Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XII, 2023
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

EMBEDDING LOW CARBON EMISSION INTO THE WATER INFRASTRUCTURE

Mirela-Alina SANDU[1], Adela-Constanta VLADASEL (PASARESCU)[2], Adriana-Magdalena PIENARU[1]

[1]University of Agronomic Sciences and Veterinary Medicine of Bucharest,
Faculty of Land Reclamation and Environmental Engineering,
59 Marasti Blvd, District 1, Bucharest, Romania
[2]Stantec, CF23 8HA, Cardiff, United Kingdom

Corresponding author email: apienaru@gmail.com

Abstract

Climate change is the biggest global challenge of our times. If, at all levels of society and organisation, we can work together to reduce carbon emissions while also planning how to adapt to change, we can prevent climate change from making our planet uninhabitable. Romania is committed to fighting climate change and pursuing low carbon development. Therefore, the Government of Romania, through the Ministry of Environment and Climate Change (MECC), has requested the World Bank to provide advisory services to help meet this commitment. To reduce the carbon footprint of the infrastructure is essential to assess the carbon embodied in the materials and construction methods, plus the operational carbon emissions of the resulting asset.
Carbon Management in Infrastructure provides a national framework for these assessments and can be directly applied to the water industry as it needs to engage the whole value chain to achieve the net zero commitments.

Key words*: Carbon Management, climate change, emissions, net zero carbon.*

INTRODUCTION

Some of the global problems humanity is facing are water scarcity, water quality degradation and changes in the water cycle in the context of climate change. Human activities and economic development exert pressure on water resources, which are unevenly distributed over the Earth's surface. In addition, rapid urbanisation, the development of municipal water supply and sewerage facilities plus climate change are all contributing to increased consumption, making water ever scarcer. In general, in the context of water scarcity, socially and politically, wastewater management receives less attention compared to the water sector, although the two are intrinsically linked. Wastewater has a negative impact on the sustainability of the water supply system, human health, the environment and economy. Increased discharges of improperly treated industrial wastewater, untreated municipal wastewater and sewage seepage have led to water quality degradation worldwide. Thus, Wastewater Treatment Plants (WWTPs) are an important part of the water cycle and in achieving the concept of circular sustainability by integrating the three dimensions: environmental, economic and social.

The primary objective of the WWTPs is to remove pollutants from wastewater to ensure the protection of the receiving water body (Fighir et al., 2019). In Europe, urban wastewater treatment is regulated by the Council Directive 91/271/EEC concerning urban wastewater treatment (UWWTD). Limited importance is attached to the ways in which these pollutants have been removed or the energy used to remove pollutants from wastewater or the number of emissions of greenhouse gases (GHG) produced. Research has shown that sewage treatment plants are an undeniable source of man-made greenhouse gas emissions that lead to global warming and climate change (Larsen, 2015; Sweetapple et al., 2014). Wastewater treatment can account for about 1-2% of total global greenhouse gas emissions to the atmosphere (Lanqing et al., 2022). Another important issue is the management of sludge from the treatment process, which comprises most of the pollutants present in wastewater (Shao et al., 2019).

Today, a different vision of sewage treatment plant design based on multiple criteria is needed and GHG emissions produced in the treatment process, can no longer be ignored.
Wastewater treatment plants have the potential to be an integral component of circular sustainability through embedding both resource and energy capture during safe water production. The transition to the circular economy embraces all areas of the economy, even the water (Sandu & Virsta, 2021) and wastewater sectors (Smol, 2023).
Climate change is forcing us to place carbon management at the forefront of every approach to water solutions (e.g. reducing carbon footprint to net neutrality and ultimately to zero net carbon emissions). These measures shape the circular economy, the heart of a sustainable future.
The primary aim of the paper is to provide an overview regarding the importance of the carbon emissions concept in wastewater treatment plants.

MATERIALS AND METHODS

The methodology applied to achieve the goals of the research incorporated a mapping to theoretical frameworks (specific elements of sewage treatment plant carbon emissions) of interest. In the initial stage of this study, the importance of WWTPs was highlighted. This comprised a review and assessment of the different levels of wastewater treatment processes and an analysis of urban wastewater production and treatment in Romania. In the second phase of this research, carbon emissions from wastewater treatment plants were correlated with GHG emissions from the municipal wastewater treatment plants during operation.
This study was conducted using the documentary research method, which implied collecting information from available resources accessible in existing published scientific databases, websites and libraries. Primary research literature has been retrieved from full-text academic databases like Elsevier, Web of Knowledge, Wiley Online, Google Scholar, Multidisciplinary Digital Publishing Institute and European Union statistics (Eurostat).

