Theoretical energy potential of biogas produced from agricultural waste in Sucre, Colombia : Subregional distribution .

J. Hernández R[1], J. Cabello E, M. Ortiz S[2], D. Otero M[1], J. Salcedo M[1], C. Cardona A[2], C. Meza S[1], K. Salgado A[1], C. Novoa P[1].

*Corresponding author: ccardonaal@unal.edu.co

Presenting author: J. Hernandez R, jorge.hernandez@unisucre.edu.co

Conference topic: Agricultural and/or livestock waste

Keywords: Subregional distribution, anaerobic digestion, geospatial location

[1]Grupo de Investigación en Procesos Agroindustriales y Desarrollo Sostenible (PADES), Facultad de Ingeniería, Universidad de Sucre, Sincelejo, Colombia

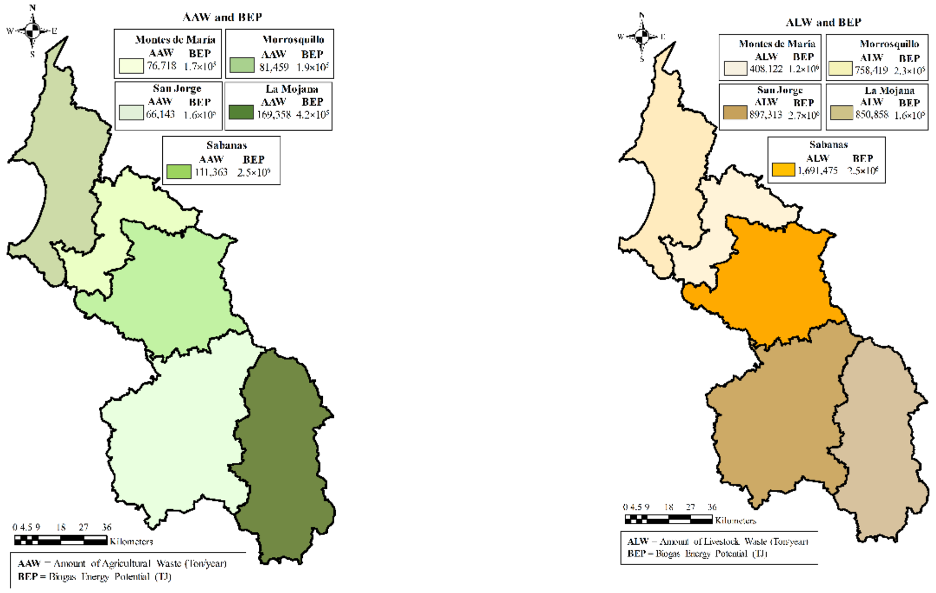
[2]Instituto de Biotecnología y Agroindustria, Departamento de Ingeniería Química, Universidad Nacional de Colombia Sede Manizales. Km 07 vía al Magdalena, Manizales, Colombia.

The growing energy demand and global warming has driven the adoption of renewable energy sources (Aravani et al., 2022). The energetic valorization of agricultural waste through anaerobic digestion (AD) for biogas production is a promising alternative because it generates clean energy, reducing greenhouse gas emissions, soil pollution, and water contamination (Gao et al., 2021). Agricultural waste production reaches 146 billion tons worldwide, with Colombia contributing approximately 126 million tons (Gómez-Soto et al., 2019). Despite its recognized energy potential, the utilization of these residues varies significantly across regions, depending on factors such as available infrastructure, technical capacity, and waste characterization. The department of Sucre has a strong agricultural vocation, contributing 11.7% to its GDP and encompassing over one million hectares dedicated to this sector. To facilitate resource management and development, Sucre is conceptually divided into five subregions: Morrosquillo, Montes de María, Sabanas, San Jorge, and La Mojana (PDD, 2024). Although studies on its biogas potential have been conducted, they have primarily focused on areas with established waste management infrastructure (González-Castaño et al., 2021). However, the precise geographic distribution of this potential remains undetermined, posing a challenge for its integration into strategies that would enable the efficient utilization of these resources in rural areas.

