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MUNICIPAL WASTEWATER TREATMENT PLANT AS A KEY COMPONENT OF THE CIRCULAR ECONOMY

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Purpose: The objective of this paper is to provide a comprehensive overview of the circular economy (CE) concept and to demonstrate, through a practical case study, the multi-level applicability of the 6R principles at the municipal wastewater treatment plant in Zabrze.
Methodology: The research was based on a systematic literature review and content analysis.
Findings: The article conceptualizes the municipal wastewater treatment plant as a pivotal component of the circular economy (CE) and illustrates the potential for its multi-level implementation. The case study demonstrates practical applications of CE principles, including sand recovery, sludge reuse, biogas production, photovoltaic energy generation, heat pumps, and water reuse. Together, these processes underscore the capacity of wastewater treatment facilities to function not only as infrastructure for environmental protection but also as active contributors to resource efficiency and energy recovery.
Practical Implications: The study positions a municipal wastewater treatment plant as an essential element of the circular economy. It illustrates the implementation of the 6R principles across different stages of wastewater treatment — from mechanical treatment (sand recovery), through sludge management and biogas generation, to the integration of renewable energy sources and water reuse. The findings emphasize that, when appropriately organized, these practices not only enhance environmental performance but also demonstrate economic feasibility.
Social implications: Against the backdrop of global climate change and diminishing natural resources, the circular economy emerges as a crucial instrument for sustainable development. Its core principle is the minimization of waste through reuse, recycling, and energy recovery. This paradigm directly contributes to corporate social responsibility and supports the improvement of quality of life by mitigating environmental degradation and fostering more sustainable resource use.
Originality: The paper presents a concrete connection between the functioning of the wastewater treatment plant and the assumptions of the circular economy in the Polish setting.
Keywords: Circular economy (CE), 6R, sludge recovery, biogas, wastewater reuse.
Category of the paper: Research paper, theoretical paper.

Introduction

The report published in 1987 by the World Commission on Environment and Development (CMMAD) of the United Nations (UN) formalized the concept of sustainable development, defining it as one that "meets the needs of the current generation without compromising the capacity of future generations to meet their own needs". However, despite this initiative, the linear production model and the culture of consumerism still generate waste of raw materials and finished products (Borschiver, Souza Tavares, 2024).

The Circular Economy (CE) is a business model designed to minimize the consumption of raw materials and the generation of waste. Its objective is to reduce greenhouse gas emissions and lower overall energy use. The circular model creates closed-loop systems in which waste is treated as a resource for subsequent production phases (www.parp.gov.pl/goz#definicja, 2025).

This approach supports the creation of a sustainable, low-emission, and competitive economy by implementing eco-design principles and the 6R concept based on the following pillars:

1. **Refuse** – Avoid purchasing products that contribute to waste generation.
2. **Reduce** – Limit the number of items used; embrace minimalism and buy only what is truly necessary.
3. **Reuse** – Reuse, exchange, and pass on unwanted items to others; consider alternative functions for used goods.
4. **Repair** – Fix items instead of discarding them at the first sign of damage.
5. **Recycle** – Sort waste properly to enable the recovery and reprocessing of secondary raw materials.
6. **Rot** – Compost biodegradable waste such as food scraps.

To prevent waste generation, the European Union introduced the obligation to treat waste as valuable resources that can be reused, recycled, or otherwise recovered, through its third Waste Framework Directive (Rakoczy et al., 2015).

The local authorities in most countries have many ways to improve the environmental performance on the local level. They are responsible for basic services such as water and wastewater management, energy supply and waste management. They have a planning monopoly and thus responsibility for urban planning with streets, green areas, and the built environment. They may be managing the educational systems and large part of the care of children, elderly and the primary health care. They often have a very large economic turnover in connection with these responsibilities. All of this leads to opportunities to improve product policies. Waste management is important for organising practical recycling opportunities and organise the reuse of products which are not in bad shape (Or even to organise repair of wasted products, which may be reused after repair). Similarly wastewater treatment and the resulting sludge management offer opportunities for recycling (Zbicinski et al., 2006).

Implementing circular economy strategies not only benefits the natural environment but also helps businesses stand out in the market, reduce operational costs, and improve service quality. The CE model is based on the principle that no waste is produced—every material is considered a resource that can be reused. As the name implies, a "closed-loop" system means materials should not be discarded or incinerated but returned to the production cycle for reuse. Products should be used as many times as possible. Moreover, by-products from one production facility may serve as valuable raw materials for another—synergies of this kind should be actively sought.