RESULTS AND DISCUSSIONS

Wastewater Treatment Plants

The mixture of municipal wastewater, runoff from streets and paved surfaces as well as industrial wastewater is called urban wastewater. Untreated, this wastewater contaminates rivers, lakes, groundwater, seas and can create serious public health risks. In Europe, most wastewater ends up in the sewer system from where it is transported to a wastewater treatment plant to reduce the concentration of pollutants The treated water is then released into the environment, usually into lakes and rivers. When pollution control at source fails, urban wastewater treatment is the ultimate opportunity to prevent pollutants from entering the environment, is an "end-of-pipe" measure.
Wastewater treatment refers to the physical, chemical, and biological processes used to eliminate pollutants from wastewater. It also includes the transformation of water into an effluent that can be cycled back into the water system. Once the effluent is returned to the water cycle, it has an acceptably low impact on the environment or is used for other applications. Different levels of processing can be carried out, usually covering the following (Figure 1).
Urban wastewater treatment UWTPs produces sewage sludge, which is usually processed to meet the sludge's suitability for its intended use or disposal (Figure 2). Wastewater carries valuable resources. These include not just water alone, but also heat, nutrients like phosphorus and nitrogen, as well as energy as well and other valuable resources which may be obtained from sewage sludge. In some areas of Europe, processed sewage sludge is prized for the nutrients and organic matter it contains in agriculture, although worries regarding contamination, mostly chemical, limit its application potential. From this point of view, the most efficient plants can fulfil the environmental thresholds for discharge and producing at minimum enough energy for their own energy demands. Through imposing requirements on the quality of incoming effluent until resource recovery, these "resource centres" could support a circular economy.

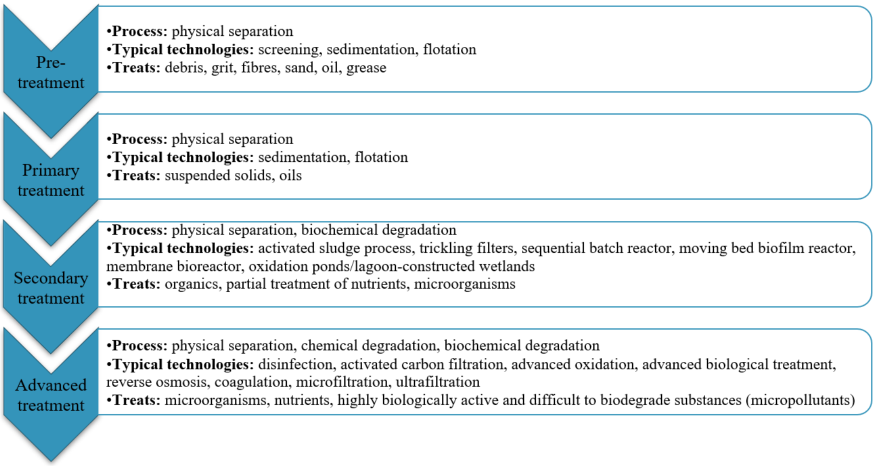

Figure 1. Wastewater treatment processes

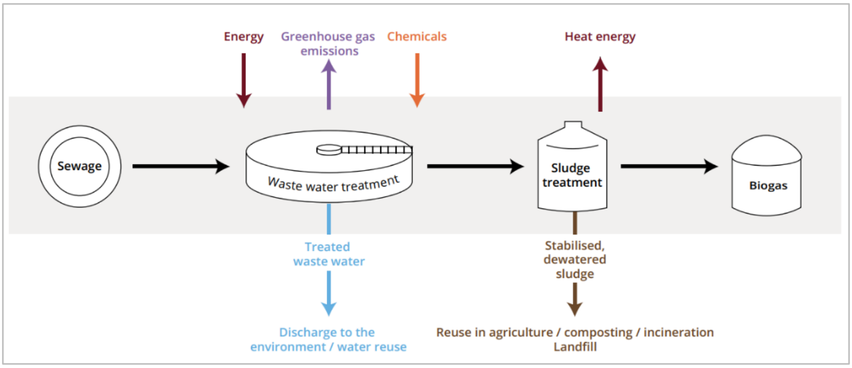

Figure 2. Urban wastewater treatment plan (EEA, 2022)

Carbon emissions in the WWTPs

It is mandatory to know the carbon emissions of the WWTPs, as measures to reduce GHG emissions are linked to measures to improve the energy efficiency of plants and lead to better plant management. Carbon emissions from wastewater treatment plants are emissions related to the collected, treated and final disposal of treated wastewater and the resulting sludge (Figure 3).

