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Exploring Circular Economy Potentials and Challenges in Brazil's Activated Sludge WWTP

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Highlights:

- Circular economy practices transform WWTP into key components of sustainable urban management by enhancing resource recovery and promoting by-products reuse.
- Circular economy practices can significantly enhance operational efficiency and sustainability in wastewater treatment.
- Implementation challenges for circular economy include technological and regulatory barriers, necessitating advancements in legal frameworks.

Keywords: Circular Economy; Wastewater Treatment; Sustainability.

INTRODUCTION

Circular economy approaches in Brazil's activated sludge (AS) wastewater treatment plants (WWTP) redefine the traditional linear focus, which aims to meet effluent quality standards at minimal costs while often ignoring the potential value of by-products in wastewater. This linear approach overlooks opportunities to harness substances and by-products in both untreated and treated wastewater (BRESSANI-RIBEIRO *et al.*, 2019). In contrast, the circular model emphasizes resource efficiency, positioning WWTP not just as treatment facilities, but as integral components of sustainable urban management. Adopting this model can lead to reduced operational costs, minimized socio-environmental impacts, and new revenue streams. Key strategies include the recovery and reuse of nutrients from sludge (N and P), converting them into valuable biosolids for soil application, and the production of biogas for energy (BRAZIL, 2016), enhancing the sustainability of these facilitie (Figure 1).

Reflecting the importance of these strategies, this paper explores the circular economy's potential and challenges across Brazil's AS WWTP, widely implemented alongside UASB reactors and stabilization ponds (ANA, 2020). This exploration is supported by a review of Brazilian and international experiences and frameworks, highlighting the transformative potential of circular economy practices to enhance environmental sustainability and economic viability.

METHODOLOGY

The study examined the potential and challenges of implementing circular economy practices across Brazilian AS WWTP. The methodology involved reviewing key Brazilian publications, established international sanitation frameworks, and local practical experiences. Legislation on circular economy was analyzed to assess legal framework for WWTP by-product utilization. Most details and complete references of the specific laws, standards, and applications reviewed are not included in this abstract due to space constraints but can be provided upon request. Based on these experiences, specific benefits for Brazilian AS WWTP were evaluated.

RESULTS AND CONCLUSIONS

The assessment of the potential for implementing circular economy practices in Brazilian AS WWTP yielded insightful outcomes, highlighting significant potential for biogas utilization, nutrient recovery, and effluent reuse. Key Brazilian publications such as the "*Cadernos Técnicos em Engenharia Sanitária e Ambiental*" (ABES, 2023) and the "*Guias Técnicos sobre aproveitamento energético de biogás*" (BRAZIL, 2015) provided an understanding of biogas management and by-product valuation in wastewater treatment. Internationally, countries like Germany and the Netherlands have set benchmarks in nutrient recovery and energy generation, demonstrating robust frameworks that guide circular economy initiatives in sanitation. Notably, Germany’s *Kreislaufwirtschaftsgesetz* and the Netherlands' practices in recovering biopolymers from aerobic granular sludge serve as pivotal examples (Table 2).

The potential benefits for the plants, listed in Table 3, showcase how circular economy can not only reduce operational costs but also enhance environmental sustainability and resource efficiency. These practices improve ecological footprints, aligning operational practices with strict global environmental standards, thereby contributing to sustainable urban development. Nonetheless, the implementation faces technological, regulatory, and financial challenges, as well as significant legal hurdles, as outlined in Table 1, which details the primary laws regulating circular economy in Brazil and their limits. Necessary technological adaptations include retrofitting existing facilities with circular systems, always respecting local reality and economic viability. Regulatory frameworks must evolve to recognize and incentivize such innovations, while substantial financial investments are needed for this transition.

In conclusion, the assessment highlights the substantial benefits that circular economy practices can offer to WWTP, particularly those employing AS technology, aligning with global sustainability goals. Successful implementation requires a comprehensive approach that leverages both national and international experiences. It also demands continuous monitoring and detailed analyses to ensure these practices are optimally integrated and yield long-term benefits, fostering an environment where circular economy principles can thrive and lead to significant ecological and economic gains.

FIGURES AND TABLES

Table 1 - Regulatory Challenges and Legal Gaps in Circular Economy Practices for Sanitation in Brazil

Resource	Legislation number	Description	Gaps
Sludge	498/2020 (CONAMA)	Sets criteria for biosolids production and application on soils.	Legislation permits disposal in landfills, competing with higher-value uses.
Biogas	685/2017 (ANP)	Rules for biomethane quality control and specifications.	Only covers biomethane, not other biogas uses.
	482/2012 (ANEEL)	Conditions for micro and mini distributed generation of electricity.	Inapplicable to biogas-generated power.

Secondary Effluent	54/2005 (CNRH)	Guidelines for non-potable direct water reuse.	Lacks detailed quality and treatment standards.
	121/2010 (CNRH)	Criteria for non-potable water reuse in agriculture and forestry.	

