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PERSPECTIVE MOVING TOWARDS THE IMPLEMENTATION OF CIRCULAR ECONOMY IN THE WASTEWATER SECTOR: THE CASE STUDY OF LATVIA

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Abstract
The transformation from a linear to a circular economy model is a political priority of the European Union to develop sustainable and more efficient raw materials and waste management. The wastewater sector is an important element in the circular economy with a great potential for resource recovery such as phosphorus recovery from waste streams. With this in view, the present study's aim was to analyse data on municipal wastewater treatment plants (>2,000 p.e.) in Latvia and the present situation with newly developed circularity indicators on waste reduction, pollutants removal, resource recovery and water reuse; thus, enabling evaluation of the level of transformation towards circularity in Latvia's wastewater treatment plants and their future perspectives. The results showed that the wastewater sector in the country complies with legal obligations, but on the other hand, only a few solutions are practised in compliance with the principles of circular economy, i.e., reduction of wastewater discharge and increasing sewage sludge utilization as fertilizer in agriculture.
Key words: circular economy, wastewater treatment, sewage sludge, nutrients, phosphorus, Latvia.

Introduction

The transition to a circular economy (CE) is a political priority of the European Union (EU) to develop a low-carbon, resource-efficient, sustainable, and competitive economy (Mazur-Wierzbicka, 2021). The CE concept was adopted in 2014 in the first European Commission (EC) communication 'Towards a circular economy: a zero waste programme for Europe'. In 2015, the first CE action plan 'Closing the loop-an EU Action Plan for the Circular Economy' was adopted, including measures and legal requirements to accelerate the transition towards a circular economy (Mazur-Wierzbicka, 2021). In the action plan, a detailed definition of CE was also introduced: 'an economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized' (European Commission, 2015). In 2020, EC adopted 'A New Circular Economy Action Plan. For a Cleaner and More Competitive Europe' which is one of the main building blocks of the European Green Deal. In the second action plan, the importance of the water and wastewater sector in the transition toward CE is highlighted especially in the field of water reuse and recovery of nutrients (European Commission, 2020a; Smol *et al*., 2022).

Water and wastewater management is one of the biggest challenges in CE. Predominantly, the water management sector faces difficulties in implementing the conditions of the Water Framework Directive (2000/60/EC) on how to achieve effective optimisation of wastewater treatment plants to prevent insufficiently treated wastewater discharge into natural streams (Wuijts *et al*., 2023), as well as water scarcity, which affects regions located in the Southeast and Southwest of Europe in particular. Although the risk of water scarcity is not generally forecasted for the Latvian region (Garrote *et al*., 2018), the rapidly increasing effects of climate change indicate that the Latvian region is increasingly predisposed to the risk of seasonal water scarcity in the period from July to September (European Environment Agency, 2023). On the other hand, the effects of climate change pose a threat to urban wastewater management as the stormwater from heavy rainfalls results in overloading of wastewater treatment plants (WWTP) or even causes stormwater overflows and discharge of untreated sewage into the environment. For instance, in Latvia from 2017–2019 regular sewage overflows occurred in at least 7 out of 49 overflow sites of WWTP (> 10,000 p.e.) (The State Environmental Service, 2020). It is considered to be one of the most pressing problems of the water management sector, as its mitigation requires large financial investments (Quaranta, *et al*., 2022). Moreover, sustainable management of solid waste is becoming an increasingly topical issue relevant to the governance of water management, striving towards a circular economy. The management of sludge generated in the water purification process is also included in the agenda of Latvian policymaking. The National Waste Management Plan states that it is essential to establish good infrastructure in the existing landfills for the processing of biodegradable waste in combination with sludge from domestic wastewater treatment plants (Cabinet of Ministers, 2021a). At the same time, there is no integrated and holistic approach to sludge management in Latvia, one of the shortcomings being the lack of a national strategy for wastewater sludge management (Geo Consultants, 2020). However, Latvia's National Energy and Climate Plan foresees that environmentally and economically sustainable solutions for sewage sludge management will be applied in Latvia by 2030 – wastewater management infrastructure will be modernised and expanded, reducing the risks of environmental pollution, and preventing the accumulation of sludge in water management companies (Cabinet of Ministers, 2021b).