The main sources of emissions from wastewater treatment plants include "energy consumption and biological, chemical and biochemical processes to achieve effluent quality" (IPCC, 2014).

According to Parravicini et al. (2016), GHG emissions can be classified into two major categories: direct and indirect emissions. Wastewater treatment plants' direct greenhouse gas emissions refer to emissions generated at wastewater collecting and discharging points. Indirect greenhouse gas emissions result from the consumption of electricity, the use and transfer of chemicals, sludge handling and stabilisation processes. Total GHG emissions are the sum of direct and indirect emissions (Parravicini et al., 2016; Masuda et al., 2015).

Greenhouse gases of concern from wastewater treatment plants are:
- carbon dioxide (CO_2),
- methane (CH_4),
- nitrous oxide (N_2O) (Shahabadi et al., 2009).

CO_2 emissions are linked to two major drivers: the treatment process and electricity consumption. In the anaerobic treatment process, BOD_5 from wastewater is embedded in biomass or transformed into CO_2 and CH_4. Part of the biomass is transformed into CO_2 and

CH_4 by endogenous respiration. Additional CO_2 emissions are from sludge digesters and digester gas flaring. During the aerobic phase, carbon dioxide is generated by the decomposition of organic matter in the activated sludge phase and, in part, by primary clarifiers (Taşeli, 2017).

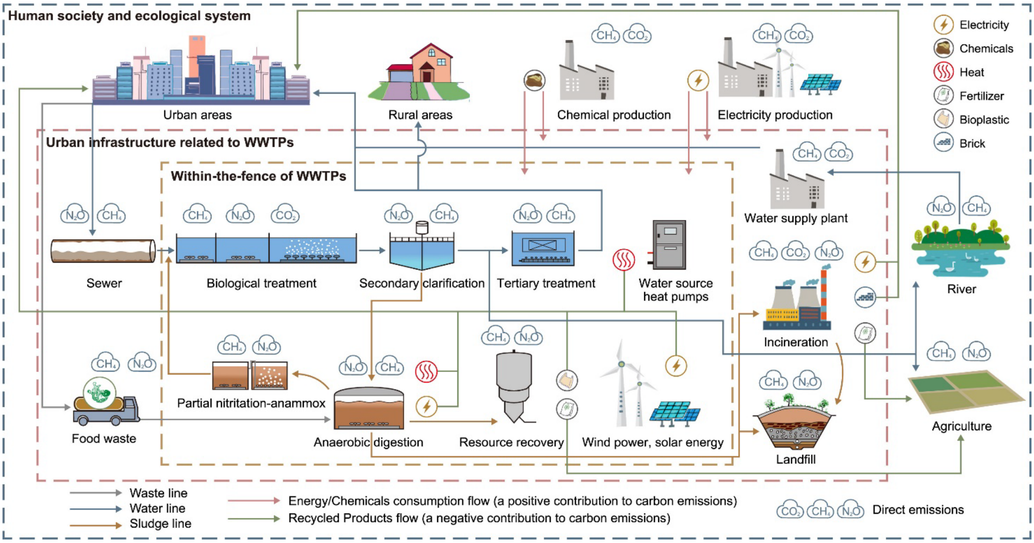

Figure 3. Carbon accounting in wastewater treatment
(Lanqing et al., 2022)

Wastewater together with sludge constituents are capable of generating CH_4 if they degrade in an anaerobic manner. About 72% of these CH_4 emissions occur in the anaerobically digested sludge line (Campos et al., 2016). According to Gupta & Singh (2015), the amount of CH_4 production depends in the first place on the type of treatment system, the amount of degradable organic matter and the temperature of wastewater. As the temperature rises, so the rate of CH_4 generation increases. This is especially important in non-controlled systems and a warmer climate.