In the circular economy, it is also vital to maximize energy recovery. Therefore, the energy aspect—such as recovering heat generated during production processes—must be a key consideration.

A municipal wastewater treatment plant exemplifies the principles of the circular economy at several levels of operation and at various stages of both wastewater treatment and sewage sludge processing.

At its core, the plant's primary function is to return treated effluent—essentially water, which is increasingly valuable in the face of climate change—back to the natural environment. In the case of the Zabrze treatment plant, the receiving body is the Bytomka River. The plant employs a treatment technology that ensures compliance with legally required discharge standards for wastewater treatment plants in the Zabrze agglomeration, as measured by the population equivalent (PE). In this case, the facility is designed for over 100,000 PE, meaning it is subject to the highest treatment standards mandated by law.

In particular, the plant meets quality standards defined in its current water permit, as well as those specified by the Regulation of the Minister of Maritime Economy and Inland Navigation of July 12, 2019, concerning substances particularly harmful to the aquatic environment and the conditions for discharging wastewater into water or soil, and for releasing rainwater or snowmelt into water or water facilities (Journal of Laws 2019, item 1311). Consequently, the agglomeration also complies with the requirements of the EU Council Directive 91/271/EEC on urban wastewater treatment.

Key performance parameters of the treatment plant (as per the valid water permit):

- Maximum discharge flow rate: up to 1.368 m^3/s.
- Average daily discharge: up to 22,000 m^3/day.
- Annual discharge limit: up to 8,500,000 m^3/year.
- Temperature of treated effluent: up to 35°C.
- pH of treated effluent: between 6.5 and 9.0.
- BOD_5 concentration: up to 15 mg O_2/l.
- COD (Cr) concentration: up to 125 mg O_2/l.

- Total suspended solids: up to 35 mg/l.
- Total nitrogen: up to 10 mg N/l.
- Total phosphorus: up to 1 mg P/l.
- Ammonium nitrogen: up to 10 mg $N\text{-}NH_4$/l.
- Nitrite nitrogen: up to 1 mg $N\text{-}NO_2$/l.
- Chlorides: up to 1000 mg Cl/l.
- Sulfates: up to 500 mg SO_4/l.
- Volatile phenols (phenol index): up to 0.1 mg/l.
- Petroleum hydrocarbons: up to 15 mg/l.

These parameters are specified in the water permit for effluent discharge issued on May 18, 2021, by the Polish Waters (PGW Wody Polskie), Director of the Regional Water Management Board (RZGW) in Gliwice.

Thus, it is clear that even in fulfilling its basic function, the municipal wastewater treatment plant in Zabrze aligns with the principles of the circular economy. However, a closer analysis of individual stages of the wastewater treatment process reveals even greater potential for utilizing various process components in a manner consistent with CE values.

Sand from Grit Chambers

The first stage of municipal wastewater treatment is mechanical treatment. One of the by-products generated at this stage is sand from the grit chamber. The grit chamber is one of the initial components of the mechanical treatment system at a wastewater treatment plant. Its main function is to separate and remove inorganic suspended solids such as sand, gravel, and small stones, which could damage equipment in subsequent treatment stages.

The grit chamber operates on a simple principle: wastewater flows through designated grit compartments at a reduced velocity, allowing heavier mineral particles to settle to the bottom, while lighter (organic) matter continues downstream. The separated sand slurry is then directed to a dedicated device—a sand washer—where it undergoes additional washing. Notably, this washing process does not use potable (clean) water, but rather treated wastewater.

Under Polish waste legislation, sand collected from grit chambers is classified as waste under code 19 08 02, and it constitutes a significant economic burden for wastewater treatment plants due to disposal costs. As Gunter Pauli famously stated, *waste does not exist — it is only a resource in the wrong place* (Pauli, 2010) a principle that aptly illustrates the potential of grit chamber sand as a material for reuse.

It is therefore important to emphasize that this material has considerable potential; its recovery and reuse offer not only tangible financial benefits but also align with the principles of the circular economy and sustainable development, emphasizing the responsible use of resources.

