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Biogas production from the specialized dairy farming and porcine subsectors in Antioquia, Colombia: theoretical and technical-energy potential approach

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Abstract. In developing countries, residual biomass usage by means of anaerobic digestion offers several benefits and opportunities, such as a sustainable energy source, production of organic fertilizers and new agrobusiness models. In Latin America, Colombia is one of the most promising markets for the implementation of this technology in terms of availability of biomass and economic growth, as recently reported by local government organizations. In this paper, special attention is given to Antioquia, a department of Colombia with the largest farms of cattle and pigs, according to information reported in 2018 by the Ministry of Agriculture and Rural Development. It is estimated that manure from the porcine subsector in Antioquia has an approximate technical-energy potential of 1,896 TJ year^{-1}, varying from 1,611 to 2,186 TJ year^{-1}, corresponding to the 95% confidence interval. In the case of manure generated by the livestock subsector in Antioquia, it is estimated a theoretical energy potential of 8,566 TJ year^{-1}. However, traditional extensive production systems disseminate manure through the pastures turning centralization of the available residual biomass a difficult task and not senseful. Based on the local practices of the specialized dairy subsector, it is estimated that manure collected during the milking process could reached up to 25% of the total available. Biochemical conversion of this amount of biomass has an estimated technical-energy potential of 187 TJ year^{-1}, varying from 156 and 236 TJ year^{-1}, corresponding to the 95% confidence. The aim of this article is to estimate the technical-energy potential for the livestock and porcine subsectors in the Department of Antioquia, based on the available residual biomass according to local farming practices.

Key words: technical biogas potential, residual livestock biomass, porcine manure, residual biomass availability, energy matrix.

INTRODUCTION

Colombia's report presented during the United Nations Framework Convention on Climate Change (COP21), held in Paris in December 2015, makes the country responsible for 0.46% of global GHG emissions, according to data reported in 2010. Despite contributing a low percentage at a global scale compared to other countries, accumulated emissions between 1990 and 2012 place Colombia among the 40 countries with the greatest historical responsibility for generating GHG emissions. The Colombian subsectors with the highest contribution to GHG emissions are livestock, deforestation, transportation, energy generation, solid waste management, manufacturing, and construction industry, and other processes (Londoño Pineda et al., 2019; Wang et al., 2021).

Earlier studies on Residual Livestock Biomass (RLB) have been conducted and presented by the Atlas of the Energy Potential of Residual Biomass in Colombia. The study was conducted and published in 2010 by the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), the Mining and Energy Planning Unit (UPME) and the Industrial University of Santander (UIS). The report estimates that livestock activities in Colombia generates approximately 105,418.066 tons per year of manure in which the department (geographical region) of Antioquia has the largest contribution with 12,882,917 tons per year. This amount of manure represents an important environmental impact considering that animal manure produces biogas, which is considered a harmful greenhouse gas (GHG) when large amounts of it is ejected to the atmosphere without inactivation nor valorization (Marrugo et al., 2016; Pupo-Roncallo et al., 2019; Hollas et al., 2021).

Key factors such as increasing GHGs emissions due to inadequate management of RLB, the increasing trend of energy consumption during the past few years, and the possibility of decreasing dependence on fossil fuels as a pillar of the economy based on clean energy, have triggered efforts from governmental agencies, educational institutions, and public/private industries towards the use of renewable energy. Low-carbon technologies such as the bioconversion of biomass by anaerobic digestion means, are of great interest due to its low environmental impact and its positive social impact (Ramirez-Contreras & Faaij, 2018).

Energy recovery of RLB in the Department of Antioquia also contributes to the fulfillment of the Sustainable Development Goals (SDGs) approved in 2015 at the United Nations (UN) summit. This strategy aims at intensifying efforts to end poverty in all its forms, reduce inequality, and protect the environment (Kall et al., 2016; Ramirez-Contreras & Faaij, 2018; Sagastume Gutiérrez et al., 2020). For example, SDG 7 focuses on access to clean energy, in which producing biogas by means of anaerobic digestion of RLB can be an energy source for non-connected communities. It also promotes access to affordable renewable energy aiming at improving living conditions of communities in the Department of Antioquia. These renewable energy sources will provide an alternative fuel for cooking, heating, and lighting. It is estimated that the use of RLB produced by the porcine and specialized milk cattle sub-sectors through anaerobic digestion in the Department of Antioquia will help to reach the COP21 commitment established to reduce greenhouse gas emissions by 20% in relation to projected emissions by 2030 (Sagastume Gutiérrez et al., 2020).

