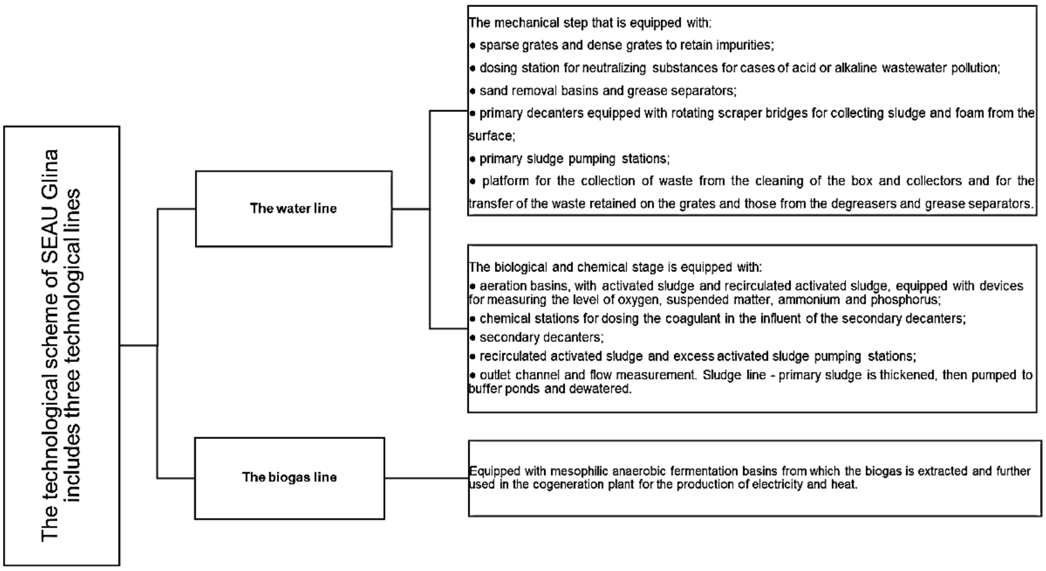

Fig.3 The technological scheme of SEAU Glina

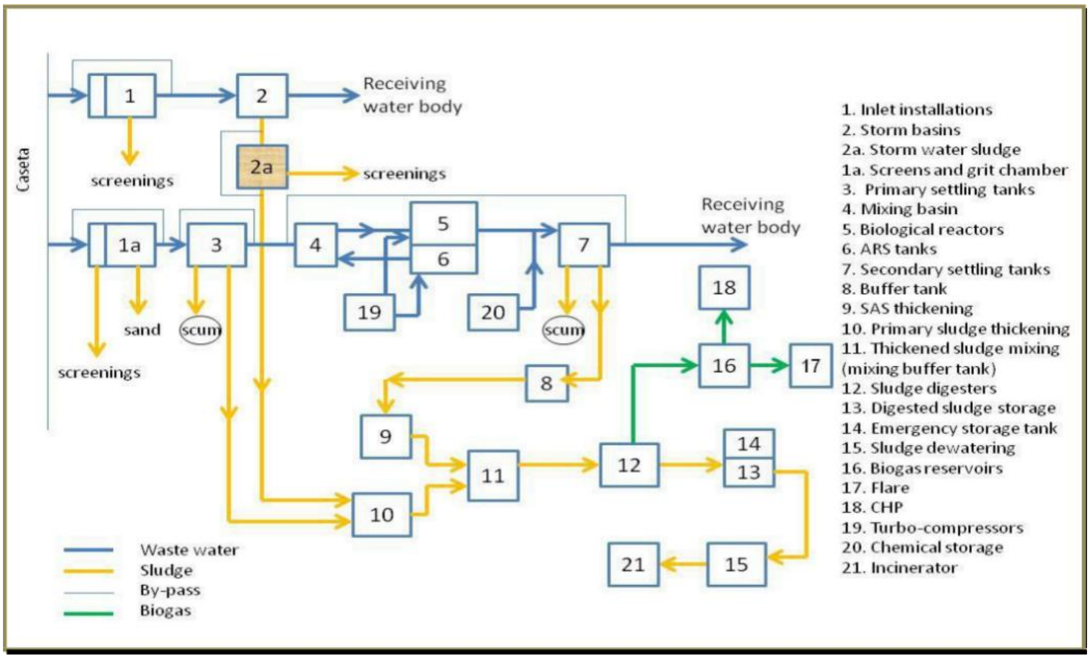

Fig.4 Flow diagram of Glina WWTP, Stage 1+2

Table 7

Glina WWTP design capacity [13]

