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Design of a Modular On-Site Anaerobic Digestion and Composting System for Organic Waste Valorisation: The COMBINE Project

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Abstract

Decentralized treatment of organic residues can reduce transportation requirements and associated environmental impacts, while retaining the benefits of resource recovery close to the point of waste generation (Castellani et al., 2023). This paper presents the concept and planned research methodology of the COMBINE project, which will develop a transportable and modular system integrating dry anaerobic digestion and aerobic composting for the on-site treatment and valorization of organic residues. The system will be adaptable to the type, quantity and physicochemical characteristics of the available feedstocks through the selection and combination of different treatment modules. The proposed approach is based on three main principles: the integration of anaerobic and aerobic biological treatment, the use of small autonomous and combinable modules, and the treatment of organic residues close to their point of generation. Its modular design is intended to support flexible capacity adjustment and application by small and medium-sized waste producers, in line with emerging decentralized waste-management approaches (Pahmeyer et al., 2022).

The planned configuration will comprise two 3 m³ solid-state anaerobic reactors, based on rotating-shaft and rotating-body designs, and two enclosed composting units with capacities of 12 and 6 m³. The experimental programme will investigate mixtures of manure and food residues, sewage sludge and food residues, and pig and poultry manure. Operating conditions will include retention times of 30 and 60 days, operation with or without heating, and the potential integration of heat pumps. Each feedstock will be examined in both anaerobic reactor configurations, while the resulting digestate will subsequently be treated in the two composting systems using different bulking agents and mixing ratios. Process performance will be monitored through sensors, telemetry, physicochemical analyses and targeted sampling during anaerobic digestion, the thermophilic composting phase and maturation. An Internet-of-Things-based monitoring and control platform, supported by predictive process models, will also be developed to enhance operational safety and facilitate process supervision with limited specialised personnel.

Environmental, economic and social performance will be assessed through Life Cycle Assessment, cost-benefit analysis and Social Life Cycle Assessment. The expected outcome is a flexible waste-to-value platform capable of supporting biogas recovery, the production of stabilised compost and the reduction of transport-related burdens, particularly in regions where seasonal waste generation and dispersed production limit the feasibility of centralised treatment.

Keywords: organic waste, dry anaerobic digestion, composting, modular treatment, circular economy

References

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