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A Framework for Modular Treatment of Industrial Effluent and Modular Environmental Life Cycle Assessment of the Treatment Scenarios

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Extended Abstract

This paper presents solutions to challenges encountered during an industrial pilot project focused on managing a modular effluent treatment plant and conducting a life-cycle assessment of the treatment scenarios. The plant's modular design allows for bypassing individual treatment units, enabling flexible and dynamic treatment configurations that can be tailored to the specific characteristics of industrial effluents and the desired water quality. The study addresses three key challenges: 1) identifying suitable treatment techniques for various pollutants, 2) determining the optimal arrangement of treatment modules to configure an effective process for specific effluents, and 3) selecting the most sustainable treatment process from several possible configurations based on the effluent composition. The objective of this research is to provide solutions to these challenges and develop an approach for environmental assessment of modular industrial effluent treatment. This is achieved through the following steps: 1) developing a parametric model encompassing a range of conventional, established, and emerging treatment technologies for industrial effluents, 2) creating a decision tree based on Best Available Techniques (BAT) to configure the appropriate treatment chain according to pollutant composition, 3) designing a modular treatment system consisting of three stages: pretreatment, membrane treatment, and finishing treatment, and 4) conducting a comparative environmental life-cycle assessment (LCA) of the treatment modules to reveal differences in their environmental impacts. An integrated approach was developed to configure treatment scenarios based on effluent composition, intended end use, available technologies, and environmental impact assessments. To address the complexity of configuring treatment chains given the diversity of contaminants and technologies, a decision tree was developed based on the Best Available Techniques (BAT) tailored to pollutant types. To facilitate environmental assessments, parametric life-cycle models were developed for treatment modules based on a thorough literature review, ensuring versatility in LCAs for different treatment scenarios and flexibility in sensitivity and uncertainty analyses. Parametric life-cycle inventories were developed for the operational phase of 15 conventional and advanced treatment modules, enabling comparative environmental impact assessments with sensitivity and uncertainty analysis. The comparative life cycle assessment revealed the hotspots and contributions of fifteen treatment modules to the environmental impacts of treating of $1m^3$ effluent, with nanofiltration, reverse osmosis, and ion-exchange having the highest overall impacts. Sensitivity analysis unveiled high sensitivity of midpoint and endpoint environmental impacts on energy, resin, and chemical consumption. This integrated approach provides a foundational framework for the further development of decision trees as a tool for configuring effluent treatment processes and assessing their sustainability. The modular configuration, along with the decision tree, offers greater flexibility in developing fit-for-purpose treatment scenarios and conducting modular LCAs for more sustainable effluent treatment. This framework can be updated and adapted to incorporate emerging treatment technologies and contaminants, facilitating future LCAs in the effluent treatment industry.