ABSTRACT

Rapid population growth, urbanization, and industrialization have led to a significant increase in Municipal Solid Waste (MSW), creating major challenges for sustainable waste management. The biodegradable fraction of MSW has considerable potential for energy recovery through anaerobic digestion or biomethanation. Biomethanation plants (BMPs) offer an environmentally sustainable solution by converting organic waste into biogas which are usable as electricity, compressed biogas (CBG), or fuel, while generating digestate that can be utilized as manure/compost/ soil conditioner, thereby reducing environmental pollution.

In India, biomethanation technology has been actively promoted through policy initiatives and financial support under programmes such as Swachh Bharat Mission (Urban and Gramin), SATAT, and various other Waste to Energy Programmes, involving multiple Central Ministries. Consequently, several BMPs have been commissioned over the past decade. However, a significant number of these plants have become non-operational or underperforming due to technical, managerial, financial, operational, challenges related feedstock, its quality, quantity etc. This highlights the urgent need for a systematic evaluation of BMP efficiency to ensure their sustainable integration into MSW management systems.

The performance of BMPs is influenced by multiple factors, including waste quantity and quality, plant capacity, reactor design, investment structure, operational costs, labour, revenue generation, biogas generation etc. In the absence of a national or state-level database on BMPs, primary data were collected through a detailed questionnaire covering technical, operational, managerial, and financial aspects. Data from 82 BMPs across 32 cities in 9 Indian states were compiled for analysis. A comprehensive assessment revealed widespread issues such as underutilization of capacity, inadequate waste segregation, poor feedstock quality, and financial non-viability, particularly in small-scale plants. Although most plants were operational, limited revenue from biogas and compost sales constrained long-term sustainability, underscoring the need for improved technologies, waste segregation practices, and viable business models.

Data Envelopment Analysis (DEA), a linear programming based technique for measuring the performance efficiency of organizational units called Decision Making Units (DMU's) was employed to evaluate the relative efficiency of BMPs, as it effectively handles multiple inputs and outputs and provides benchmarking insights. Using the CCR output-oriented model, efficiency scores were calculated for 30 BMPs (after excluding plants with incomplete or zero-value data) across five states. Four DEA models were developed to assess operational, technical, economic, and environmental efficiencies using relevant input–output variables.

The results showed that 86% of plants were operationally inefficient, while technical efficiency was relatively higher, with 56% of plants nearing optimal performance. Economic efficiency was observed in only 30% of the plants, and environmental efficiency was notably poor, with only one plant achieving full efficiency. Overall, most BMPs operated below optimal levels due to underutilization, high costs, and operational inefficiencies.

This study presents a comprehensive framework for evaluating MSW based BMPs in India and identifies efficiency gaps, best-performing plants, and benchmarking opportunities. The findings emphasize the need for standardized monitoring, centralized data systems, and targeted policy interventions to enhance the sustainability and effectiveness of biomethanation technology. While DEA provides valuable comparative insights, further plant level microanalysis and sector wide evaluations are necessary to replicate best practices and strengthen long term viability.