Processing sand from grit chambers in a dedicated installation that removes the organic fraction and leaves behind a clean mineral fraction makes it possible to formally declassify the material as waste. As a result, the sand can be repurposed as a valuable raw material for repair and construction works within the municipal sewer infrastructure.

Sludge Management

Sludge in a wastewater treatment plant is a mixture of solid particles separated from wastewater during the treatment process. It is primarily generated through mechanical and biological processes, and its proper management is critical to the overall efficiency of the plant. During the treatment process, several types of sludge are produced:

1. Primary sludge, which forms in the primary sedimentation tanks (at the initial stage of treatment) and consists mostly of mineral and organic particles separated by sedimentation.
2. Excess activated sludge, produced during biological treatment and composed mainly of microorganisms (bacteria) that break down organic pollutants.

Sludge treatment and reuse are integral parts of modern wastewater management, enabling energy recovery and nutrient recycling (Tchobanoglous, Burton, Stensel, 2014).

Sludge contains nutrients beneficial to plant growth—especially nitrogen and phosphorus—making it a valuable resource for improving soil quality. However, its application is strictly regulated and depends on its physicochemical characteristics.

In the context of the Circular Economy (CE), properly stabilized and dewatered sludge can be used agriculturally under R10 recovery operations. The conditions for such use are defined in the Regulation of the Minister of the Environment of February 6, 2015, on the application of municipal sewage sludge, issued pursuant to Article 96(13) of the Waste Act of December 14, 2012 (Journal of Laws of 2022, items 699, 1250, 1726, 2127, and 2722). According to the regulation, municipal sewage sludge may be applied to land provided that:

1. The content of heavy metals does not exceed the limits specified in Annex 1 of the regulation.
2. When used in agriculture or for land reclamation for agricultural purposes, no Salmonella bacteria are detected in a representative 100g sample of sludge collected in accordance with §5(3).

3. The total number of viable eggs of intestinal parasites (Ascaris sp., Trichuris sp., Toxocara sp.) per 1 kg of dry matter does not exceed:
   a. 0 for agriculture and land reclamation for agricultural purposes,
   b. 300 for land reclamation,
   c. 300 for land-use adaptation based on waste management plans, zoning plans, or land development decisions,
   d. 300 for growing plants intended for compost production,
   e. 300 for cultivating non-food and non-feed crops.
4. The concentration of heavy metals in the topsoil layer (0-25 cm depth) of the receiving land does not exceed permissible values specified in Annexes 2 and 3 of the regulation.
5. Soil pH in agricultural areas where sludge is applied is not lower than 5.6.
6. The use of sludge does not degrade the quality of soil, land, surface water, or groundwater, and does not cause environmental damage as defined in the Act of April 13, 2007, on Preventing and Remedying Environmental Damage (Journal of Laws 2020, item 2187).
7. The sludge is not applied during the growing season of crops intended for direct human consumption, defined as the period from sowing or planting to harvest.

The sewage sludge produced at the Zabrze wastewater treatment plant meets these criteria. After undergoing fermentation, the sludge contains:

- 3.15% d.m. of total nitrogen,
- 2.90% d.m. of total phosphorus,
- 22.8% d.m., of which 56.7% is organic dry matter (o.d.m.),
- 6.37% d.m. of calcium,
- 0.672% d.m. of magnesium.

Additionally, it exhibits low concentrations of heavy metals, such as:

- Zn: 561 ppm,
- Pb: 36 ppm,
- Cd: 1.06 ppm,
- Cr: 36.8 ppm,
- Cu: 127 ppm,
- Ni: 25.3 ppm,
- Hg: 0.18 ppm.

It is also free of pathogens and parasites, making it suitable for return to the environment under the R10 recovery process.

The implementation of circular economy principles at a wastewater treatment plant is not just a catchy slogan—it is already a daily operational reality. However, that does not mean that further improvements are not possible. R10 sludge utilization still represents a significant cost to the plant, and as environmental standards become more stringent, waste management processes will become increasingly complex and expensive.

Therefore, it is worth considering the next step: transforming sewage sludge into a product, such as a soil improver or fertilizer. A soil improver is a material that enhances the physical, chemical, or biological properties of soil, but is not legally classified as a fertilizer. It may support:

- Improved soil structure, porosity, and aeration.
- Increased water retention capacity.
- Stimulation of beneficial soil microorganisms.
- Enhanced fertility and root development.
- Reclamation of degraded land.

