Techno-economic tradeoffs of bioenergy recovery and system retrofitting in anaerobic digestion infrastructure for expanded treatment service

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Abstract

In recent years, anaerobic digestion infrastructures worldwide have been expanding their scope of treatment services, where an enlarged energy recovery and extra tipping fees can further support their regular operation. For example, food waste co-digestion is put into the policy agenda of many countries in recent years, and there is a huge increase in relevant implementations. However, when exploring more feasibilities of expanded service, plant operators are often confused about the uncertainty and economic trade-offs between the new investment and tangible gains, particularly if there is no case demonstration reported by others. The implementation gap is the lack of evaluation tools to consolidate potential technological scenarios in a quantitative and systemic manner. Regarding this, we propose an evaluation framework that consolidates the techno-economic impact of waste processing units, energy balance analysis, and retrofitting needs to derive the overall financial outlooks.

For overall assessment steps, the methodological challenge of a direct economic computation is the unknown microbial responses in the anaerobic digestion unit as well as potential mitigation expenses of downstream processing (including biogas purification and digestate handling). Therefore, experimental validations were first carried out to obtain the quantitative profiles. Meanwhile, because of the potential increase of bioenergy recovery from expanded service, it also questions the decision-making of applying different energy devices to recover electricity and heat. Therefore, the methodological framework also needs to consider the dynamic scenarios of system retrofitting and biogas utilization methods against the existing practice in anaerobic digestion infrastructures (e.g. only processing heat recovery) (Liu et al., 2021; Shen et al,. 2015). The predictive evaluation of such system retrofitting in wastewater treatment plants easily creates confusion, in view of the system scalability, process complexity, and multiple contradictory tradeoffs in financial performance. Without an appropriate quantitative framework, it would be very abstract to what extent of capital/operating expenditures need to be committed (in different scenarios) to support the new policy agenda of urban decarbonization, and whether they could be ultimately offset in long run by the enlarged energy recovery and additional revenues. Therefore, we propose a methodological framework for addressing the aforementioned aspects and it was applied to study the economic tradeoffs and technological decisions for the expanded service to municipal leachate. From a systems perspective, it could serve as a powerful economic tool to measure the economic impacts of emerging technologies for potential decisions of facilities upgrade, where the evaluation matrix can be further adjusted/expanded to examine more different scenarios.

Currently, there is a clear implementation gap between the policy encouragement of sustainable waste management and the availability of evaluation frameworks to incentivize/accelerate stakeholder engagement. Through comparative economic analysis, it would allow the establishment of relevant evaluation metrics to give more consolidated accounts for economic tradeoffs and uncertainties. Particularly, while many studies of energy recovery are being researched for anaerobic digestion, they are often being studied on the technical aspects of biogas enhancement (Tsui et al., 2022). It would be more ideal to illustrate the economic impacts for implementation and thereby accelerate the process of technology transfer. For more different scenarios (e.g. recovery of value-added products, emerging system approaches) (Tan et al., 2021), the evaluation metrics can be further expanded/adjusted to measure their potential economic impacts on the overall financial outlook.

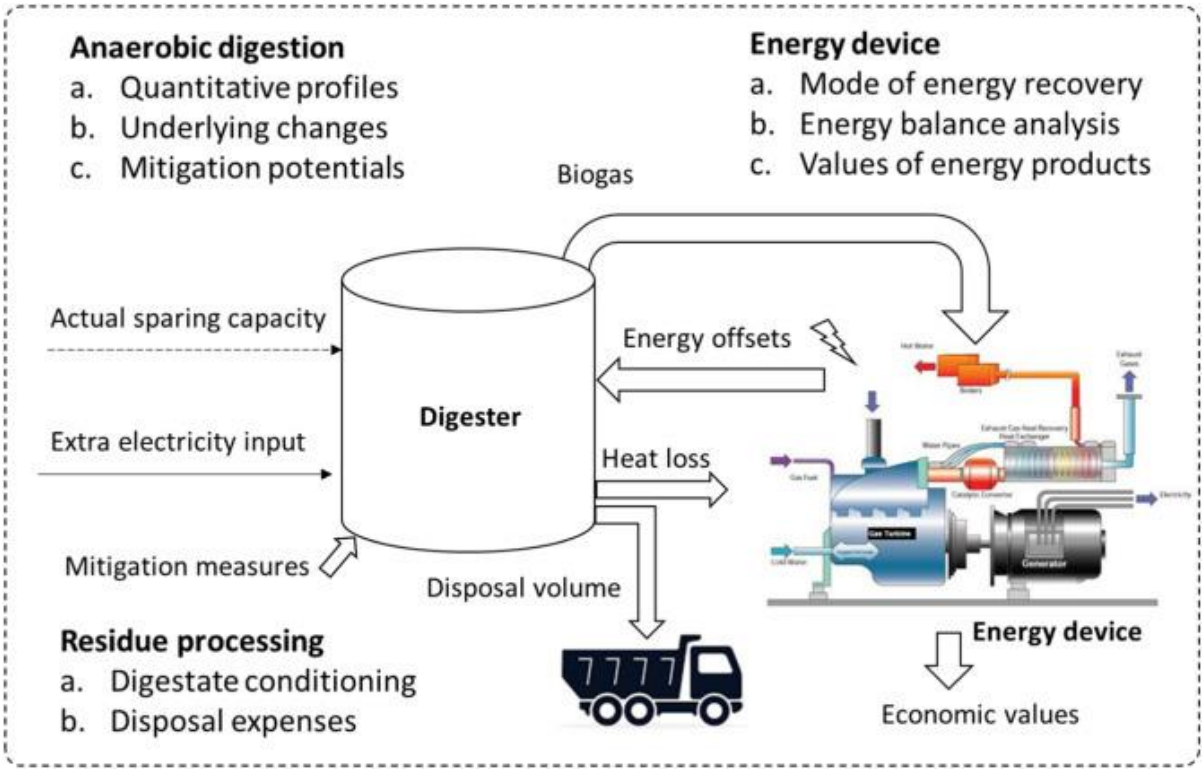

Figure 1. Overall techno-economic framework of system scenarios

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