Biomethane production potential from selected agro-industrial waste in Colombia and perspectives of its use in vehicular transport

F Posso$^1$ and N Mantilla$^2$

$^1$ Grupo de Investigación en Nuevas Tecnologías, Universidad de Santander, Bucaramanga, Colombia
$^2$ Grupo Ambiental de Investigación Aplicada, Universidad de Santander, Bucaramanga, Colombia

E-mail: directormgcti@udes.edu.co, ne.mantilla@mail.udes.edu.co

Abstract. The proper disposal and management of the waste generated from the agro-industrial activity in Colombia constitute a problem with environmental, economic and social implications, such that its solution constitutes a matter of national interest. Thus, the objective of this work is to estimate the potential of biomethane production by biochemical conversion of selected agro-industrial waste and, its use is proposed in vehicular transport currently moved by natural gas. Methodologically, the study relies on official statistics of the national entities that report the volume of crops and waste generated yearly. Three crops were selected, applying criteria of abundance, geographic distribution, and energy properties: sugarcane, palm oil, and rice; the waste considered for each of them were sugarcane bagasse, empty fruit bunches of palm oil and rice straw. The conversion of said waste to energy vectors is by anaerobic digestion producing biogas, and from its purification, biomethane. The volume of biomethane obtained was $1,290 \times 10^6$ m$^3$/year. This important value was compared with studies from other countries. The prospects for the final use of biomethane as vehicle fuel are promising. So, biomethane is a potentially attractive develop option in Colombia, which would make it necessary to carry out more specific and detailed studies include economic, environmental and social aspects that would positively impact the route to the sustainable development of the country.

1. Introduction

The resurgence of renewable energies (RE), is evident in the growing participation of the global energy market, and the energy matrix of many countries and regions [1]. Within the RE, biomass is one of the most attractive as a starting point to produce different energy vectors due to its availability, energy potential, and competitive cost [2]. In Colombia, one of the most sources of biomass are the residues of agriculture activity. Its production is close to 17.1 million tons [3], a large part can transform into biofuels (liquids, and gases) where its use is mainly thermal and electricity and could supplying needs in different sectors of the economy.

In the case of biomethane, one of its routes of production is by anaerobic digestion of the biomass. Where biogas purification derived biomethane, with a concentration equal or greater than 94%, which stands out for its energy potential and its contribution to the efficient management of agricultural and urban waste and the mitigation of environmental pollution, in all areas and forms [4]. These comparative advantages of this vector explain the growing interest in its development as it is outlined as a
compliment, in the short term, of fuel vectors based on fossil fuels, and as a substitute in the medium term [5].

Thus, studies on the production of biomethane from biomass are broad-spectrum, such as the analysis of the effect of biomass pretreatment to favor its conversion to biogas [6], the selection of the biogas purification process considering economic criteria and the final use of biomethane [7]; the use of natural gas transportation and distribution infrastructure to achieve greater penetration of biomethane in the energy market as a result of the reduction in the associated costs for it [5]; the optimization of the selection of the location of the process plant for the production of biomethane based on the minimization of supply chain costs based on the distributed nature of the raw material [8].

The first step before any intention of proposing a development project for the use of biomethane is the estimation of the theoretical potential obtainable from residual biomass that also has been studied. In that sense, estimates are reported in Sicily based on biomass of plant and animal origin [9]; in Chile, assessing the potential of biomethane production, mainly from forest residues [10]; in China [11], evaluating the potential, theoretical and technical, of the five principal biomass resources for biomethane production; globally, a prospective study by 2050 of the potential of biomethane produced by anaerobic digestion and gasification is known, together with the capture of carbon dioxide [12]. Finally, a theoretical approach for the estimation of the potential of biomethane by anaerobic digestion of lignocellulosic biomass based on a predictive statistical model that combines a linear canonical model and a quadratic model, based on the main structural components of biomass: cellulose, hemicellulose and waste, analyzing a broad knowledge base of works reported in the literature [13].

Now, with focus on Colombia, from the documentary review, it is obtained that the study of biomethane as an energy vector is incipient, several studies have been reported, as the evaluation of the biomethanization potential of the mixture of certain organic waste: organic fraction of municipal solid waste, pig manure, cocoa shells and pods, residues of the bottled fruit and rice straw beverage industry from different productive sectors [14]. The production of biogas and biomethane from residues of fishing activity has also been evaluated for the Tumaco region, in the southwest of the country. From the annual production of fishing waste, 500 ton/year, is obtained an electric generation potential of 489 MWh, sufficient quantity to meet the needs of electrical energy and thermal energy for cooking in more than 200 households of fishermen in that region, with a positive impact on their quality of life [15].

