Environmental Performance of Waste-to-Energy in Promoting Sustainable Food Waste Management

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Abstract

Mismanagement of organic waste especially food waste (FW) in municipal waste through landfill method amplifies the lost opportunity for circular nutrient recovery. Large-scale FW disposal has an adverse impact on the environment and causes a financial strain but has the potential as low-cost feedstocks for biological process by producing valuable biochemicals such as biogas. Anaerobic digestion (AD) is one of the promising technologies available to produce value-added products from FW among other conventional alternatives such as composting and incineration. Large-scale food waste disposal has had an adverse impact on the environment and causes a financial burden. AD is a potential technology for managing food waste compared to conventional disposal options (such as landfilling, incineration, and composting) through the production of biogas.

AD of food waste improves the management of organic wastes and promotes the generation of renewable energy along with the recycling of nutrients (Feiz et al., 2020). The global attraction in assessing the impacts of valorizing FW can be attributed to the prominence in devising an alternative that could address issues associated with food loss and waste contributing to landfills and unsustainable consumption. Hence, providing insight towards the environmental performance of AD in producing FW-sourced biogas is essential to incorporate it on a large-scale and understand its benefits and drawbacks on an environmental-scale. This paper aims to assess the environmental performance and impacts of sourcing biogas from FW in the context of a Malaysian scenario.

Numerous studies have reviewed on the applicability of biogas as a renewable energy outlining its associated benefits, challenges and progress (Lim et al., 2021; Mhd Syahri et al., 2022; Nevzorova & Kutcherov, 2019; F. Xu et al., 2018) indicating a well-established interest towards its capability. With circular economy (CE) gaining momentum and traction, repurposing what is considered a waste into useful commodity is ideal and should be prioritized to enhance circularity while simultaneously reducing the amount of waste disposed in landfills. It is estimated that more than 26500 t of solid waste are disposed to operating landfills with 1.1 kg per capita in Malaysia daily (Kamaruddin et al., 2017). On the other hand, understanding the environmental impacts and benefits associated with sourcing biogas from FW is crucial to avoid burden shifting while attempting to reduce existing impacts. Thus, life cycle assessment (LCA) is a highly relevant tool that can be employed to quantify these impacts and identify significant hotspots throughout the chain process based on the ISO 14040/44 standards (ISO 14040, 2006; ISO14044, 2006).

The LCA methodological framework was also used according to the four fundamental phases of LCA based on the ISO 14040/44 series. The analysis considers the gate-to-gate approach using an LCA software (SimaPro 9) to perform the calculation. Operational data from a small-scale composting plant was obtained with the functional unit (FU) of 1 ton of FW to quantify the environmental impact. The goal of this analysis is to assess the environmental performance and hotspot of generating biogas from FW through anaerobic digestion process. The boundary for this analysis is set as 'gate-to-gate' with the functional unit (FU) defined as 1 ton of FW processed. Defining the FU is crucial in any LCA study as it serves as the reference basis for all calculations surrounding the impact assessment in a quantified description (Arzoumanidis et al., 2020). Figure 1 represents an overview of the plant's system boundary in generating biogas energy. EcoInvent 3.8 and Agri-Footprint 5.0 were chosen as the background library for the LCA calculation. When available, dataset from Malaysia were used as input in this analysis to closely represent the local data but substituted with a global dataset if unavailable. ReCiPe 2016 was selected as the method to calculate the impacts at both midpoint and endpoint level. As there are often sources of uncertainty surrounding the data used for LCA methods, uncertainty analysis helps address this issue by calculating the total degree of uncertainty associated with the parameters and model selections by estimating the confidence interval for the results.

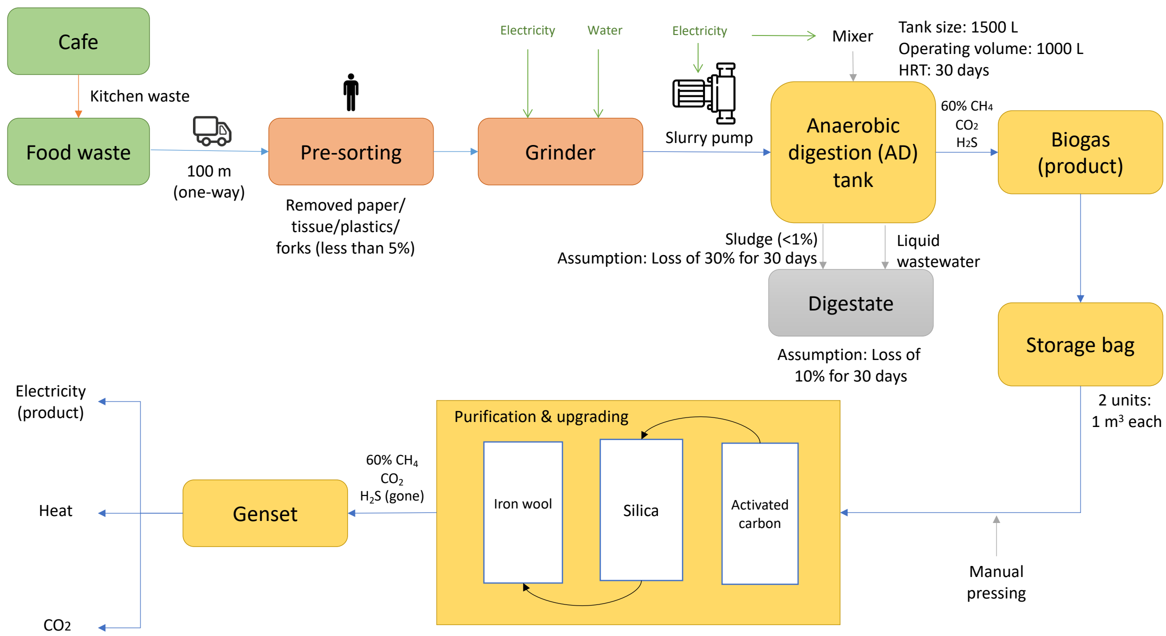

Figure 1: Schematic diagram of the small-scale biogas generation plant.

This study considers the environmental impact on the operational phase of converting the food waste to biogas that will be utilised as a source of electricity. This includes the consumption of raw materials and environmental emissions of the overall process. In treating 1 ton of FW, the electricity consumption was shown to have a high potential impact particularly on the global warming potential (GWP) and towards the overall environmental impact due to the AD process. The valorisation of FW also had a greater effect on the production of fine particulate matter (PMFP), terrestrial acidification (TAP), and terrestrial ecotoxicity potential due to the emission of nitrogen oxides and ammonia during the AD process (TETP). The transportation of raw materials during the landfill stage had high potential impacts, according to C. Xu et al. (2015), who found that there was less stress on the GWP because the distance from the source of FW to the treatment centre was short. However, this stress can increase as the distance increases. Despite the fact that treating FW by AD has been the subject of numerous LCA research, it is challenging to directly compare the findings of different studies since they use different system boundaries, functional units, assumptions, and LCA methodologies.

The outcome of this study would help decision-makers by offering useful information for further development of the technology and lessen reliance towards landfills. From this finding, processes from the valorization of FW treatment that contributed to the degradation of the environment can be mitigated by considering the circularity of its supply chain and setting precedent for a sustainable waste management system as the recovered resources can be recycled back into the chain. This would also aid future research in adopting renewable energy alternatives and moving towards achieving Agenda 2030 and the Sustainable Development Goals.

Keywords: *Life cycle assessment, biogas, food waste, anaerobic digestion*

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