# Prefeasibility analysis of different anaerobic digestion upgrading pathways using organic kitchen food waste as raw material

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Food waste and losses are generated in all links of the food value chain. It has become a global problem associated with food safety factors and environmental impacts that requires immediate action. In fact, the Food and Agriculture Organization of the United Nations (FAO) estimated that one third of global food production is lost or wasted along the supply chain [1]. Food waste is all food that is discarded or incinerated from harvest (slaughter, recovery) to processing or marketing. Commercial, residential, and industrial solid waste generated at the municipal level is referred to as municipal solid waste (MSW) [2]. The world generates approximately 2 billion tons of municipal solid waste per year, and at least 33% is not safely disposed of into the environment. The composition of MSW differs according to socioeconomic and cultural context. However, it is estimated that a person generates between 0.3 and 0.74 kg of MSW per day and about 60% represents organic waste [3]. Biogas production has attracted great interest in the last decades due to its applications, the simplicity of the process and the implementation of different feedstocks such as organic food waste (OKFW). In fact, the global biogas industry has increased by more than 90% between 2010 and 2018 [4] and has been successfully implemented in European countries, the United States, and some Latin American countries [5] [6]. Biogas is a gaseous mixture composed mainly of methane and carbon dioxide, with traces of impurities [7]. Anaerobic digestion (AD) is the main process that results in biogas generation [8]. Although the main route of AD focuses on biogas production, recent research studies have shown that AD could be designed to produce volatile fatty acids (VFA), either separately or simultaneously [9]. VFA are short-chain linear carboxylic acids with low molecular weight, containing between six or less carbon atoms, including acetic acid, propionic acid, iso-butyric acid, n-butyric acid, iso-valeric acid, among others [10]. They are important precursors of biopolymers (i.e., polyhydroxyalkanoates - PHA) and other valuable products, such as biofuels, alcohols, aldehydes, and ketones. The increased application areas of VFAs have led to the intensification of research work on alternative production processes [11]. The aim of this work is to evaluate in techno-economic terms the best route to obtain biogas and VFA through organic kitchen food waste (OKFW) anaerobic digestion. For this purpose, an experimental and a simulation section are considered. Six scenarios are evaluated experimentally. The first three scenarios involve biogas production from (Sc1) dry and thermally pretreated feedstock, (Sc2) wet feedstock and (Sc3) dry feedstock. Then, VFA production from (Sc4) dry and thermally pretreated feedstock, (Sc5) wet feedstock and (Sc6) dry feedstock is evaluated. The best results for each process will be input data to the simulations. Two scenarios for biogas production are considered in the simulation: (Sc1) biomethane production and (Sc2) energy production. For VFA production, the separation of the acids by distillation to obtain individual products is considered. The bioprocesses were simulated in Aspen Plus V.9.0 software where the material and energy balances are obtained. Then, for the economic analysis, the Aspen Economic Analyzer V.9.0 software is used. The economic feasibility will be defined from the calculation of the net present value, cash flows and return on investment based on the Peter and Timerhaouse methodology.

The methodology proposed includes an experimental stage (OKFW characterization, biogas production and VFA) and a techno-economic analysis stage. The characterization was performed based on international standards and in triplicate. Chemical characterization was performed in terms of chemical composition (holocellulose, lignin, extractives, ash, fats), solids analysis (total and volatile solids), proximate analysis (fixed carbon, volatile material, ash, and moisture) and elemental analysis (from literature correlations). Biogas production was developed according to the VDI 4630 standard method. Sludge was used as inoculum from an anaerobic sludge reactor of a coffee processing wastewater treatment plant located in Chinchiná, Caldas. VFA production was carried out as reported by Iglesias R in [12]. The quantification of VFA was carried out through the colorimetric method described by Montgomery in [13]. Biogas and VFA production were performed considering six scenarios (Sc): (i) biogas production from dry feedstock with pretreatment (autohydrolysis); (ii) dry feedstock; (iii) wet feedstock; (iv) VFA production from dry feedstock with pretreatment; (v) dry feedstock and (vi) wet feedstock. The techno-economic analysis was carried out based on the conceptual process design. The OKFW flow considered was 207.22 tons/day (dry basis) corresponding to the amount of organic waste disposed at the oasis landfill in Sincelejo. The conceptual design was carried out based on the methodology reported by Moncada et al in [14]. Matter and energy balances were obtained from Aspen Plus v9 software. The results of the experimental stage were used as input data (i.e., performance, operating conditions) in the design of the processes. The technical analysis of the proposed systems was evaluated in terms of mass and energy indicators (i.e., process mass intensity, mass rate, specific energy consumption, resource energy efficiency index). Finally, the economic analysis was performed by applying the methodology reported by Petter and Timerhouse [15]. The economic feasibility of OKFW valorization was defined based on the Net Present Value (NPV). The Colombian context was considered to define the annual interest rate of 17% and income tax. The cost of capital was obtained from the Aspen Process Economic Analyzer v.9.0 software. For the case of VFA production, a sensitivity analysis was performed to determine the minimum selling price for the process to be profitable.

The chemical characterization of the OKFW was 30.3%w/w extractives, 9.19% w/w fats, 28.56% cellulose, 7.42% hemicellulose, 19.84% lignin and 4.68% ash. These results show the potential of the raw material for anaerobic digestion processes due to its high carbohydrate content (e.g., cellulose, pectin, starch). The high content of extractives evidences the potential of this raw material for the extraction of bioactive compounds. These results present similarities with reports by other authors such as Lopez M et al. in [16]. The solids characterization was 22.1% volatile solids and 23% total solids. The proximate analysis presented contents (on dry basis) of ash, volatile material, fixed carbon 6.04%, 77.80% and 16.16% respectively. The VFA production obtained concentrations of 31, 26.53 and 20.23 g VFA/L at stages 4, 5 and 6 in a period of 10 days, respectively. This shows that the water content present in the raw material directly affects the accessibility of the substrate. In addition, pretreatment favored higher substrate accessibility. Similar results have been reported in the literature. For example, Nuo Liu (2018) in [17] obtained a maximum VFA concentration of 26.16 g VFA/L from food waste over a period of 5 days. Liangwu et al. (2018) in [18] obtained a production of 56.7 g VFA/L over a period of 7 days using activated sludge, furthermore, the results also showed that pretreatment with acid and alkali improved VFA production by 12.5 times. 225 ml, 220 ml and 197 ml of biogas were produced for scenarios 1,2 and 3 respectively. The trend of these results is explained by the above mentioned. These results are similar to those of other authors. These report that pretreatment techniques favor biogas generation by decreasing the hydrolysis time of biopolymers, as well as proteins and lipids [19]. Finally, the techno-economic analysis reflected that the scenarios aimed at VFA production present greater feasibility than the use of OKFW for biogas production. In economic terms, VFA production has a shorter payback period due to higher sales costs. The capital and operating costs of VFA production are similar to those of biogas production. Finally, the sensitivity analysis showed that VFA sales costs can vary between 0.3 USD/kg and 2 USD/kg to maintain economic viability. These values represent the selling price of the cheapest VFA (acetic acid) and the most expensive (butyric acid). In conclusion, the use of OKFW for VFA production is more technically and economically feasible than biogas production.

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