Indicator	M.U.	Actual situation (2011)	Future situation (2040)
Volume of treated wastewaters as required by Directive 91/271/CEE	mÂ³/d	438834	832500
Total BOD treated/eliminated	kg BOD/day	67,500 /66,200	145,000 / 127,137
Total COD treated/eliminated	kg COD/day	163,200 / 155,000	410,000 / 320,684
Total N treated/eliminated	kg N/day	10,500 / 7,000	37,200 / 30,055
Total P treated/eliminated	kg P/day	1,930 / 1,600	5,200 / 4,485

As it is shown in table 6, a comparison is made between the situation in 2011 and predictions for 2040. The volume of treated wastewater will increase by 393,666 m³/day.

Romania has 174 biological treatments with nitrogen and phosphorus removal, 434 biological treatment and 34 primary treatments. Also, 12% of sewage is treated in line with EU legislation.

Further efforts are needed to providefor urban wastewater collection and treatment:

- Collection of additional 7.16 million p.e of urban wastewater (35.9%)

- Biological treatment to additional 12.87 million p.e of urban wastewater (65.7%)
- Biological treatment with nitrogen and phosphorus removal to additional 7.72 million p.e. of urban wastewater (58.8%) [14]

Marselisborg WWTP (Denmark)

Marselisborg WWTP has a capacity of wastewater equivalent to 200,000 persons (BOD), and a production of 192% energy. Through the anaerobic digestion of sludge and the use of advanced drives and pumps, the plant generates 50% more energy than it consumes, exporting the excess energy back to the grid. Totally up to 40-50% of the phosphorus in the incoming wastewater can be recovered [16].

Romania generated over 247,760 tons of wastewater sludge in 2018, while Denmark generated over 106,000 tons of wastewater sludge in 2018.

In Denmark, 99% of sewage is treated in line with EU legislation, 323 biological treatments with nitrogen and phosphorus removal, 14 biological treatment [17].