N_2O is linked to the nitrogen constituent's degradation in wastewater (proteins, nitrates and urea). Household wastewater comprises human wastewater combined with other domestic wastewater, possibly containing effluent from washing machines, sinks, shower drains, etc. Wastewater treatment facilities can incorporate a variety of technologies, starting with lagoons to tertiary treatment technologies to remove nitrogen constituents. Once processed, the effluent treated usually is released into receiving water. Nitrous oxide generation is related to biological nitrogen removal from wastewater, as it is a by-product of both nitrification and denitrification processes (Wu et al., 2009; Fighir et al., 2019). Because water and other resources are withdrawn for reuse from wastewater, these operations generate costs associated with energy consumption and greenhouse gas emissions. There is no other part of water infrastructure that is considered to be more energy intensive per unit of treated water than wastewater recovery, and it is the sector with the greatest capacity to become carbon neutral. Carbon footprint may be reduced to a minimum through energy and chemical inputs into treatment processes and maximising wastewater energy generation through carbon and heat capture (Pagilla, 2022).

The embedded carbon or embodied carbon footprint of WWTPs includes the total amount of greenhouse gas emissions from their construction, maintenance and disposal (Nayeb et al., 2019).

At a basic scale, the energy contained in wastewater and its extraction in a utilizable form creates possibilities for reductions in the carbon footprint of WWTPs. Inputs of energy for treatment represent costs that contribute to the carbon footprint. Maximising opportunities and minimising inputs by optimisation are the formula for achieving net zero carbon in WWTPs (Pagilla, 2022).

Net zero refers to the balance between the quantity of greenhouse gases produced by a company and the quantity removed from the atmosphere through mitigation measures. Net zero is reached when the amount we add will not be greater than the amount removed.

Improvements in urban wastewater treatment have been made since the 1990s. These have led to the prevention of significant methane emissions due to efficient and centralised wastewater collection and treatment (EC, 2020). As a result, emissions have steadily decreased reaching 17,351 kt CO_2 equivalent (CO_2e) in 2019. This reduction is seen only in CH_4 emissions, which have fallen by more than half from 1989. Nitrous oxide emissions decreased very slightly from 2000, to 6,100 kt CO_2e per year (EEA, 2023b). The fossil fuel use for electricity generation and for drying and transportting sewage sludge represent indirect emissions from UWWTPs (Zheng & Ma, 2019).

Greenhouse gas emissions from wastewater treatment may be minimised in a number of ways, starting with optimising operation and ending with modifications to the plant.

In European countries, improvements have been made to sanitation systems in recent years. Today, municipal wastewater is treated at the tertiary level in most EU countries. Still, there are countries where less than 80% of the population is connected to public municipal wastewater treatment systems (EEA, 2022). Countries with high percentages of population hooked up to wastewater treatment plants are Luxembourg, Netherlands, Malta, with Croatia and Romania at the opposite end (Smol, 2023).

Different tools have been developed in order to identify and reduce GHG emissions from WWTPs.

A first tool is called the *Energy Performance and Carbon Emissions Assessment and Monitoring* (ECAM), which is an open-source software. This tool has been developed to collect essential information for energy performances of installations at operational level within a WWTP, with main purpose to identifying critical areas for GHG emission reduction, for increasing energy savings where possible, and improving the overall efficiencies for costs reduction. This tool can be applied and useful for all key stakeholders involved in the water and wastewater sector, for service management and planning regarding GHG emission and energy performance assessments and resulting suitable and operative perspectives for limitation of the overall carbon dioxide emissions (http://wacclim.org/ecam/v1/).

Another tool for calculating the carbon footprint for wastewater treatment plants has been developed in the project "Calculation of the carbon footprint from Swedish wastewater treatment plants" (SVU 12-120). This tool is an Excel file, containing 13 sheets, in each sheet different data and information are saved and calculated, grouped on different categories, such as:

- Group 1: input data (important information regarding the process within the selected WWTP, chemicals used, energy data, information on basic transports of the sludge, destination routes, resulted waste, etc.)
- Group 2: represents results of the simulation and calculations;
- Group 3: emission factors for electricity production, heat production, biogas use, etc. Global Warming Potentials (GWP) and different conversion factors, as well as constants used for the calculation; and the last group is
- Group 4: includes appropriate references and input data for the use of the tool.

It is a complex tool offering interesting and solid results for the carbon footprint of a WWTP.

Urban wastewater production and treatment in Romania

In households and certain industries in Romania, 20.0 million p.e. of wastewater are generated every day. This amount of wastewater is treated in 642 plants before being discharged. Thus, depending on the type of treatment applied there are 434 biological treatment plants, 174 biological treatment plants with nitrogen and phosphorus removal and 34 primary treatment plants.