This study assesses the biogas production potential of agricultural waste generated by the Sucre department located in Colombia. The residues were selected considering the potential results extrapolation to other world regions with the same crops. The waste was characterized based on quantity, composition, and energy yield to generate key information that supports its integration into rural sustainability strategies and the transition to more sustainable energy systems. The most significant crops and livestock activities were identified (DANE, 2024; MINAGRICULTURA, 2024; PDD, 2024). The quantification of agricultural waste considers crop types, production areas, yields per hectare, and waste generation factors. In the livestock sector, waste estimates were based on generation factors and the age structure of the animal population. Agricultural waste generation by subregion was determined using geographic and statistical data from official sources (UPRA, 2024), using ArcGIS 10.5 and the Spatial Analyst Tools, areas of high and low waste generation were identified, along with their energy potential (Luna-delRisco et al., 2024). Samples from 10 types of waste were collected in triplicate, dried, and ground (≤1 mm) to ensure homogeneity in the analyses. Chemical, proximate, and elemental characterization was conducted following international standards (ASTM, NREL, AOAC), prioritizing waste types with limited data in the literature. The biogas production potential was estimated using the Buswell & Sollo, 1948 model, while the energy potential was calculated following the methodology of Sagastume Gutiérrez et al., 2022. The anaerobic digestion process was also simulated in Aspen Plus using the Bechara, 2022 model to estimate theoretical biogas generation.

The agricultural residues with the highest annual generation were rice straw (148,619 tons), cassava stems, leaves, and rhizomes (68,696 tons), maize stover (20,106 tons), yam stover (16,420 tons), plantain leaves, pseudostems, and rachis (38,646 tons), coconut pruning waste (3,049 tons), oil palm pruning waste (14,622 tons), and mango pruning waste (5,260 tons). In the livestock sector, the highest manure generation was associated with cattle, pigs, and poultry, with annual productions of 10,664, 445, and 795 tons, respectively. The proximate composition of agricultural waste showed moisture content ranging from 41% to 93%, volatile solids from 13% to 89.4%, volatile matter from 66.8% to 83.8%, ash content from 5.2% to 18.7%, protein content from 1.7% to 20.3%, and starch content from 3.0% to 25.0%. The chemical analysis revealed cellulose content between 5% and 46.3%, hemicellulose between 1% and 50%, and lignin between 1% and 34%, which are parameters for biodegradability and biogas production efficiency. The elemental analysis indicated variations in nitrogen (1%–5.1%), carbon (35.9%–54.3%), hydrogen (5%–7.5%), and oxygen (33.1%–57.9%), which are fundamental values for estimating the energy potential of these residues.

The theoretical analysis of biogas production potential reveals that pig manure has the highest energy values, with 199.4 MJ and 1,013.4 mL biogas/gVS, followed by plantain leaves (156.3 MJ and 875.1 mL biogas/gVS) and avocado pruning waste (150.6 MJ and 799.5 mL biogas/gVS). Cattle manure (139.2 MJ and 833.3 mL biogas/gVS) and poultry manure (134.1 MJ and 845.8 mL biogas/gVS) also exhibit significant potential. Among agricultural residues, cassava stems (131.7 MJ and 805.8 mL biogas/gVS) and coconut palm residues (130.5 MJ and 804.7 mL biogas/gVS) show acceptable performance. In contrast, plantain pseudostems (91.9 MJ and 669.8 mL biogas/gVS) and rice straw (99.9 MJ and 703.2 mL biogas/gVS) have lower energy potential but still present high theoretical biogas yields. These results indicate that while livestock waste generates more energy, agricultural residues can also be competitive for energy recovery and biogas production (Ferdeș et al., 2022). These results provide an opportunity to investigate co-digestion with different waste mixing ratios. The simulation results confirmed the potential of pig manure (2,460.6 kg biogas/h) and plantain pseudostems (204.9 kg biogas/h) as substrates for biogas production through anaerobic digestion, with a significant difference in the conversion efficiency of both residues. The individual biogas generation and energy potential results for agricultural and livestock residues were integrated by subregion, as shown in **Figures 1a** and **1b**. The Sabanas and San Jorge subregions exhibited the highest agricultural waste generation rates, while the highest biogas energy potential (BEP) was observed in the Sabanas and La Mojana regions. The highest generation rates for livestock waste were recorded in the Sabanas and San Jorge subregions, where the highest BEP values for the livestock sector were also concentrated.



a. Agricultural waste **b.** Livestock waste.

