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Small-Scale Sewage Treatments in Paraná/Brazil: Case Study of Four Different Technologies – General Analysis and Net Present Value Analysis

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Highlights:

Comprehensive Study: Analyzes sewage treatment configurations for small communities in Paraná/Brazil within Public-Private Partnerships, comparing nature-based and technical solutions.

Net Present Value (NPV) Analysis: Provides a detailed comparison of costs for four treatment configurations, focusing on the economic feasibility of wetland applications.

Operational Insights: Discusses operational considerations and technology selection, emphasizing the importance of low-maintenance and robust solutions for small-scale facilities.

Scalability and Impact: Examines the scalability of nature-based solutions for larger treatment facilities, highlighting the practical implications for sewage treatment in Latin America.

Keywords: Small-Scale Sewage Treatment; Net Prsent Value Analysis; Nature-Based Solutions;

INTRODUCTION

Achieving universal sanitation requires solutions for small-scale sewage treatment plants on a large scale. In Brazil, 58,3% of municipalities, and in Paraná 68,4%, have populations of less than 15.000 inhabitants (IBGE, 2024). This study explores the design and economic viability of nature-based and technical solutions, specifically analyzing four configurations through a Net Present Value (NPV) Analysis to determine long-term cost-effectiveness.

CASE STUDY

SANEPAR, the state sanitation provider for Paraná, Brazil, recently opened bids for three areas under a Public-Private Partnership (PPP), covering 112 districts with 171 treatment plants (SANEPAR, 2024). In Brazil, small treatment plants are typically defined as those serving up to 15.000 inhabitants, with a capacity of 30 liters per second (l/s); 146 of these plants fall within this category.

This publication explores design options suitable for implementing wetlands, setting a threshold at 20 l/s, which includes 130 plants. This result in 73 plants which must meet the effluent standard of 60 mg/L BOD, while 48 plants are required to meet stricter limits of 40 mg/L BOD or lower.

Key Criteria for Technology Selection

Small treatment systems must be selected with maintenance needs in mind. The operational demands of a 10 l/s plant are only marginally lower than those of a 20 l/s plant. Thus, specific labor costs double when calculated per liter treated. Labor-intensive stages in treatment plants include pretreatment, primary treatment, and sludge handling, which must be given special attention. The level of equipment required is also critical; as a rule of thumb, the process should be as robust as possible, with less equipment to minimize failure risks.

Based on these criteria, the following technologies were selected:

- **First stage French System:** This wetland system treats raw wastewater and aerobically mineralizes sludge at the surface. A significant advantage is the minimal need for sludge handling, as the beds only require cleaning every 10 to 15 years. This system has demonstrated reliability over 30 years of use in Europe, with more than 4,000 installations (Morvannou et al., 2015). For less stringent treatment requirements in Brazil, the first treatment stage is sufficient (Latune & Molle, 2017; Dotro et al., 2017). The minimal operational costs contribute to a favorable net present value over time.
- **Aerated French System (Rhizosph'air®):** The Rhizosph'air® process is a more recent development, combining the advantages of the first-stage French wetland for raw wastewater treatment with an additional polishing step, featuring artificial aeration to meet stricter effluent requirements (below **20** mg BOD_5/l) (ecoBIRD, 2024). This advanced configuration increases operational costs but improves treatment efficiency, making it suitable for areas with stringent discharge limits.
- **SBR (Sequencing Batch Reactor) with sludge mineralization reed beds:** This treatment technology has shown its advantage for high peaks which are typical in smaller communities. The SBR technology smooths out peak flows and allows for a very robust treatment with stringent effluent requirements. Necessarily the excess sludge must be handled. In this case with sludge mineralization beds as described by Hoffmann et al. (2024) at this conference. The sludge is stored and treated in the mineralization beds for about 10 – 15 years before emptying the first bed.
- **SBR with centrifuge:** Similar to the SBR system described above, this configuration uses a centrifuge for sludge handling instead of mineralization beds. While the wastewater treatment process remains robust, the use of a centrifuge increases operational costs due to higher energy and maintenance requirements.

Investment Costs

A cost analysis of CAPEX (capital expenditure) was performed for all four systems. Wetlands primarily incur costs for filter material and lining, while the main costs for the SBR systems are in secondary treatment, which includes glass-coated steel tanks, aeration systems, and blowers. Table 1 provides a breakdown of CAPEX for the four technologies. Costs for land requirement were not taken into account. The costs were determined during the above-mentioned bidding process (SANEPAR, 2024).

Table 1 - **Capital and Operational Expenditure by technology**

Item	Technology	CAPEX (USD)	OPEX (USD/m³)
1	French system	$1.070.863,78	$0,0529/m³
2	French system aerated	$1.337.513,27	$0,0669/m³
3	SBR with sludge mineralization beds	$1.543.581,91	$0,1732/m³
4	SBR with centrifuge	$1.389.223,72	$0,2466/m³

Operational Costs and Net Present Value

Operational costs for wetlands are estimated at $0,0345/m³, while the aerated French system costs $0,0345/m³. For the SBR with sludge mineralization, the primary costs are labor, maintenance, transportation, and sludge disposal, without factoring in economies of scale. For the SBR with a centrifuge, labor, transportation, disposal, and energy are the primary expenses.

For the sludge handling a sludge removal every 10 years was calculated for the wetlands, even though practical experience shows that normally cleaning intervals of 15 years or more are achieved. The same was estimated for the sludge mineralization beds.

Although the authors advocate for agricultural reuse of sludge, this study assumed landfill disposal, as agricultural reuse conditions vary significantly between the solutions. Table 2 shows the baseline figures used to calculate operational costs. A significant difference between the centrifuge and the sludge mineralization wetland is the estimated 22% dry solids content for the centrifuge, compared to 35% for the mineralization bed. Moreover, sludge mineralization results in a substantial reduction in sludge volume, estimated at 80% of the original dry solids mass.

Labor costs vary widely as for System 1 a simple qualification with 2 visits per week is necessary, while system 4 requires daily presence and qualified operators.

Table 2 – **Operational Expenditure cost criteria.**

Item	Cost	Price
1	Energy (Kwh)	$0,126/Kwh
2	Transport and Destination (Ton)	$39,604/Ton
3	Maintenance	5% of equipment cost
4	Reinvestment equipment	15 years
5	Labor cost	variable in time and qualification

The net present value (NPV) was calculated based on the resulting treatment cost per m³. The authors did not apply different inflation rates for various elements (sludge disposal, maintenance, labor, etc.). Table 1 shows the resulting costs per m³. The reference period for this analysis is 24 years, aligning with the duration of the PPP contract. The internal interest rate was set at 8,6%,

Discussion

Table 3 demonstrates a clear advantage for the less technical solutions. The difference between the solutions was more significant than expected. It appears that nature-based solutions (NBS) could be used for much larger plants than previously anticipated. The current limiting factor is the lack of experience with such solutions in Latin America.

Table 3 – **Net present value by technology – period 24 years**

Item	Technology	NPV
1	French system	$1.341.943,29
2	French system aerated	$1.719.265,78
3	SBR with sludge mineralization beds	$2.413.547,41
4	SBR with centrifuge	$2.638.680,51

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