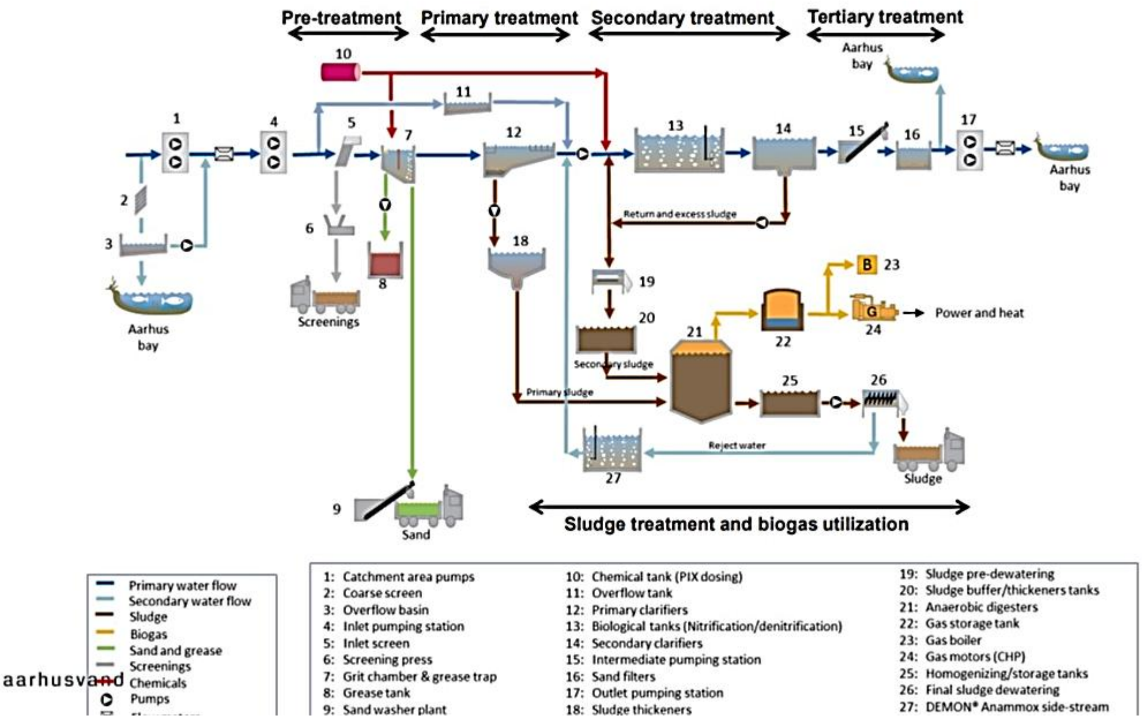

Fig.5– Marselisborg WWTP-Main Flow Diagram [15]

Tabel 8

Wastewater Parameters Load 2017

Parameter	Load 2017
Flow	26,687 [m³/d]
BOD5	8,235 [kg/d]
Total N	1,736 [kg/d]
Total P	231 [kg/d]
PE_{BOD}	137,000 a 60g BOD/pxd

The comparison between Romania and Denmark regarding wastewater sludge disposal is related in Fig. 6.

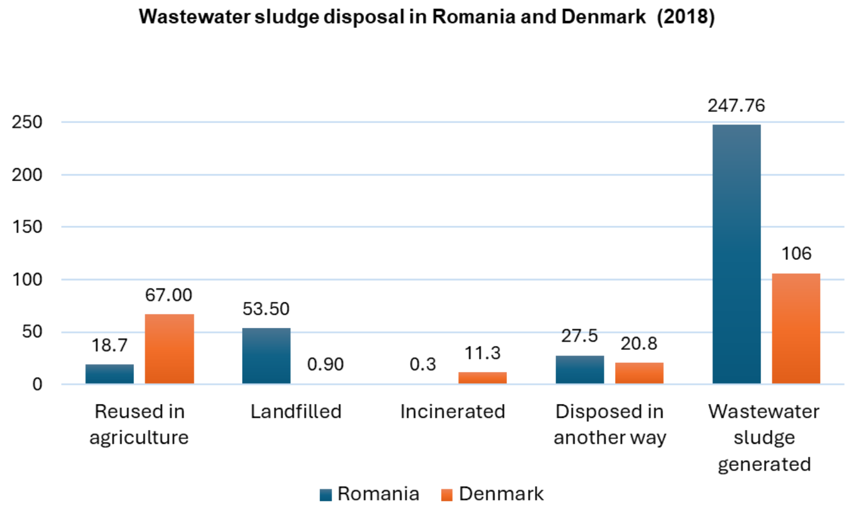

Fig.6 Wastewater sludge disposal in Romania and Denmark 2018

Key Technologies

The traditional wastewater treatment process includes integrated steps for the removal of solids, organic matters, and nutrients from wastewater. Combinations of physical, chemical, and biological processes are typically involved in a sequential way to achieve treated wastewater with certain specifications. The wastewater treatment process includes some common sub-processes like adsorption, photodegradation, coagulation-flocculation, ionic exchange, precipitation, biological and membrane separation.

The traditional methods of wastewater management are not sufficient for the increasingly polluted wastewater streams from municipal and industrial activities. This is raised from the increase in wastewater quantities and pollution degree. Subsequently, there is increasing attention to develop innovative wastewater treatment technologies in order to ensure safe discharging of the municipal and industrial wastewater to the ecosystems. However, the recent technologies are mainly hybrid systems where two or more treatment methods are combined to fulfill the required quality of the discharged water. The hybrid systems can save operational space, time, cost, and energy consumption [18].

The standard technologies of filtration and chlorination are utilized by the majority of water treatment facilities in Romania. Activated sludge is the most often used technique for biological treatment in wastewater treatment facilities. There are pilot projects or more advanced stations that are beginning to adopt modern technologies such as ozonation and membrane treatment, but they are not yet widespread.

