Sustainability assessment of valorisation for sewage sludge: Indian case study

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Developing countries like India have major waste management issues and energy crisis (Ray et al., 2025). Sewage sludge management is a critical challenge in India, with increasing urbanisation leading to higher sludge generation. Improper disposal of sludge in landfills results in severe environmental and health impacts, including water contamination, greenhouse gas emissions, and soil degradation (Ghorbani et al., 2022; Siddiqua et al., 2022). Adopting sustainable waste-to-energy (WTE) technologies can resolve the waste and energy issue i.e it has gained significant attention recently (Varjani et al., 2022). Among the available technologies, anaerobic digestion (AD) and gasification are promising approaches that convert sludge into valuable energy products. The study evaluates the feasibility of four WTE pathways using Techno-Economic Assessment (TEA) and Life Cycle Assessment (LCA) to determine India's most viable option for sewage sludge treatment. The study aims to provide insights into economic sustainability, energy recovery potential, and environmental impact of each pathway, helping policymakers and industry stakeholders make informed decisions.

The LCA followed the ISO 14040/14044 standards, assessing key environmental indicators. A gate-to-gate approach was used, covering sludge inflow, processing, energy recovery, and product. A comprehensive TEA following LCA was conducted to evaluate each pathway's capital investment, operational costs, energy output, and overall economic feasibility. Data for the assessments were obtained from sewage treatment plants (STPs), government reports, and peer-reviewed literature. The preliminary result of the study is shown in the figure 1.

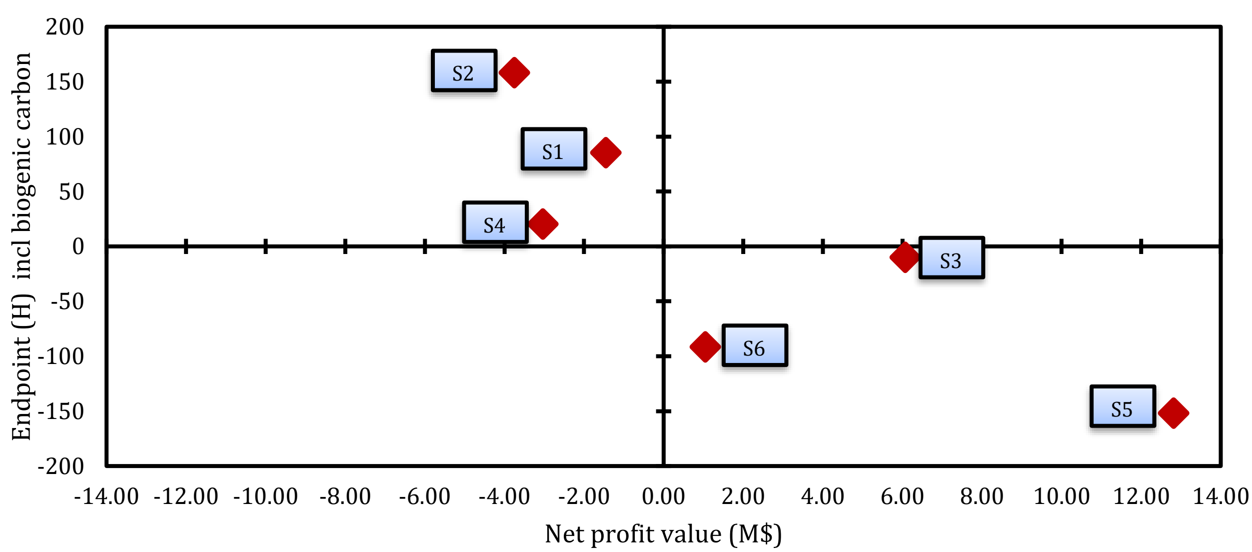

Figure 1: Trade-off of Environmental indicators and economic feasibility

S1: sludge disposal **S2:** sludge incineration **S3:** gasification producing syngas
S4: gasification producing electricity **S5:** anaerobic digestion producing biogas **S6:** anaerobic digestion producing electricity

Gasification pathways demonstrated a higher energy recovery due to the full utilisation of waste, but the net energy recovery was low due to the energy utilisation for drying wet sludge. On the other hand, AD pathways provide better energy conversion efficiencies when operated under optimised conditions. The LCA results revealed trade-offs between the two technologies. S5 was the most effective in reducing environmental impact and has a high NPV. However, S3 had a high NPV but a high endpoint impact. The TEA results indicated that anaerobic digestion has a lower capital investment requirement, making it more attractive for immediate implementation in municipal sewage treatment plants. However, gasification offers long-term economic advantages, particularly when integrated with advanced syngas processing technologies. The payback period for anaerobic digestion was 1 to 6 years, whereas gasification ranged from 5 to 25 years, depending on plant scale and syngas utilisation. India's National Bio-Energy Mission and WTE Policy provide incentives for biogas-based energy recovery, making anaerobic digestion an easier option for policy adoption. However, for gasification to become a feasible solution, targeted policy interventions are required, such as subsidies for upgrading syngas, research funding, and incentives for industrial biochar applications.

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