Only 12% of urban wastewater in Romania is treated in accordance with UWWTD requirements and this is well below the EU average of 76% (Figure 4).

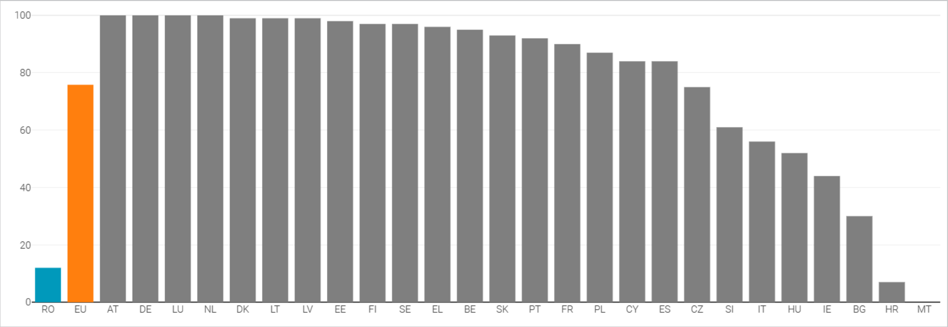

Figure 4. The proportion of urban wastewater that meets all requirements of the UWWTD [Romania (europa.eu)]

According to the latest report by the specialists of the National Administration "Romanian Waters" on the "Status of urban wastewater treatment works and capacities in execution and put into operation for human agglomerations in 2020", a level of connection to collection systems (sewerage networks and appropriate individual systems) of 66.15% and to treatment systems (treatment plants and appropriate individual systems) of 63.58% was assessed for urban agglomerations with more than 2,000 inhabitants equivalent.

The annual production of wastewater sludge in Romania was over 247,760 tons in 2018. Based on data reported up to 2018, Figure 5 shows a significant range in the uses of sewage sludge: 53.5% were landfilled, 18.7% of sewage sludge was used in agriculture, 0.3% was incinerated, and 27.5% was disposed of in other ways (EEA, 2023a).

According to EEA greenhouse gases - data viewer (2023b), emissions of greenhouse gases by the urban wastewater treatment sector in Romania have decreased by 25.9% between 2010 and 2019 (Figure 6).

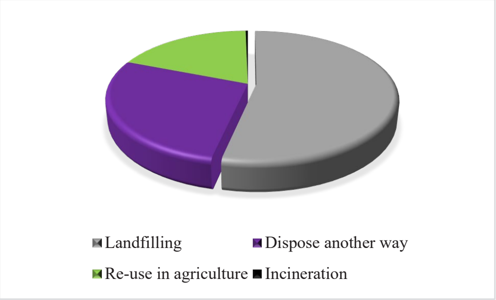

Figure 5. The proportion of wastewater sludge from treatment plants reused or disposed (EEA, 2023a)

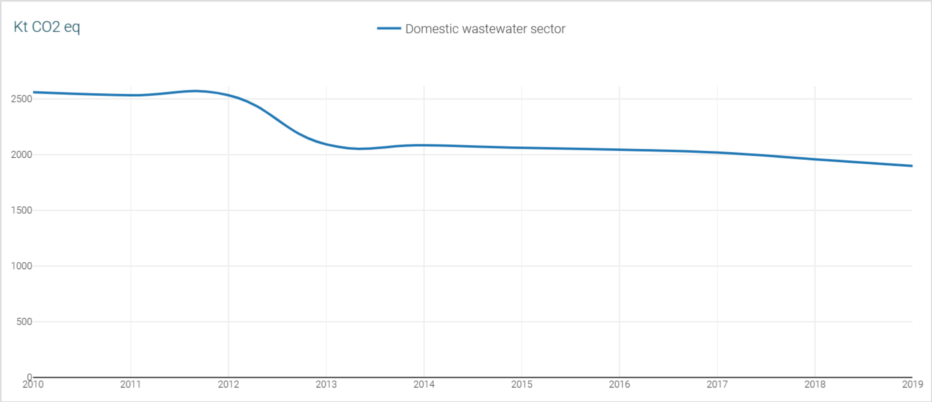

Figure 6. Greenhouse gases emissions generated by the urban wastewater treatment sector in Romania (EEA greenhouse gases - data viewer, 2023)