In order to evaluate the current situation regarding the transformation towards the CE model in the water and wastewater sector, a new CE framework monitoring is developed. Based on existing 'xR' models in waste management, the EU waste hierarchy (European Parliament, 2008) and comprehensive literature analysis, Smol, Adam & Preisner (2020) introduce six following actions to implement CE principles in the water and wastewater sector: reduce, remove, reuse, recycle, recover and rethink. 'Rethink' can be applied to all other actions in the CE model (Figure 1).

Figure 1. Circular economy model framework in the water and wastewater sector (based on Smol *et al.*, 2022).

One of the most frequently applied CE principles in the water management sector is the reuse of water from both treated wastewater and collected stormwater. Good practices cover various solutions in any water use cycle, starting from harmonised water minimum use to a site-based approach for treated wastewater use in agriculture irrigation systems, energy or industrial use like technical water, and effluent discharge in constructed wetlands (Voulvoulis, 2018). As a result, a reduction of the impact of the forecasted water stress and scarcity that will affect half of Europe's river basins by 2030 is expected (European Commission, 2012).

Furthermore, the wastewater sector has been identified to have high potential in terms of nutrient recovery due to the significant amount of phosphorus (P) and nitrogen (N) concentration in all municipal WWTPs (Preisner *et al.*, 2022). For example, numerous pilot and full-scale techniques for P recovery can be integrated into one of three stages of the wastewater treatment process: 1) P recovery from direct agricultural utilization of dewatered sludge; 2) P recovery from undrained sludge after anaerobic digestion, e.g., AirPrex, Seaborne or recovery from sludge liquor after dewatering, e.g., Anphos, Ostara Pearl, Struvia; 3) P recovery from ash after incineration, e.g., AshDec, EcoPhos (Schoumans *et al.*, 2015; Chrispim, Scholz, & Nolasco, 2019). Recovery of P via wastewater can decrease imported P lost as waste to 55% (Jupp *et al.*, 2021) solving two dovetailing problems: 1) the risk of phosphorus shortage as it is a critical raw material (European Commission, 2020b), 2) the overabundance of P in water systems leading to eutrophication (Smol *et al.*, 2020).

This article presents the results of a study aimed at assessing the circularity of the wastewater sector in Latvia using the novel CE model framework proposed by Smol, Adam & Preisner (2020) as well as analyzing the potential for further development.

Materials and Methods

The indicators used to evaluate the transition of the wastewater sector in Latvia to a CE were based on Smol, Adam & Preisner (2020), Preisner *et al.* (2022) and Kruopienė & Žiukaitė (2022) scientific publications where indicators are identified and summarized through a detailed literature review. In this work, 8 indicators were used, covering four actions to implement CE principles (Table 1).

The current situation was evaluated by analyzing data spanning from 2009 to 2021. Data were collected

Table 1

Indicators used in this work to evaluate the transition towards CE in the wastewater sector

No.	Indicators	CE model actions
1	Water consumption and wastewater discharge	Reduce
2	Wastewater service coverage	
3	Nutrient removal efficiency	Remove
4	Effluent inorganic content	
5	Pollutant content indicator for the recovered sewage sludge	
6	Reuse of water for industrial and non-potable applications	Reuse
7	Sewage sludge processing	Recover
8	Biogas production	

on municipal WWTPs in agglomerations where more than 2,000 p.e. of wastewater is generated. In 2019, there were 74 such agglomerations, while in 2021 only 56. Information necessary for computing and evaluating the indicators was obtained from various sources including the ‘Latvian Environment, Geology and Meteorology Centre’ (LEGMC) database, EC reports, feasibility studies, river basin management plans and LIFE GoodWater IP project’s assessments results of the current situation in Latvia regarding the sewage sludge.

Results and Discussion

1. Reduction

It is necessary to integrate the principle of prevention in reducing pollution by enabling the reuse of both purified wastewater and products formed in the purification process as sewage sludge (Mazur-Wierzbicka, 2021). The prevention and reduction principle starts with sewage inclusion into the treatment processes (Voulvoulis, 2018). The number of wastewater treatment facilities in Latvia is increasing, for instance, in 2019, 1,301 wastewater treatment facilities were registered in the LEGMC database. Of these, 302 treatment plants were operating with primary treatment (mechanical WWTP), 936 with secondary treatment (biological WWTP), and 31 with biogenic reduction (WWTP with tertiary treatment in addition to N, P reduction) (State statistics report, 2022). While the total annual amount of wastewater to be treated in Latvia fluctuates, 99% of sewage is treated in line with EU legislation. In addition, 99% of urban wastewater meets all requirements of the Urban Wastewater Treatment Directive (91/271/EEC) (UWWTD) (Water Information System for Europe 2020), instead of 98% of urban wastewater collected and 75.8% satisfactorily treated on average in the EU (European Economic and Social Committee, 2023).