A fertilizer, on the other hand, is a substance or mixture that provides plants with essential nutrients for growth, development, and yield improvement. Its primary uses include:

- Supplementing soil nutrient deficiencies (e.g., nitrogen, phosphorus, potassium).
- Increasing crop yields.
- Enhancing crop quality.
- Supporting soil regeneration after intensive farming.

Whether producing a soil improver or fertilizer, appropriate testing and approval procedures are required. The final step in the process is obtaining a decision from the Minister of Agriculture, authorizing the product for use. Depending on the type and form of the product, investment in dedicated facilities at the wastewater treatment plant may also be necessary. This includes obtaining permits (e.g., building permits) and approvals (e.g., environmental decisions), making this a multi-year project requiring significant financial investment.

Given these factors, it is important to avoid the illusion of simple solutions. Even producing a low-processed soil improver can bring challenges in terms of distribution, storage (as low-processed sludge may cause odor problems), and application limits in the environment. Therefore, it may be more effective to develop an advanced product—marketable, easy to store, and sell. One such option is a single-nutrient mineral fertilizer, such as ammonium sulfate [$(NH_4)_2SO_4$], all of whose components—including sulfur—are available at the treatment plant. Sulfur can be recovered through the biogas desulfurization process.

Biogas

The development and improvement of technologies enabling energy recovery from sewage sludge is gaining increasing importance each year (Czekała, Kujawiak, 2025).

One of the sludge treatment methods used at the Zabrze wastewater treatment plant is anaerobic stabilization. This process not only produces stabilized sludge—thereby reducing its volume and improving its dewaterability—but also generates biogas. Biogas is a mixture of gases, primarily methane (CH_4) and carbon dioxide (CO_2), formed through the anaerobic decomposition of organic matter. It is a renewable energy source, commonly used for the production of electricity and heat.

At the Zabrze facility, biogas is generated mainly through the anaerobic digestion of sewage sludge. The biogas production process takes place in dedicated fermentation chambers (WKF)—two closed, reinforced concrete tanks with a total capacity of 6300 m^3, situated above ground and thermally insulated. Fermentation occurs at a temperature of 35-37°C, requiring the sludge to be heated and continuously mixed. The retention time in the fermenters is approximately 30 days. After fermentation and gas release, the digested sludge is directed to centrifuges for dewatering.

The biogas yield potential at the Zabrze plant is currently estimated at approximately 100-200 m^3 per 1000 m^3 of incoming wastewater. The current annual production amounts to approximately 1.5 million m^3.

Biogas produced in Zabrze is used as fuel for two combined heat and power (CHP) units, each with an electrical capacity of 190 kW and thermal capacity of 230 kW. Most of the electricity generated is consumed on-site by the wastewater treatment plant, with only a small surplus fed into the power grid. The generated thermal energy is used for heating buildings, producing domestic hot water, and as process heat—for example, to maintain the operating temperature of the fermentation chambers (WKFs).

From the perspective of the Circular Economy (CE), this is a clear example of the 6R principles, particularly Refuse and Recycle. Moreover, the biogas production process can be enhanced by adding various co-substrates to the fermentation chambers, which help to increase biogas volume, such as:

1. Food industry waste:
   a) whey, vegetable and animal fats,
   b) food scraps, waste from fruit/vegetable processing, dairies, slaughterhouses,
   c) flotation sludge from meat or dairy processing.
2. Municipal biowaste:
   a) vegetable and fruit peels,
   b) expired unpackaged food,
   c) green waste from park and lawn maintenance (e.g., leaves, grass clippings).

3. Agricultural waste and energy crops:
   a) slurry (from cattle or pigs),
   b) manure,
   c) silage from maize, grass, or sugar beets,
   d) post-harvest residues (e.g., straw),
   e) surplus or damaged cereal grains,
   f) fruit and vegetable pulp or pomace.

Naturally, the addition of any of these co-substrates requires formal approval procedures to allow their use in existing treatment processes.

In the context of the Circular Economy, it is also worth highlighting the importance of biogas storage in specially adapted gas tanks, which can act as energy reservoirs when integrated with other renewable energy sources such as photovoltaics.

Photovoltaics and Heat Pump at the Wastewater Treatment Plant

The cost of solar photovoltaic panels (PVs) has dropped by 90 percent since 2010, and their efficiency can range from 16 to 22 percent (the first solar cells, created by Bell Labs in 1954, were just 6 percent efficient). And there is a lot that we can harvest: the energy from the sun can be up to 16,300 kilowatts, at any one time, for every person on the planet (Potter, 2021).