CONCLUSIONS

In 2021, 36 billion tons of carbon dioxide were emitted globally. As the amount of carbon dioxide increases, the planet continues to warm. Thus, devastating effects such as increased flooding, extreme heat, drought and worsening forest fires are increasingly being felt by millions of people around the world. In 2020, Romania emitted 71.48 million tons of CO_2, according to Our World in Data (*Romania: CO2 Country Profile - Our World in Data*). The figure represents 0.21% of the total issued globally. In the same year, Romania registered 3.72 metric tons of CO_2 emitted per capita. CO_2 emissions from industrial processes in Romania are relatively high, even if they decreased by 64% between 1989 and 2011, due to the reduction of industrial activity after the communist period. In the same interval, transport emissions (17% of the total) increased by 67%, exceeding a 55% increase in greenhouse gas emissions, according to Climate Analytics (*Romania - 1.5ºC Pathways for Europe: Achieving the highest plausible climate ambition - Oct 2021 (climateanalytics.org)*). Romania has ratified and transposed into national legislation two of the most important international treaties regarding climate change: the United Nations Framework Convention on Climate Change and the Kyoto/Japan Protocol. In order to achieve the goal of the Paris Agreement (*The Paris Agreement | UNFCCC*), the EU is working to achieve "net zero" emissions by 2050. The goal of the agreement is to limit global warming to less than 1.5 degrees Celsius compared to pre-industrial levels. The Earth is already approaching this value, with temperatures already reaching the threshold of 1 degree Celsius.

Regarding the necessary measures to achieve the goal of "net zero" by 2050, the European Commission recommended that Romania increase the level of ambition for 2030. Among these necessary new measures is a plan to decarbonize the environment by increasing the share of energy from renewable sources by at least 34%.

Wastewater treatment plants have the capacity to generate valuable water resources, energy, and new secondary raw materials, which can be utilized across various sectors such as municipalities, industries, and agriculture. In a world where the demand for fresh water is continuously increasing, and existing water resources face growing pressures from over-extraction, pollution, and climate change, it would be imprudent to overlook the opportunities that arise from improved wastewater management. Successful resource recovery from wastewater contributes to the principles of the circular economy and fosters long-term sustainable development. However, achieving a shift from merely removing pollutants to actively recovering resources necessitates a paradigm shift. Resource recovery should be a strategic objective incorporated into the earliest planning stages of new investments whenever feasible. Recent developments in EU regulations indicate an increasing support for resource recovery and a growing momentum for change, although a comprehensive approach has yet to be fully embraced.

Wastewater treatment plants, which consume significant amounts of energy and produce high carbon emissions, have the potential to transition into substantial energy producers and generators of recycled organic and metallic materials. This transformation can effectively contribute to broader sustainable development objectives, the circular economy, and the interconnected systems of water, energy, sanitation, food, and carbon.

The WWTPs plant operations and process optimization role is essential not just to meet water requirements and plant quality goals, but also to achieve resource and sustainability recovery goals or outcomes. The carbon footprint for an existing plant is the operational activities and therefore the potential to achieve net zero carbon.

Understanding the carbon footprint of WWTPs is essential to comprehending their environmental impact. Through quantification of emissions, plants can identify areas for improvement and implement specific strategies to reduce their carbon footprint.

ACKNOWLEDGEMENTS

This paper was carried out with the financial support of University of Agronomic Sciences and Veterinary Medicine of Bucharest – Romania, Research Project 1059/15.06.2022, acronym HybridPraxisLab in the competition IPC 2022.

REFERENCES

Campos, J.L., Valenzuela-Heredia, D., Pedrouso, A., Val del Rio, A., Belmonte, M., Mosquera-Corral, A. (2016). Greenhouse Gases Emissions from Wastewater Treatment Plants: Minimization, Treatment, and Prevention. *J. Chem., 2016*, 1–12.

EC (2020). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on an EU strategy to reduce methane emissions.https://ec.europa.eu/energy/sites/ener/files/eu_methane_strategy.pdf

European Environment Agency - EEA (2022). Beyond Water Quality-Sewage Treatment in a Circular Economy. ISBN 9789294804785, ISSN 1977-8449, doi:10.2800/897113

European Environment Agency - EEA (2023a). Waterbase - UWWTD: Urban Waste Water Treatment Directive - reported data https://www.eea.europa.eu/en/datahub/datahubitem-view/6244937d-1c2c-47f5-bdf1-33ca01ff1715.

European Environment Agency - EEA (2023b). EEA greenhouse gases - data viewer. https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer.

