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Integrated Valorisation of Saline Wastewaters in a Circular Context

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Abstract

Saline wastewaters, prevalent in industries ranging from fish processing and aquaculture to oil and gas and chlor-alkali production, pose a dual challenge: they threaten freshwater security and cause severe environmental degradation upon discharge. Conventional physicochemical and biological treatment methods are frequently compromised by high salinity, leading to inefficient resource recovery and persistent ecological risks. As global freshwater scarcity intensifies and industrial water recycling becomes mandatory, the development of robust, novel treatment systems becomes of high significance. This study presents a holistic, integrated value chain designed for the simultaneous recovery of water, organic matter, and minerals from saline effluents, transitioning from a dissipative treatment model to a circular economy framework. The proposed system employs a sequential, multi-stage approach. First, a robust anaerobic digestion process utilizing salt-resistant microbial granular entities facilitates the removal of organic load while generating biogas as a renewable energy source. Subsequently, a specialized microbial consortium comprising methane-oxidizing bacteria and microalgae converts residual nutrients into high-value ectoine. This stage allows for selective promotion of specific biological pathways to optimize either biogas valorisation or ectoine synthesis. Finally, a pilot-scale desalination unit is integrated to achieve target-oriented, energy-efficient water recovery while minimizing brine discharge volumes. A comprehensive environmental life cycle assessment (LCA) quantifies the net environmental impact of the entire value chain with attention to the trade-offs between energy recovery, chemical production, and water reuse against the environmental costs of desalination and microbial cultivation. The assessment utilizes standardized impact categories, including global warming potential, eutrophication, and water depletion, to benchmark the integrated system against conventional saline wastewater treatment. Preliminary results indicate that the circular approach significantly reduces the overall environmental footprint, primarily driven by the displacement of fossil-based energy and the avoidance of brine discharge impacts. However, the LCA also highlights critical sensitivity points regarding energy intensity during the desalination phase and the carbon footprint of nutrient supplementation. By identifying these leverage points, the study provides a roadmap for optimizing the value chain's environmental sustainability profile. Furthermore, the evaluation includes an assessment of societal readiness and policy compliance, ensuring that the technological innovation aligns with regulatory frameworks and public interest. This comprehensive analysis demonstrates that integrated valorisation offers a scientifically sound and environmentally viable pathway for managing saline wastewaters.

Keywords: Anaerobic digestion, Desalination, Methalgae, Saline wastewater, Water circularity

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