1.1. Water Consumption and Wastewater Discharge. 2009–2021 the total volume of discharged wastewater in Latvia has slightly decreased from 186,9 up to 176,6 million m^3 per year. A significant part of the total volume is carried out by the Riga wastewater district treatment facilities. For instance, in 2020, the total volume in Riga was 52.04 million m^3, which is 27% of the total volume of wastewater discharged into the environment in Latvia (State statistics report, 2022). From the proportion of urban wastewater collected and treated as a percentage of the total population, 62% of sewage is treated with stringent ‘tertiary’ treatment, mainly to reduce nutrients (European Environment Agency, 2020). Changes in lifestyles, improving the standard of living as well as climate change impacts significantly increased water consumption during recent years both in absolute terms and per capita (Garrote *et al.*, 2018). In Latvia, annual water uses at a household level increased from 80.68 million m^3 in 2010 to 96.30 million m^3 in 2019 (Eurostat, 2022a).

1.2. Wastewater Service Coverage. The share of the Latvian population connected to at least secondary urban wastewater treatment has increased significantly from 58.9% in 2010 to 80.4% in 2020. In the period from 2002 to 2010, the increase was less progressive - from 51.1% to 58.9%. Among the Baltic countries, Estonia has the highest coverage with urban wastewater treatment – 83% of the population in 2020, but Lithuania has the lowest – 77% (Eurostat, 2022a). Access to centralised wastewater collection systems in Latvia by agglomeration division is different. Only two cities – Riga and Daugavpils - correspond to agglomeration with >100,000 p.e. In Riga, access to centralised systems was 95.1%, while in Daugavpils it was 90.9% of inhabitants in 2019. In the division from 10,000 to 100,000 p.e. accessibility was for 95% of inhabitants, and around 62,000 inhabitants have decentralised wastewater systems in 2019. In agglomerations from 2,000 to 10,000 p.e. access was 82%, which is 16% lower than in UWWTD stated, and around 49,000 inhabitants were decentralised wastewater systems in 2019 (Ismade, 2020). The coverage of household water use from public water supply per inhabitant in Latvia has a slight decrease from 37.8% in 2005 to 37.6% in 2020. For Lithuania, the data show a more rapid increase from 19% to 27.4%, but still holding a lower position in 2020 than in Latvia. Data about Estonian household water use from the public water supply is not available (Eurostat, 2022a). Latvia has gradually enhanced the coverage of centralized wastewater systems. However, there is still work to be done on UWWTD goal achievement.

2. Removal

2.1. Nutrient Removal Efficiency. The entire territory of Latvia is defined as a highly sensitive territory, which is subject to higher requirements for municipal wastewater treatment. Such requirements are followed because the eutrophication levels of the inland waters of Latvia and the Baltic Sea are one of the most urgent environmental problems. To address this issue, in Latvia's largest cities, it is crucial to treat collected wastewater and reduce the pollution of N and P. In 2019, from all 1,301 WWTPs (including those in agglomerations <2,000 p.e.) 58 facilities discharged insufficiently treated wastewater into various water bodies in Latvia, thereby significantly worsening the water quality of rivers and lakes. This type of situation arises because the largest number of WWTP in Latvia is located in small agglomerations but enhanced N, P reduction is required only for urban areas where p.e. is more than 10,000 (Water Information System for Europe, 2020; The State Environmental Service, 2022).

2.2. Effluent Inorganic Content. Elevated levels of nutrients in water bodies are a key factor in causing eutrophication, a global issue that causes harmful algal blooms, hypoxia, and degradation of freshwater ecosystems (Smol *et al.*, 2022). Since 2009, the discharge of nutrients into the environment via treated wastewater has fluctuated, but decreasing trends have been evident, particularly since 2011. Analyzing the amount of pollution discharged into the environment, the total amount of N and P concentration from 2015 has decreased annually (Figure 2).

