RETASTE Conference Abstracts
RETASTE-AWR-1350-In-person Poster
Rethymno, September 16-18, 2026
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DOI:10.5281/zenodo.23678071

Comparative Energy Consumption and Environmental Footprint Assessment of Wastewater Treatment Systems: Literature-Based Benchmarking vs. ADVANTEX Technology

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Abstract

Wastewater treatment systems are increasingly evaluated not only for treatment efficiency but also for their energy demand and overall environmental footprint. Conventional centralized treatment technologies, including activated sludge systems, membrane bioreactors, and sequencing batch reactors, are often associated with high operational energy requirements and greenhouse gas emissions. In the context of circular economy principles and sustainable water management, decentralized and low-energy treatment technologies have emerged as promising alternatives. This study presents a comparative assessment of the energy consumption and environmental impacts of commonly applied wastewater treatment systems based on literature-derived benchmarks, with particular emphasis on the ADVANTEX® Treatment System as a decentralized alternative technology. A comprehensive review of published studies, technical reports, and life cycle assessment (LCA) datasets was conducted to evaluate operational energy use, carbon footprint, sludge generation, and resource efficiency indicators across different treatment configurations. In addition to the literature review, primary operational data were collected from three ADVANTEX installations of different treatment capacities located in Crete, Greece, allowing for a comparative evaluation under real operating conditions. The analysis indicates that conventional activated sludge processes typically exhibit energy consumption values ranging between 0.30 and 0.80 kWh/m³ of treated wastewater, depending on plant scale and operational conditions. Membrane-based systems generally demonstrate even higher energy demands due to aeration and membrane fouling control requirements. In contrast, ADVANTEX technology, which utilizes a packed-bed textile filter medium for attached-growth biological treatment, demonstrates comparatively lower energy requirements and reduced sludge production while maintaining high removal efficiencies for organic matter and nutrients. The primary data collected from the three full-scale installations further support the literature findings, highlighting stable operational performance and low specific energy consumption across varying treatment capacities. Environmental footprint benchmarking further suggests that decentralized treatment approaches may contribute to lower greenhouse gas emissions, reduced infrastructure requirements, and enhanced adaptability for small communities and peri-urban applications. The literature also highlights additional sustainability benefits associated with ADVANTEX systems, including operational simplicity, lower maintenance frequency, and compatibility with water reuse strategies. The findings of this study contribute to the ongoing discussion on sustainable wastewater management by providing a literature-based comparative framework for evaluating treatment technologies under energy and environmental

performance criteria. The proposed benchmarking approach can support decision-makers, utilities, and researchers in selecting wastewater treatment solutions aligned with climate mitigation targets and circular economy objectives.

Keywords: Wastewater treatment, Environmental footprint, Energy consumption, Life Cycle Assessment, ADVANTEX technology

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