In another experimental study, the effect of the organic load of the cage chicken manure on the potential of biomethanization was evaluated using as inoculum the bovine manure sludge, obtaining that the chicken manure is a potential substrate to be degraded by anaerobic digestion and that the yield of the process is directly proportional to the substrate concentration [16]. The production potential of biomethane and biohydrogen from coffee, cocoa mucilage and, pig manure has also been estimated utilizing an experimental Box-Behnken type design, both individually and together, given the compound with the best potential for biomethane production.

Based on the above, the majority of studies on biomethane in Colombia are limited to the assessment of its production potential for specific biomass through direct experimentation, under controlled conditions, which limits its scope and replicability. In this work the estimation of the potential of biomethane production by anaerobic digestion of the biomass generated in the processing of three crops selected for their abundance, geographic distribution and, properties, for their transformation into biogas and subsequent purification to biomethane, is presented, valuing its use as a complementary fuel to vehicular natural gas.

The contribution of this work can be seen from different dimensions: scientific, contribute to broadening the knowledge base on the production and, the potential use of a type of secondary energy in the country with clear competitive advantages. Environmental, contributing to solving a problem of disposal and management of large volumes of agro-industrial waste. Economic, by valuing a waste whose current energy use is inefficient and localized. Energy, by proposing an alternative of substitution of natural gas as a fuel for vehicles, releasing volumes that can be directed to other purposes with greater
added value and, at the same time, avoiding the consumption of a fossil primary source whose reserves are limited [17], which also gives it the strategic nature in favor of Colombia's energy autonomy.

2. Materials and methods
Methodologically, the documentary information was obtained from different sources and official statistics on the main crops of Colombia by departments (provinces), taking as criteria of classification: the biomass produced (ton), the cultivated area (He) and yield (ton/He). From the resulting classification, the three crops with the greatest presence and relevance in the country are selected, the basis of this study; subsequently, attending Marrugo et al 2016 [18].

On the characterization of the residual biomass of agro-industrial activities in Colombia, the most attractive waste is selected as the primary source for obtaining biomethane. From this procedure, it turns out that sugarcane, palm oil, and rice qualify as the three base crops; while the bagasse, rachis (empty fruit bunches of palm oil) and straw, constitute, in their order, the selected waste. The values of the biomass available, biogas and biomethane produced, are obtained from the application of energy conversion models and specification of the residual factors, operational parameters, yields and percentage of purification, indicated in previous studies [6,19]. Finally, the useful energy obtainable is quantified based on the calorific value of biomethane, proposing its use in vehicular transport as an alternative energy vector.

3. Desarrollo

3.1. Sugarcane crop
In 2018, the Sugarcane (SC) production of the country was 25 million tons; Colombia has privileged weather in the region of geographical valley of the Cauca River, where it is possible to plant and harvest sugarcane the whole year. In this region, there are 13 sugar mills, six of these, produce sugar and ethanol through attached distilleries. The cultivated land is about 243,232 hectares, with a yield of 132.9 cane tons per hectare in 2017. The main participation is from the department of Valle del Cauca, with 76.3% of cultivated land, the second main is the department of Cauca with a participation of 17.7%. The total area of these departments is 55,500 km², according to 2014 agricultural census in Colombia, 4% of this territory is cultivated with sugarcane, 30% of the total area cultivated in concentrated in Palmira, Candelaria and El Cerrito towns [20].

The sugarcane has two main biomass residues, sugarcane bagasse (SCB), an agro-industrial waste, and straws, a crop residue. Calculated with a yield of 0.15 ton on SCB per ton of SC, were produced 3,755,425 ton dry SCB in 2018, about 7 million ton of wet SCB at the exit of the mills with moisture close to 50%.

According to [21], the maximum value of production of 299.3 m³ per ton of volatile solids, which could result in 1,090 million m³ of methane per year from SCB in Colombia. The study shows the need for pretreatment before anaerobic digestion to obtain it yields in methane production. In this case, the pretreatment was performed with 10% ammonia and 50% ethanol during 24 hours and 70°C. The anaerobic digestion had a duration of 45 days and 37°C. The study does not report the costs of the processes used, however, they showed that it is possible to obtain a high amount of biomethane production.

3.2. Palm oil crop
Colombia is the fourth producer of palm oil in the world and the first in America; in 2018, it is reported a harvested area of 516,961 hectares with palm oil production of 1,619,209 tons [22]. The average yield of empty fruit bunches per ton of crude oil palm is 38% [23], therefore, the production of empty fruit bunches in Colombia was 602,920 tons. Through thermophilic solid-state anaerobic digestion, in [19] were able to convert 223.2 m³ from one ton of volatile solids. The anaerobic digestion was realized to conditions of temperature and time of 55°C and 45 days, respectively.
3.3. Rice crop

Colombia had harvested in 2018 a total area of 530,323 hectares [24], 30% of the total production is located in the department of Tolima, the departments of Meta, Casanare, and Huila, each one has about 16% of the total production. These lands are mainly flat land, where it could be possible for the mechanized recollection. The total rice straw production was 795,485 tons/year. The biomethane production was favored with alkaline thermal pretreatment (5% of calcium hydroxide to total solid), where the highest production was 203 m3 metano/ton VS. The anaerobic digestion was development at 37°C and an average of 30 days [25].