As of now, no photovoltaic systems are installed at the Zabrze wastewater treatment plant. However, their implementation is planned as part of the Multi-Year Development Plan for Water and Sewer Infrastructure for 2025-2026, adopted by Resolution No. XIV/114/25 of the Zabrze City Council on January 27, 2025.

The treatment plant has sufficient land reserves to host a PV farm without incurring additional land acquisition costs. The electricity generated will primarily meet the internal energy demands of the treatment plant, with any surplus fed into the local energy cluster.

An important element of the future system—fully aligned with the Circular Economy (CE) concept—is a 4 MW heat pump, to be installed at the treated effluent outlet. Influent wastewater arrives at elevated temperatures and thus carries a significant thermal energy load. Recovering heat from a source with temperatures above 10°C in winter and over 20°C in summer is highly efficient. In May 2025, a letter of intent was signed between Zabrze Water and Sewage Company and Zabrze District Heating Company, with the goal of building a suitable heat pump on the treatment plant's premises. The thermal energy generated is intended for the production of domestic hot water for the city of Zabrze.

Water

The final element aligned with the principles of the Circular Economy is water production.

Water plays an irreplaceable role in ensuring societal well-being—it is essential for human health, environmental balance, economic stability, and industrial development. Sustainable water management is one of the United Nations' Sustainable Development Goals (SDGs), as outlined in the 2030 Agenda, adopted by 193 UN Member States during the General Assembly in New York in September 2015 (Karło-Białozor, Gieleciak, 2025).

Currently, treated wastewater at the Zabrze plant is already used internally as process water for various operations (e.g., screening wash water, sand washing, cleaning of thickeners and centrifuges). However, no technical barriers prevent its broader reuse. Technologies such as ultrafiltration, nanofiltration, reverse osmosis, and UV disinfection allow the production of water suitable for agricultural, industrial, or even potable purposes.

Naturally, this would require adjustments to other parts of the system. For example, using such water for irrigation of green spaces would require storage and distribution infrastructure. While costs could be reduced by using an electric vehicle fleet powered by on-site renewable energy, other expenses—such as storage infrastructure, maintenance, and labor—could render such projects financially uncertain.

A major constraint in advancing circular water systems is the limited use of comprehensive cost-benefit and lifecycle valuation methods. Conventional project assessments often focus on upfront capital costs and short-term financial returns, which disadvantages circular interventions that provide long-term and multidimensional benefits. Accurately valuing circular water investments requires shifting the analytical lens to include total costs and broader impacts over the full system lifecycle (Brears, 2025).

Water recovery from wastewater is not a new idea. It is particularly advanced in Southern Europe, Australia, and the southern United States. In 2018, the European Commission published a study evaluating EU citizens' attitudes toward water reuse. It revealed that Eastern European countries exhibit the lowest levels of public trust in treated wastewater, while in Mediterranean countries, reuse has long been practiced and accepted, largely due to the recognized need to reduce pressure on natural water resources in agriculture (Ramm, 2024).

Nevertheless, using even high-quality treated wastewater for human consumption could face not only economic but also socio-cultural barriers, stemming from the source of the water. This area merits further sociological research.

The development of water reuse from wastewater is far from straightforward. It requires stakeholder cooperation, as well as the implementation of organizational and technological solutions that ensure safe operations. The key lies in developing systems that can consistently recover water free of pathogens and micropollutants, with an appropriate nutrient content (Ramm, 2024).

Summary

In the face of global climate change and dwindling natural resources, the Circular Economy (CE) is emerging as a key tool for achieving sustainable development. The core principle of CE is waste minimization through reuse, recycling, and energy recovery. This paper presents a wastewater treatment plant as an integral component of such a system. It outlines the circular potential at various stages of municipal wastewater treatment—from mechanical treatment (sand recovery) to sludge management, biogas production, the integration of renewable energy sources, and water reuse—demonstrating their real-world application and economic viability when implemented through well-structured processes.

Other actions are, of course, possible (e.g., phosphorus recovery), though they currently lack sufficient economic and environmental justification.

