

Organic waste treatment: anaerobic digestion role as biorefinery

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INTRODUCTION

The constant increase in global population, economic development and urbanisation have resulted in an increase of energy demand and the generation of various types of wastes, especially municipal organic wastes, over the years (WORLD BIOGAS ASSOCIATION, 2021). To counter this trend European policies have been pushing for the introduction of more energy-efficient and/or less demanding technologies, and for greater use of Renewable Energy Sources (RES) (European Commission (EC), 2023). This has encouraged a greater propensity for material reuse and the energy use of waste, considering landfill disposal as an extreme solution to be minimized as much as possible. From all this, it is clear that the collection and treatment of Municipal Solid Waste (MSW) have a significant impact on the waste management system. Consequently, there is now a search for feasible solutions that can reduce the energy demand for the service or compensate in other ways than by using traditional sources.

Organic waste treatment through anaerobic digestion (AD) has emerged as a promising technology for renewable energy generation, environmental impact mitigation, and nutrient recycling (Piadeh et al., 2024). AD processes convert organic waste into biogas, which can be used as a renewable energy source in substitution to traditional fossil fuels, and digestate, a nutrient-rich by-product. However, the management of digestate remains a challenge due to its volume and potential environmental impact. In order to satisfy the circular economy's appeal for a contemporary society, research efforts are focused on properly treating the AD digestate or suggesting innovative uses that can make use of the digestate as a renewable resource (Wang et al., 2023).

To this concern Hydrothermal Carbonization (HTC) as gained relevant attention in the literature as a path to exploit AD by-products in an environmentally sound way (Cao et al., 2019). For example Zhao et al. investigated the efficiency of phosphate recycling from digestate (Zhao et al., 2018), while Rosas-Mendoza et al. investigated the valorization of complex organic wastes from municipal solid waste through AD and HTC, concluding that those represent promising alternatives for valorization. (Rosas-Mendoza et al., 2024)

Although some attempts have been made to address this energy demand and further utilization AD by-products, research typically investigated HTC only from the process perspective and, from the above exposed literature it emerges that some issues for organic waste treatment plant integration with HTC, like the consideration of competing objectives from the plant manager point of view, have not yet fully been addressed. This work aims at filling this gap in order to provide a tool that allows to identify the optimal system configuration, supporting economic performances of the plant as well as environmental ones. The model has been subsequently applied to a local case study to unveil its practicality and utility.

MATERIALS AND METHODS

In this study, we developed a model for an organic waste treatment plant that incorporates the use of digestate produced from the AD process to generate biochar through HTC. The biochar produced can be utilized within the plant to reduce its dependency on external fossil fuel sources or sold to generate revenue for the plant's managing company. The model includes detailed simulations of the anaerobic digestion plant, focusing on materials and energy flows. Subsequently, the HTC process parameters, in terms of plant size and digestate dedicated to this path, have been considered as optimization variables to identify optimal plant configuration. A multi-objective optimization method was employed to consider both economic and environmental goals from the company's perspective, aiming to find an optimal compromise solution. The integration of biochar utilization within the plant was analyzed to assess its impact on overall energy consumption and greenhouse gas emissions. Additionally, economic analyses were conducted to evaluate the potential revenue from biochar sales and the cost savings from reduced fossil fuel usage. To this purpose a multi-objective genetic algorithm (MOGA-II) has been adopted. This approach not only enhances the sustainability of the waste treatment process but also provides a viable economic incentive for plant operators to adopt innovative waste-to-energy technologies.

RESULTS

The implementation of the proposed model to a real world case study showed to yield significant environmental and economic benefits. By utilizing biochar produced from the digestate, the plant can reduce its reliance on external fossil fuel sources, leading to a decrease in greenhouse gas emissions and overall energy consumption. The multi-objective optimization method ensures that the solution balances economic gains with environmental sustainability. Financially, the sale of biochar could generate additional revenue streams for the plant, enhancing

its economic viability. Furthermore, the improved efficiency of the waste treatment process could result in lower operational costs and increased environmental benefits. The model's validation with real-world data suggests that these benefits are achievable and scalable, providing a robust framework for other waste treatment facilities to adopt similar technologies. Overall, the integration of biochar production and utilization within the plant represents a promising step towards more sustainable and economically viable waste management practices

CONCLUSIONS

In conclusion, the developed model for the organic waste treatment plant demonstrates a viable approach to enhancing both environmental sustainability and economic viability. By integrating the production and utilization of biochar from digestate, the plant can significantly reduce its dependency on external fossil fuels and lower greenhouse gas emissions. The multi-objective optimization method ensures a balanced consideration of economic and environmental goals, providing a robust framework for decision-making.

Future developments could focus on further refining the optimization algorithms to enhance efficiency and scalability. Additionally, exploring the potential for integrating other renewable energy technologies, such as solar or wind power, could further reduce the plant's carbon footprint. Research into the long-term impacts of biochar application on soil health and crop yields could also provide valuable insights for broader agricultural applications. Overall, this study lays the groundwork for innovative waste-to-energy solutions that can be adopted by waste treatment facilities worldwide

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