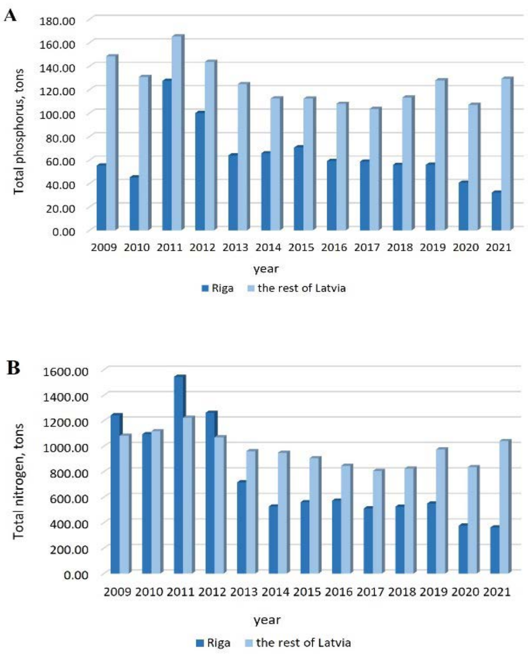

Figure 2. Total phosphorus (A) and total nitrogen (B) discharged with wastewater per year (LEGMC, S.a).

The implementation of Directive 91/271/EEC has led to significant reductions in N and P emissions. However, urban WWTPs are still a significant contributor of these pollutants to the environment (Water Information System for Europe, 2020). Technological advancements and best practices have shown that the current emission limit values set under the directive are outdated and need to be strengthened. To address this, tertiary treatment should be mandatory for all urban wastewater treatment plants with a capacity of 100,000 p.e. or more as they are a significant source of N and P discharge (European Commission, 2022a). The capital of Latvia (Riga) discharges the largest amount of wastewater, resulting in the highest residual N and P pollution being released (LEGMC, S.a). Similarly, in Lithuania, most of the discharge is largely determined by the largest WWTP.

If this plant were excluded, the percentage of N and P in total discharge would be reduced to 54–56% and 40–42%, respectively (Kruopienė & Žiukaitė, 2022).

2.3. Pollutant Content Indicator for the Recovered Sewage Sludge. In Latvia, the possibility of using sludge is affected by the quality class of sewage sludge, which determines the allowable concentration values of heavy metals, the presence of microbiological pathogens and agrochemical parameters by distinguishing five quality classes of sewage sludge (Cabinet of Ministers, 2006; Dejus *et al.*, 2021a). Heavy metal pollution in sewage sludge in Latvia mostly corresponds to Class 1 – the highest quality. In the study of the analysis of sewage sludge, digestate and compost samples carried out as part of the LIFE GoodWater IP project, only one case was found when the concentration of heavy metals exceeded Class 2 (the concentration of nickel and chromium in the sludge), which is most likely related to the uncontrolled discharge of production wastewater into the central sewage system (Dejus *et al*., 2021b).

3. Reuse

It is known that out of 40,000 million m^3 of treated wastewater in the EU, only 964 million m^3 is reused (European Commission, 2022a). Within the Interreg Europe programme AQUARES project, it was determined that the most socio-economically beneficial solutions for water reuse in Latvia should concern management and sustainable use of stormwater. Such good practice examples have also been implemented in Latvia – Bioswale at the shopping centre Spice Home parking lot, and Tukums District Branch of the State JSC 'Latvian Road laying Maintenance' in Kandava, where stormwater was used for car washing and sand reused for road coverage in the winter season, creating company savings on drinking water in the amount of EUR 4089 in six years. Increasingly, solutions relating to rainwater management are more frequent in Latvia with the aim of relieving the burden on centralized wastewater systems. Another good example is Evopipes, a company that reuses water multiple times in the cooling process of the production of plastic pipes, thus reducing the total amount of water used (Interreg Europe, 2020).

4. Recovery

4.1. Sewage Sludge Processing. In Latvia, the production of sludge is growing rapidly – in 2017 WWTPs produced 22,995 t, in 2018 – 23 145 t, and in 2019 – 22,530 t of dry matter of sewage sludge, while theoretical calculations indicate that extent could be even 13–19% higher (Dejus *et al*., 2021b). Latvia's sewage sludge production (dry matter) per inhabitant was 16.5 kg, compared to 22.50 kg on average in the EU (Bianchini *et al*., 2016). 40% of total sewage sludge is generated by WWTP in Riga, which is the largest facility in Latvia and treats about half of the total volume of centrally treated wastewater.