Table 2 – Summary of International Benchmarks in Circular Economy in WWTP

Netherlands: Known for pioneering the recovery of various by-products from WWTP. Achievements include the recovery of biopolymers from aerobic granular sludge for uses such as agricultural moisture retainers and industrial flame retardants. Other applications involve the recovery of cellulose using fine screens.

Germany: Supported by the Closed Substance Cycle Waste Management Act (*Kreislaufwirtschaftsgesetz*), WWTP optimize by-product utilization based on norms and guidelines issued by the German Association for Water, Wastewater and Waste (DWA). Techniques include sand washing for reuse with less than 5% organic matter, energy production from biogas, and codigestion practices. Legislation mandates phosphorus recovery from incineration in plants serving over 100,000 people by 2029.

UK: A significant portion of sludge is sanitized and used in agriculture (>65% of sludge in 2017). Many plants implement thermal hydrolysis before methanization to optimize anaerobic digestion, utilizing biogas for natural gas grid injection or electricity generation.

US: 4.5 million tons of biosolids were produced in 2021, with 43% applied to agricultural use and land restoration.

Mexico: The Atotonilco WWTP, with a treatment capacity of 42 m³/s, uses biogas for cogeneration of electricity and heat, supporting both plant operations and agricultural irrigation in the Mesquital Valley, benefiting over 300,000 farmers.

Additional Global Experiences: In Portugal, green hydrogen production from reused water is highlighted, while in Australia, 67% of biosolids produced in 2020 were extensively used in agriculture. Chile's "biofactories" concept generates reusable water, biosolids, and electricity, with potential for biometane production. Other international WWTP have adopted 'SMART Plant' solutions, including cellulose recovery in the Netherlands and biogas cogeneration in Israel.

Table 3 - Key Benefits of Circular Economy Practices for Brazilian Activated Sludge (AS) WWTP

Sand Reuse: The sand removed from grit chambers, once washed and in suitable conditions, offers a range of applications including sublayers for roads, non-structural uses in construction, and in drying beds. Supported by characterization and feasibility studies, such as those conducted for the WWTP Onça (Belo Horizonte, MG), sand reuse has proven economically viable, with a complete recovery of initial investment within 20 months. Additional studies in Barueri and São Carlos (SP) demonstrate potential for construction industry applications, providing both economic returns and environmental benefits by reducing raw sand extraction from riverbeds (SILVA; POAGUE; NUNES, 2018).

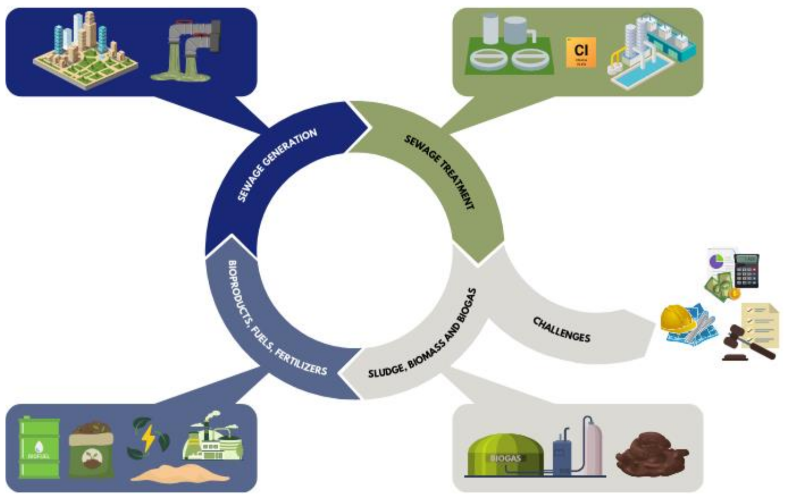
Treated Effluent Reuse: Treated effluent serves as a substitute for potable water in industrial or agricultural processes, thereby generating revenue. This is especially significant in regions like São Paulo, which have experienced acute water shortages. Projects like Aquapolo and EPAR Capivari II exemplify the success of high-quality reused water in generating significant outputs (364 L/s), highlighting the role of treated effluent in addressing regional water scarcity.

Energy Efficiency: Energy conservation measures such as optimizing pumping, correcting excessive hydraulic losses, and refining aeration control with sensors help in reducing energy costs significantly. These measures not only enhance operational efficiency but also contribute to overall sustainability.

Biogas Utilization: Capturing methane-rich biogas from sludge digestion reduces energy costs and the carbon footprint of WWTPs. Optimization of anaerobic digestion and co-digestion with organic wastes further enhances energy production, offering economic and environmental benefits. The potential for additional biogas generation through co-digestion and the use of pre-treatment techniques like hydrolysis could significantly improve the efficiency and economic viability of biogas systems.

Sludge Utilization: Transforming sludge into biosolids for safe soil application recycles nutrients and improves soil properties, offering economic, environmental, and social benefits. With widespread international adoption, the use of biosolids in agriculture is a validated practice that reduces the reliance on chemical fertilizers, further enhancing sustainability.

Figure 1 – Circular Economy in WWTP



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