Figure 1. Quantity of waste generated by subregions in the Sucre department.

The results spatially indicate where the highest potential for biogas facilities is in the Sucre department based on at least two factors. To determine the size and location of these potential facilities, advanced techniques incorporating these and other criteria are necessary to define spatial clusters at a detailed level. In conclusion, biogas can be profiled as an option to upgrade agricultural residues based on the high opportunity of energy production applying the anaerobic digestion processes. Moreover, implementing software tools such as ArcGIS plays a key role in defining the location of biomass upgrading processes based on resource availability. Finally, the biogas production potential for more than 30 residues was elucidated to design new renewable energy systems to provide decentralized energy.

Referencias.

Aravani, V. P., Sun, H., Yang, Z., Liu, G., Wang, W., Anagnostopoulos, G., Syriopoulos, G., Charisiou, N. D., Goula, M. A., Kornaros, M., & Papadakis, V. G. (2022). Agricultural and livestock sector's residues in Greece & China: Comparative qualitative and quantitative characterization for assessing their potential for biogas production. Renewable and Sustainable Energy Reviews, 154, 111821. https://doi.org/10.1016/j.rser.2021.111821

Bechara, R. (2022). Improvements to the ADM1 based Process Simulation Model: Reaction segregation, parameter estimation and process optimization. *Heliyon*, *8*(12), e11793. https://doi.org/10.1016/j.heliyon.2022.e11793

Buswell, A. M., & Sollo, F. W. (1948). The Mechanism of the Methane Fermentation. *Journal of the American Chemical Society*, *70*(5), 1778–1780. https://doi.org/10.1021/ja01185a034

DANE. (2024). *National Administrative Department of Statistics*. https://www.dane.gov.co/
Ferdeș, M., Zăbavă, B. Ștefania, Paraschiv, G., Ionescu, M., Dincă, M. N., & Moiceanu, G. (2022). Food Waste Management for Biogas Production in the Context of Sustainable Development. *Energies*, *15*(17). https://doi.org/10.3390/en15176268
Gao, X., Tang, X., Zhao, K., Balan, V., & Zhu, Q. (2021). Biogas production from anaerobic co-digestion of spent mushroom substrate with different livestock manure. *Energies*, *14*(3), 1–15. https://doi.org/10.3390/en14030570
Gómez-Soto, J. A., Sánchez-Toro, Ó. J., & Matallana-Pérez, L. G. (2019). Residuos urbanos, agrícolas y pecuarios en el contexto de las biorrefinerías. Revista Facultad de Ingeniería, 28(53), 7–32. https://doi.org/10.19053/01211129.v28.n53.2019.9705.
González-Castaño, M., Kour, M. H., González-Arias, J., Baena-Moreno, F. M., & Arellano-Garcia, H. (2021). Promoting bioeconomy routes: From food waste to green biomethane. A profitability analysis based on a real case study in eastern Germany. *Journal of Environmental Management*, *300*(January), 1–8. https://doi.org/10.1016/j.jenvman.2021.113788
Luna-delRisco, M., Mendoza-Hernández, S., Da Rocha Meneses, L., González-Palacio, M., Arrieta González, C., & Sierra-Del Rio, J. (2024). Geospatial analysis of hydrogen production from biogas derived from residual biomass in the dairy cattle and porcine subsectors in Antioquia, Colombia. *Renewable Energy Focus* , *50*(April). https://doi.org/10.1016/j.ref.2024.100591
MINAGRICULTURA. (2024). *Ministry of Agriculture and Rural Development*. https://www.minagricultura.gov.co/paginas/default.aspx
PDD. (2024). *Sucre Land of Opportunities Development Plan 2024-2027*. https://www.sucre.gov.co/planes/plan-de-desarrollo-sucre-tierra-de-oportunidades-2024
Sagastume Gutiérrez, A., Mendoza Fandiño, J. M., Cabello Eras, J. J., & Sofan German, S. J. (2022). Potential of livestock manure and agricultural wastes to mitigate the use of firewood for cooking in rural areas. The case of the department of Cordoba (Colombia). *Development Engineering*, *7*(November 2021). https://doi.org/10.1016/j.deveng.2022.100093
UPRA. (2024). *Municipal Agricultural Evaluations - EVA*. https://upra.gov.co/es-co/Paginas/eva.aspx