Public utility companies, operating under local governments, play a critical role in areas such as district heating, waste management, municipal housing, public transport, and the supply of electricity and gas—all of which fall within the municipalities' legally assigned responsibilities. Local governments at various administrative levels should assume a coordinating role, ensuring effective waste management and leveraging the economic potential of municipal utilities in advancing sustainable development—especially in support of energy independence (Bitkowska, Chruściel, 2024).

Building multi-sector cooperation platforms is essential to overcoming siloed thinking in CE development. The involvement of municipal enterprises and private business partners can help bridge knowledge gaps and accelerate innovation transfer. This requires the removal of legal and organizational barriers to collaboration within CE frameworks. It is essential to stimulate demand for circular solutions within municipalities through coalitions between local government, industry, and SMEs, and by integrating environmental goals into public-private partnerships (PPPs) and public procurement strategies. Additionally, it is important to embed education and information policies on CE into standard municipal operations (Rzeńca, Sobol, Ogórek, 2021).

In the case presented, a holistic approach is essential—one that views all processes occurring at the wastewater treatment plant in an integrated way, with the goal of optimizing the use of available resources. Certainly, there are barriers—regulatory, economic, and socio-cultural. Some can be addressed through expert guidance and the systematic execution of required research, documentation, and administrative procedures. External funding, including EU grants and other R&D-related subsidies, can help overcome financial obstacles. Such support is crucial for the development of innovation, the growth of enterprises, and increased market competitiveness.

A key step forward is a shift in the perception of the water utility—not just as a supplier of drinking water and collector of wastewater, but as an active stakeholder in the circular economy, an energy producer, and a driver of environmental stewardship, knowledge dissemination, and community awareness.

The Circular Economy offers a wide range of benefits that cover not only the economic realm, but also the social and environmental aspects. These benefits make the shift to a circular model essential for long-term sustainable development (Silva, 2024).

In conclusion, the growing environmental challenges demand the adoption of new resource management strategies. One of the most critical approaches is undoubtedly the circular economy, which aims to minimize waste generation and maximize resource recovery. Wastewater treatment plants, traditionally seen as pollution control facilities, can become key players in implementing CE principles, through the recovery of water, energy (electric and thermal), and nutrients that enhance soil quality.

References

1. Bitkowska, A., Chruściel, T. (2024). Rola samorządowych przedsiębiorstw komunalnych w Polsce w perspektywie zrównoważonego rozwoju i niezależności energetycznej. In: *Gospodarka odpadami komunalnymi jako narzędzie walki ze zmianą klimatu. Wybrane zagadnienia*.
2. Borschiver, S., Souza Tavares, A. (2024). *Circular economy a new mindset on sustainable development*.
3. Brears, R.C. (2025). *Circular Water Economy: An Our Future Water Insight on Water Security, Climate Resilience, and Sustainable Infrastructure*.
4. Czekała, W., Kujawiak, S. (2025). Odzysk energii z osadów ściekowych. *Wodociągi i Kanalizacja, no. 1/25(251).*
5. https://www.parp.gov.pl/goz#definicja, 6.07.2025.
6. Karło-Białozor, A., Gieleciak, Z. (2025). Droga do zrównoważonej gospodarki wodnej. *Wodociągi i Kanalizacja, no. 4/25(254).*
7. Pauli, G. (2010). *The Blue Economy: 10 Years, 100 Innovations, 100 Million Jobs*.
8. Potter, C. (2021). *Welcome to the circular economy. The next step in sustainable living.*
9. Rakoczy, B., Karpus, K., Szalewska, M., Walas, M. (eds.) (2015). *Zasada zrównoważonego rozwoju w wymiarze gospodarczym i ekonomicznym*.
10. Ramm, K. (2024). Ponowne wykorzystanie wody odzyskanej ze ścieków. *Kierunek Wod-Kan, 3/24(863).*
11. Rzeńca, A., Sobol, A., Ogórek, P. (eds.) (2021). *Raport o stanie polskich miast. Środowisko i adaptacja do zmian klimatu*.

12. Silva, A. (2024). *Circular Economy*.
13. Tchobanoglous, G., Burton, F.L., Stensel, H.D. (2014). *Wastewater Engineering: Treatment and Resource Recovery*.
14. Zbicinski, I., Stavenuiter, J., Kozlowska, B., Van de Coevering, H. (2006). *Product Design and Life Cycle Assessment, Book 3 in a series on Environmental Management*.