Sludge management solutions have changed significantly over the last decade (2010–2020). The main utilization methods of sewage sludge in Latvia are related to agricultural use, composting and temporary storage (Table 2). Still, a high amount of sludge – 3,600-10,600t – is in temporary storage. Nevertheless, the amount of sludge in temporary storage tends to decrease from 34% to 47% of the total amount in 2010–2014 to 16–22% of the total amount in 2018–2020 (Dejus *et al*., 2021b). In 2018, peak composting proportion was reached, with 36% of the total amount of sludge, but in recent years, a trend of reduction of composted sludge has been observed in Latvia: 23% in 2019, and 20% in 2020. On the other hand, starting from 2018, the proportion of treated sludge in agriculture has been increasing, reaching 28% of the total amount of sludge in 2020. Taking into account that both the compost, in the preparation of which sewage sludge is used, and digestate from biogas production are mainly used in agriculture, it can be considered that the main purpose of utilisation of sewage sludge in Latvia is for field fertilisation in agriculture (Dejus *et al*., 2021b; Eurostat, 2022b).

Table 2

Sludge generation and processing from WWTP in agglomerations > 2,000 p.e. (based on Eurostat, 2022b)

Year	Total	Agricultural use		Compost		Incineration		Landfill	
	Mg $Year^{-1}$	Mg $Year^{-1}$	%	Mg $Year^{-1}$	%	Mg $Year^{-1}$	%	Mg $Year^{-1}$	%
2016	25.92	4.25	16.39	7.71	29.7	0	0	0.15	0.57
2017	24.94	3.32	13.31	5.72	22.93	0	0	0.02	0.49
2018	24.59	4.29	17.44	8.84	35.94	0.98	3.98	0.07	0.28
2019	24.17	6.23	25.77	5.49	22.71	0	0	0	0
2020	23.15	6.46	27.9	4.66	20.12	1.57	6.78	0.73	3.15

Similarly, in neighbouring countries sludge is also significantly used in agriculture and compost, e.g., in Lithuania 30% for agriculture and 21% for compost in 2020 (Kruopienė & Žiukaitė, 2022).

4.2. Biogas Production. Currently, biogas production from sewage sludge is one of the potential future perspectives worldwide, which can reduce the use of fossil natural gas. Biogas can be produced via anaerobic digestion from municipal waste, sewage sludge and animal waste rich in organic matter (Makisha & Semenova, 2018). In 2020, there were 49 operating biogas power plants owned by agricultural organizations in Latvia with a total capacity of 56,636 MWe. According to the data provided by the Latvian Biogas Association, there is currently one biogas plant in the country which operates using only sludge (WWTP 'Daugavgriva'). Two plants use food production residues and/or sewage sludge, while the other biogas plants mix sewage sludge with biomass from the agricultural sector (Dejus *et al.*, 2021c).

In Latvia, one of the challenges regarding sludge usage in biogas plants is the price of biogas which is higher than for other energy resources, incl. fossil fuel, so the maintenance of its market requires subsidy-type support, about which there is currently no clarity, and it is possible that its payment can be terminated, thus endangering the future availability of existing infrastructure and the long-term stability of sewage sludge treatment, recycling and utilization (Dejus *et al.*, 2021b).

Conclusions

The data analysis, which aimed to evaluate the circularity and perspective of the wastewater sector in Latvia, indicated the main achievements and challenges that should be focused on in the further development of this sector. The results revealed that:

1) During the last decade, the total volume of discharged wastewater in Latvia has slightly decreased from 186,9 up to 176,6 million m^3 per year. In addition, water consumption is not currently a concern as it is among the lowest in the EU.
2) Removal efficiency of nutrients in wastewater increases every year, thus preventing eutrophication in surface waters and the Baltic Sea.
3) There is no reuse and recycling of wastewater in Latvia mainly due to the availability of sufficient water resources. Nevertheless, there are good practice examples of stormwater, process, and cooling water reuse in the country.
4) With an upward trend the main solutions for sewage sludge utilization are field fertilization in agriculture (28%) and composting (20%) while a still large amount of sludge is placed in temporary storage.

In order to accelerate circularity in the wastewater sector in Latvia and other EU countries, firstly change in the policy documents would be necessary starting with Urban Waste Water Treatment Directive (UWWTD). EC is already planning significant and necessary changes in UWWTD: 1) to expand the scope of the Directive to cover all urban agglomerations above 1,000 p.e. (in Latvia incl. more than 70 WWTP); 2) to further and set a more strict limit for nutrient releases; 3) treatment of N and P will be applied to all larger facilities also above 10,000 p.e. as well as 4) stricter changes to be set in the settlement of decentralized wastewater facilities (European Commission, 2022b).

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