4. Result and analysis

4.1. Potential

Table 1 shows the results of the estimation process of biomass potential, crop selection and production of biogas and biomethane, appreciating the high volume of the latter that catalogs it as an attractive vector to develop with a view to its gradual penetration in the energy supply of secondary energy in Colombia.

| Table 1. Selected crops and potential biomass production in Colombia. 2018. |
|-------------------------------------------------------------|
| **Production** | **Residue Factor** | **Residue** | **Dry Residue Produced** |
| Sugar cane | 0.15 ton dry bagasse/ton SC | SCB | *3,755,425 ton dry SC/year |
| Crude oil palm | 0.32 – 0.42 ton empty fruit bunches/ton crude oil palm | EFB | *602,920 ton dry EFB/year |
| Rice | 1.5 ton/he | Rice straw | *731,846 ton dry RS/year |

Firstly, in Table 2 regarding the presence and relevance of the country's main crops for 2016, the results indicate that sugarcane is the first, with a production of 25,036,168 ton, representing 67% of total crops, for the oil palm has a production of 1,629,596 tons and in the case of rice, a harvested area of 530,323 Ha. Secondly, in Table 2 from the anaerobic digestion process of the waste, a total volume of biomethane of 1,278 x 10^6 m^3/year is obtained; with a contribution of 85% of bagasse, 10% in the case of the RS and 5% for the palm rachis.

| Table 2. Biogas and biomethane potential for three crops in Colombia 2018. |
|-------------------------------------------------------------|
| **% Volatile** | **Methane yield m^3/ton volatile solids** | **Potential methane production million m^3/year** |
| SCB | 97.8% (ton volatiles/ton dry SCB) | 299.3 [21] | *1,090 |
| EFB | 73.5% (ton volatiles/ton dry EFB) | 223.2 [23] | *62.3 |
| RS | 84.5% (ton volatiles/ton dry RS) | 203 [24] | *125.6 |

Sugarcane crop contributes most to biomethane Colombia potential because it has the highest biomass production in the country. Colombia is the fourth-largest producer of palm oil in the world. Whereby, the rachis has important potential for biomethane production, however, rice residues would generate the double of biomethane production as palm rachis. With the data obtained from biomethane production for these three types of waste in Table 2, the calculation will be carried out to determine the potential in equivalent terms of gasoline that would generate these wastes if they were only used for biomethane generation.

Table 3 lists the biomethane that would be obtained in Colombia with respect to those obtained in studies for other countries, although strictly the comparison does not proceed when considering in these studies different types of organic waste, it is a referential framework of the importance of production...
and production density of Colombia, taking into account the amount of crops considered, clearly by widening the base of crops taken as the primary source of biomethane production in Colombia, production values that are more representative of the country's potential should be achieved.

Table 3. Relations of the biomethane in Colombia respect to other studies.

| Country   | Biomass                                | Biomethane potential (x10^6 m³) | Density of biomethane production (m³/km²) |
|-----------|----------------------------------------|---------------------------------|------------------------------------------|
| Colombia  | 3 agricultural waste                   | 1,278                           | 1,120                                    |
| Chile [10] | Agricultural, forestry                 | 26,400                          | 33,000                                   |
| China [11] | Agricultural, energy crops, municipal solid waste, livestock | 888,000                         | 92,819                                   |
| Sicily [9]  | 15 agricultural waste                  | 145                             | 5,639                                    |

4.2. The final use of the biomethane produced

The most widespread use of biomethane is its use as a fuel vector in transportation; Thus, in 2015, Europe was the region with the largest presence of biomethane in the vehicle fuel supply network, having 697 refueling stations that handled around 160 million m³ [31]. Although barriers inherent in the cost of producing and distributing biomethane still must be overcome to achieve competitiveness with traditional fluid fuels. Economic analyze of three routes of production of biomethane and five processes of improvement and purification, their results indicate that in the most favorable case, the biomethane injected into the network is approximately 19% more expensive than natural gas [32].

Of the energetic valuation of the use of the biomethane as vehicular fuel in Colombia, it is obtained that barely with 12% of the annual volume produced (155 × 10⁶ m³) total consumption of vehicular natural gas is completely covered throughout the country and by 2018 [32]. In addition, the volume of biomethane remaining 1,126 × 10⁶ m³/año, energetically equivalent to 1258 × 10⁶ liters of gasoline, represents 44% of the country's total annual gasoline consumption [32], which demonstrates the potential of fossil fuel substitution for biomethane with a favorable environmental and economic impact.