In many European countries, membrane treatment (ultrafiltration, nanofiltration) is frequently used, providing a high degree of purification and reducing the need for chlorination. Energy recovery from water and sludge treatment processes, such as anaerobic digestion, which enables the production of biogas is also a method widely used in developed countries, along with ozonation and UV radiation that are used to disinfect water.

Results

From the analysis presented, it is confirmed that many European countries have already implemented the tertiary stage of wastewater treatment, which includes advanced nutrient removal (nitrogen and phosphorus), water disinfection and other processes that ensure a higher quality of water discharged into the environment. In Romania, only a few treatment plants have adopted the tertiary stage, and in many cases, it is still being implemented or is not widely applied. From fig.7 it is shown that overall, 12% of the urban wastewater in Romania is treated according to the requirements of the UWWTD. This is below the EU average of 76% [19].

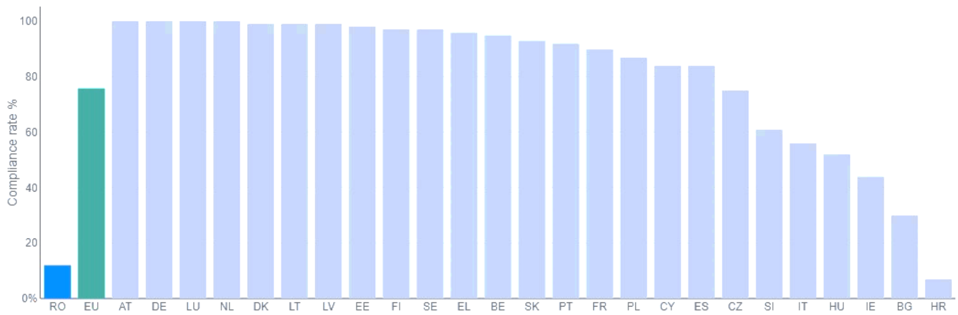

Fig.7 The proportion of urban wastewater that meets all requirements of the UWWTD (collection, biological treatment, biological treatment with nitrogen and/or phosphorus removal) in compliant urban areas

It should be noted that the population connected to sewage systems in 2022 represented 59.2% of the population resident of Romania and the population connected to the sewage systems provided with treatment stations represented 58.1% of the resident population of Romania [20].

The centralization of the data on the treatment plants investigated in 2022 leads to the conclusion that, out of the total number of 2864 treatment plants, a number of 1089 plants functioned properly, and the remaining 1775 plants functioned improperly [21].

In Fig. 8 the number of WWTP is shown by type of treatment for different countries in Europe. Datas were collected from WISE-Freshwater Information System for Europe.

We can observe that in terms of the level of treatment, Romania has the most wastewater treatment stations that have only primary treatment, and the fewest stations that can offer advanced treatment.

In contrast, countries such as Germany and France have successfully implemented tertiary treatment, removing nutrients and micropollutants. Some stations in Europe use cutting-edge technologies to eliminate micropollutants, such as pharmaceutical substances and microplastics, projects that are also underway in Romania, such as the use of advanced filters and innovative separation methods.
Other countries in Eastern Europe have managed to effectively absorb and make better use of European funds, but Romania faces administrative and implementation challenges.

