Optimization of Wastewater Treatment Plant Design Using an Early-Stage Techno-Economic Analysis Under Uncertainty

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Selection of an optimal wastewater treatment plant (WWTP) layout is a formidable challenge that is growing in complexity due to increasingly stringent legal demands on effluent quality, the ever-growing

number of competing treatment technologies, and the limited financial resources. Several environmental decision support tools (Bozkurt et al., 2015; Castillo et al., 2016) have been proposed to assist design engineers in their early stage decision making for building or retrofitting a WWTP network. These tools provide users with a number of candidate process flow diagrams for WWTP layout given a defined objective by making use of expert knowledge-based and mathematical programming-based process synthesis approaches. Further techno-economic evaluation of these candidate designs with a level of detail available at the early stage of the project development is needed to foster the decision making process. Although a variety of methodological approaches have been reported in the literature which account for different types of costs of wastewater treatment (i.e. energy costs, environmental externalities such as effluent tax, etc.) with a varying level of detail (Rodríguez-Garcia et al.,2011; Molinos-Senante et al., 2013), the comparability and applicability of these works at the early stage of decision making is limited. It is well-known that significant economic trade-offs exists between investment and operational costs which are subject to a large uncertainty (U-tapao et al., 2015). Therefore, there is a significant need for a comparative techno-economic analysis of the early-stage alternative candidate designs to further assist decision making under various uncertainties like variations in influent wastewater pollutant load and composition, cost of electricity used for aeration, and the price of biogas produced in sludge digesters, etc.

The main objective of this work is to develop an early-stage techno-economic assessment methodology for the selection of the optimal network among the alternative WWTP networks by taking into account available plant-wide simulation data to better estimate operational costs (sludge disposal, effluent tax, and energy consumption) along with major capital investment costs. To this end, as opposed to simplistic input-output type process models used at the design stage, a Monte Carlo sampling-based optimization under uncertainty framework, utilizing rigorous non-linear mechanistic models of individual technological treatment units able to handle industrially relevant problems and scales, has been developed to select candidate designs among alternative treatment technologies. In order also to incorporate uncertainties at the design selection stage, a techno-economic analysis methodology accounting for investment costs and operational costs with data generated from rigorous plant-wide simulations is used. Effluent quality index (EQI) and net present value (NPV) metrics are respectively used to evaluate technical and economic performances of the alternative designs. Uncertainty and sensitivity analyses are complementarily carried out in order to judge the robustness of the assessments against uncertainties in influent wastewater characteristics and technical performance metrics. The proposed methodology effectively quantifies the effect of uncertain information on the optimum design selection, further fostering decision-making in industrially relevant wastewater treatment design problems.

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