Fighir, D., Teodosiu, C., Fiore, S. (2019). Environmental and Energy Assessment of Municipal Wastewater Treatment Plants in Italy and Romania: A Comparative Study. *Water, 11*(8), 1611. https://doi.org/10.3390/w11081611

Gupta, D. &Singh, S.K. (2015). Energy use and greenhouse gas emissions from wastewater treatment plants. *International Journal of Environmental Engineering, 7*(1), 1–10.

IPCC (2014). Climate change 2014: mitigation of climate change. summary for policymakers and technical summary.

Lanqing Li, Xiuheng Wang, Jingyu Miao, Aliya Abulimiti, Xinsheng Jing, Nanqi Ren, (2022). Carbon neutrality of wastewater treatment - A systematic concept beyond the plant boundary, *Environmental Science and Ecotechnology, 11*, https://doi.org/10.1016/j.ese.2022.100180.

Larsen, T.A. (2015). CO_2 neutral wastewater treatment plants or robust, climate friendly wastewater management? A system perspective. *Water Res., 87*, 513–521.

Masuda, S., Suzuki, S., Sano, I. (2015). The seasonal variation of emission of greenhouse gases from a full-scale sewage treatment plant. *Chemosphere, 140*, 167–173.
https://doi.org/10.1016/j.chemosphere.2014.09.042.

Nayeb, H., Mirabi, M., Motiee, H., Alighardashi, A., Khoshgard, A. (2019). Estimating greenhouse gas emissions from Iran's domestic wastewater sector and modeling the emission scenarios by 2030. *Journal of Cleaner Production, 236*, 2019.

Pagilla, K.R. (2022). Book chapter. Pathways to Water Sector Decarbonization, Carbon Capture and Utilization. *Chapter 4: Operational optimization and control strategies for decarbonization in WRRFs*. IWA Publishing. doi: https://doi.org/10.2166/9781789061796_0051

Parravicini, V., Svardal, K., Krampe, J. (2016). Greenhouse gas emissions from wastewater treatment plants. *Energy Procedia, 97*, 246–253. https://doi.org/10.1016/j.egypro.2016.10.067.

Romania (europa.eu)

Sandu, M.A. & Virsta, A. (2021). The water footprint in context of circular economy. *AgroLife Scientific Journal, 10*(2), 170-177.

Shahabadi, M.B., Yerushalmi, L., Haghighat, F. (2009). Impact of process design on greenhouse gas (GHG) generation by wastewater treatment plants. *Water Res., 43*(10), 2679–2687.

Shao, S., Mu, H., Yang, F., Zhang, Y., Li, J. (2019). Application of energy analysis to the sustainability evaluation of municipal wastewater treatment plants. *Sustainability, 9*, 8.

Smol, M. (2023). Circular Economy in Wastewater Treatment Plant-*Water, Energy and Raw Materials Recovery. Energies, 16,* 3911. https://doi.org/10.3390/en16093911.

Sweetapple, C., Fu, G., Butler, D. (2014). Identifying sensitive sources and key control handles for the reduction of greenhouse gas emissions from wastewater treatment. *Water Res., 62*, 249–259.

Taşeli, B.K. (2017). Point source pollution and climate change impact from sequential batch reactor wastewater treatment plant. *Global NEST Journal, 20*(1), 33–41.

UNFCCC https://unfccc.int/process-and-meetings/the-paris-agreement

Wu, J., Zhang, J., Jia, W., Xie, H., Gu, R., Li, C., Gao, B. (2009). Impact of COD/N on Nitrous Oxide Emission from Microcosm Wetlands and Their Performance in Removing Nitrogen from Wastewater. *Bioresour. Technol., 100*, 2910–2917.

Zheng, M., & Ma, Y. (2019). *Energy use and challenges in current wastewater treatment plants*. A-B Processes: Towards Energy Self-sufficient Municipal Wastewater Treatment, IWA Publishing https://doi.org/10.2166/97817890 60089_0001.

http://wacclim.org/ecam/v1/.

https://climateanalytics.org/media/romania.pdf

https://ourworldindata.org/co2/country/romania#per-capita-how-much-co2-does-the-average-person-emit

https://rowater.ro/wp-content/uploads/2022/09/Stadiul-implementarii-Directivei-ape-uzate-in-anul-2019.pdf - "Status of urban wastewater treatment works and capacities in execution and put into operation for human agglomerations in 2020".