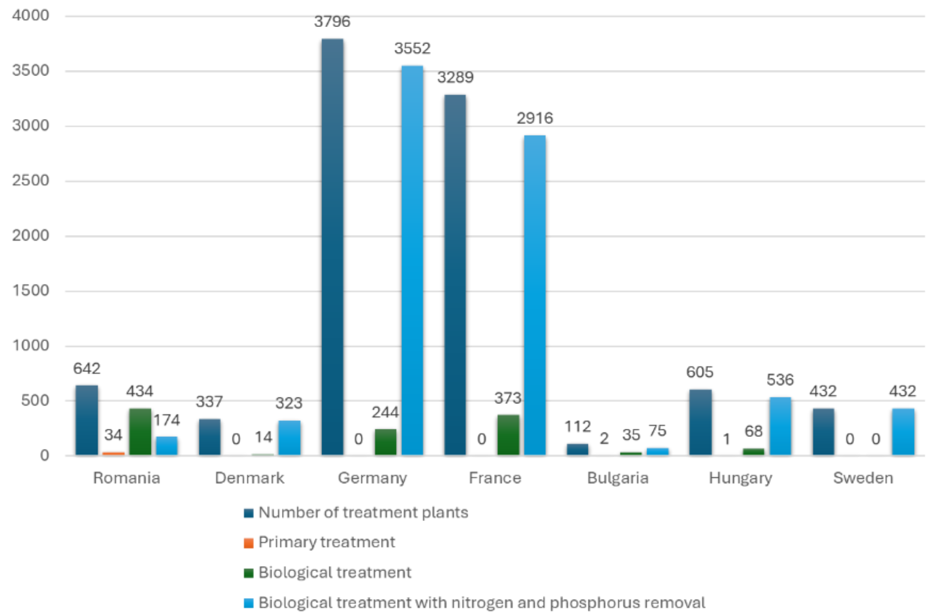

Fig.8. Number of WWTP by type of treatment for different countries in Europe

After upgrading, the Glina station should provide secondary and tertiary treatment, including nutrient removal, which is a significant improvement over the current situation. The station will take steps towards more sustainable resource management but will probably not reach the level of energy self-sufficiency seen at Marselisborg, which is an example of energy self-sufficiency, actually generating more energy than it consumes, thanks to advanced anaerobic digestion and energy recovery from sludge. In addition to biogas, Marselisborg recovers phosphorus and other valuable resources from wastewater, contributing to a circular economy.

Romania could use the Marselisborg example as a model for future upgrades and innovations post-2025, focusing on increasing energy efficiency and resource recovery.

3. Conclusions

The water sector in Europe is in a transitional phase with unique opportunities for water reuse to be implemented on a larger scale as a sustainable practice within a framework of integrated water management. Success of integrated water management policy depends on individual, local communities and companies as much as on centralized rules and regulations [22].

This paper highlights the importance of implementing urgent measures to rehabilitate wastewater treatment plants in Romania in order to align with European standards. It also provides details about the energy recovery in the wastewater treatment process, which is a significant aspect as reflected in the proposals included in the "Fit for 55" climate package. It is very important to highlight the necessity of creating more climate-friendly and energy-saving technologies.

It is clear that most countries in Europe have made and continue to make progress in sustainability, circular economy, and wastewater management. In addition to these advancements, they continue to innovate treatment processes for higher purification, energy, and economic efficiency. It is important for less developed countries like Romania to draw inspiration from these advancements and implement new technologies.

Although the planned upgrades for Glina station will bring significant improvements and better compliance with European standards, other WWTP from Europe have already implemented these technologies for many years. Glina can use Denmark's experience to continue to evolve post-2025, with long-term goals that include energy self-sufficiency and better integration of circular economy practices.

Romania falls behind many European countries in its wastewater treatment infrastructure, both in terms of population connectivity and the technological sophistication of its treatment plants. To meet European standards, it is essential for Romania to continue investing in the modernization of existing facilities, adopt more advanced technologies, and enhance the efficiency in utilizing available funds.

A comprehensive comparative analysis was conducted between the two wastewater treatment plants, examining treatment technologies in Romania and Denmark—a topic seldom addressed in existing literature. Additionally, comparisons were extended to other European countries to provide context, illustrating Romania's positioning.

This study synthesized and interpreted differences in each country's adaptation to European regulatory standards, particularly in sludge management practices. Furthermore, it presents a comparative analysis of wastewater treatment plant (WWTP) distribution by treatment type across various European nations.

The case study presented in this paper, based on a comparison between Glina Wastewater Treatment Plant in Bucharest, Romania, and the Marselisborg Wastewater Treatment Plant in Aarhus, Denmark, which is a special point of view, offers a particular picture regarding the advancements and differences between wastewater treatment facilities in Europe and the progress that Romania must make in order to align with EU legislations and commitments.

By detailing the technological processes at Glina (Romania) and Marselisborg (Denmark), this research identifies several potential advancements for Romania, such as energy recovery, anaerobic sludge digestion, and the integration of high-efficiency engines and pumps.

The analysis incorporates updated data and recent studies, leveraging information previously unexplored in similar comparative contexts, thus enhancing the novelty and relevance of this work.

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