5. Conclusions

The biomethane production potential obtained from the agro-industrial waste of three selected crops due to their abundance and geographical distribution, represents an attractive option for the sustainable mobility of Colombia, being able to replace and complement the fossil fuels traditionally used for the vehicular transport. With the addition of contributing to the diversification of the energy supply, offer a solution to the efficient management of large volumes of waste derived from agro-industrial activity and move towards the country's energy security and autonomy. The results obtained merit comprehensive studies of the penetration of biomethane in transport, including environmental, technical and economic dimensions, especially in those departments of the country that constitute a niche of opportunity to combine a high supply of biomethane with a high demand for fossil fuels, such as the department of Valle del Cauca.

Acknowledgments

The authors thank the University of Santander for the financial support for the realization of this article through the Research Project of Institutional Strengthening. PFI 061-18. They also thank the The Ibero-American Science and Technology for Development program (CYTED), for the institutional and financial support for the strategic framework project: Production of biomethane for transport fuel from biomass.

References

[1] Østergaard P, Duic N, Noorollahi Y, Mikulcic H and Kalogirou S 2020 Renewable Energy 146 2430
[2] Lago N, Caldés N and Lechón Y 2018 Role of Bioenergy in the Emerging Bioeconomy (London: Academic Press)
[3] Ministerio de Agricultura 2018 Anuario Estadístico del Sector Agropecuario (Bogotá: MinAgricultura)
[4] Wua B, Sarker B and Paudel P 2015 *Applied Energy* **158** 597
[5] Paturska A, Repel M and Bazbauers G 2015 *Energy Procedia* **72** 71
[6] Hosseini E, Dahadha S, Bazyar A, Azizi A and Elbeshbishy E 2019 *Journal of Environmental Management* **233** 774
[7] Sun Q, Li H, Yan J, Liu L, Yu Z and Yu X 2015 *Renewable and Sustainable Energy Reviews* **51** 521
[8] Wua B, Bhaba R, Sarker K and Paudel P 2015 *Applied Energy* **158** 597
[9] Chinnici G, Selvaggi R, D’Amico M and Pecorino B 2018 *Renewable and Sustainable Energy Reviews* **82** 6
[10] Seiffert M, Kaltschmitt M and Miranda J 2009 *Biomass and bioenergy* **33** 564
[11] Liu C, Wang J, Ji X, Qian H, Huang L and Lu X 2016 *Chinese Journal of Chemical Engineering* **24** 920
[12] Koornneefa J, van Breevoorta P, Noothouta P, Hendriksa C, Luninga L and Camps A 2013 *Energy Procedia* **37** 6043
[13] Thomsen S, Spliid H and Østergård H 2014 *Bioresource Technology* **154** 80
[14] Cabeza I, Thomas M, Vásquez A, Acevedo P and Hernández M 2016 *Chemical Engineering Transactions* **49** 385
[15] Cadavid L, Vargas M and Plácido J 2019 *Sustainable Energy Technologies and Assessments* **34** 110
[16] Marin J, Castro L and Escalante H 2015 *Revista Colombiana de Biotecnología* **17** 18
[17] Henao F, Rodríguez Y, Viteri J and Dyner I 2019 *Renewable Energy* **132** 81
[18] Marrugo G, Valdés C and Chejne F 2016 *Energy Fuels* **30** 8386
[19] Hailong L, Daheem M, Thorin E and Zhixin Yu 2017 *Energy Procedia* **105** 1172
[20] Escobar S and Peñuela E 2016 *Tercer Censo Nacional Agropecuario* (Bogotá: DANE)
[21] Sajad S, Karimi K and Majid A 2019 *Fuel* **248** 196
[22] García A 2018 *Revista Palmas* **39** 6
[23] Van Dam J 2016 *Revista Palmas* **37** (No. Especial Tomo II) 149
[24] Suksong W 2017 *Industrial Crops and Products* **95** 502
[25] Du J, Qian Y, Xi Y and Lü X 2019 *Renewable Energy* **139** 261
[26] Rein P 2017 *Cane Sugar Engineering* (Berlin: Verlag Dr. Albert Bartens KG)
[27] Rivera Y, Méndez Deisy, Rodríguez T and Romero H 2017 *Journal of Cleaner Production* **149** 743
[28] Nader G and Robinson P 2010 *Rice Producers’ Guide to Marketing Rice Straw* (Davis: University of California)
[29] Mustafa A, Li H, Radwan, Sheng K and Chen X 2018 *Bioresources Technology* **259** 54
[30] Talero G, Rincón S and Gómez A 2019 *Fuel* **242** 496
[31] Scarlat N, Dallemand J F and Fahl F 2018 *Renewable Energy* **129** 457
[32] Espinosa M, Cadena A and Behrentz E 2019 *Energy Policy* **124** 111