Generally, in Colombia, not all the RLB can be collected, especially those related to cattle farming performed under traditional extensive production systems. Manure collection and centralization for energy generation are hard to achieve because farms are dispersed throughout the country.

This research focuses on the estimation of technical-energy potential by anaerobic digestion means of the Colombian livestock residual biomass. The following substrates were assessed: i) the productive system of specialized milk, which performs the temporary confinement of animals for two (2) times a day for milking. This practice facilitates the collection of 25% of the manure produced daily by the animals, and ii) biomass from the porcine sub-sector in Antioquia, in which the animals are handled in confinement.

METHODOLOGY

Main sources of information consulted for the estimation of Residual Livestock Biomass (RLB)

Different sources of information were consulted to estimate RLB, such as the census conducted by Colombian Institute of Agriculture (ICA) in 2018 for the porcine and livestock subsectors, reports form the Agricultural Assessments by Consensus, the Agricultural and Technical Assistance Municipal Units (UMATAS) and the Ministry of Agriculture (Ministerio de Agricultura, 2020).

The information reported by ICA clearly specifies the distribution of animals by age group for cattle and pigs, where the former is classified as cattle under one year old, cattle between 1 and 2 years old, cattle between 2 and 3 years old, and cattle over 3 years. In the case of the porcine subsector the classification is presented as piglets (1–60 days), weaners (61–120 days), growers (121–180 days), reproducers, females (120–240 days), breeding females (more than 240 days) and backyard pigs, which are those that remain in small-scale family farms.

In 2018, information provided by the Colombian Ministry of Agriculture specifies livestock activities in terms of milk production for each of the 125 municipalities of the Department, specifying the number of animals in traditional milking systems, dual-purpose dairies, and specialized dairies. In this study, it is considered Manure Production Rate (MPR) as an indicator of manure generated by species, according to the age of the animal and the type of activity for which it is raised (UPME, 2011). Both, the number of animals per age range and the MPR are inputs for the estimation of residual livestock biomass per species in each of Antioquia's 125 municipalities.

Estimation of RLB in the Department of Antioquia for the porcine and specialized dairy subsectors

Traditional extensive production systems in Colombia lead to the dissemination of manure through the pastures turning centralization of the available residual biomass a difficult task and not senseful. However, pasturing practices opens possibilities to produce animal products from residual sites, in which grazing enables fresh uptake of grass and herbs without energy losses and with selection of best nutrient content by the animal. Considering that grazing is an important source for feces-based nutrient networks, pathogenic risks need to be under consideration to avoid cross pollution.

Estimation of RLB in the Department of Antioquia is calculated by means of a mathematical model based on the number of animals per subsector and the Manure Production Rate (kg animal^{-1} day), which is an indicator of manure generated by species, depending on the age of the animal and the type of activity for which it is raised.

Since the porcine sub-sector establishes practices such as animal confinement and intensive production systems, it is estimated that the technical-energy potential from manure for this sub-sector only depends on the capacity of the bioconversion technology to process the available residual biomass, but it is not limited to the accessibility of it. On the other hand, since extensive production systems predominate in the livestock sector, only manure generated by the sub-sector of specialized dairies during milking, could be defined as technically usable manure. This is equivalent to 25% of the manure generated by this sub-sector.

Equation 1 presents the model used for the estimation of the residual biomass produced by the porcine and cattle sectors in the Department of Antioquia.

$$RLB = nA \times MPR \quad (1)$$

where RLB – Residual livestock biomass; nA – number of animals; MPR – manure production rate.

Theoretical estimation of the technical-energy usable potential for the porcine and specialized dairy subsectors in the Department of Antioquia

To calculate the technical-energy potential of manure generated by the porcine and dairy subsectors in the Department of Antioquia, a mathematical model was implemented based on the following variables: Residual Livestock Biomass - RLB (kg of fresh manure), Dry Matter - DM (kg DM kg^{-1} manure), Volatile Solids (kg VS kg^{-1} DM), Biochemical Methane Potential - BMP (Nm^3 CH_4 kg VS^{-1}) and Lower Calorific Value of methane, which corresponds to 35.8 MJ Nm^{-3}.

Table 1 presents bibliographic information on the characterization of cattle and pig manure for parameters such as dry matter - DM (kg DM kg DM^{-1}), volatile solids (kg VS kg DM^{-1}) and methane biochemical potential (Nm^3 CH_4 kg VS^{-1}). These values correspond to the characterization of manure produced in various countries with different climatic conditions and implementation of different conditions of animal management, including variations in the type of feed supplied.

The Center for Environmental Studies and Research - CEIAM of the Industrial University of Santander (UIS) characterized pig manure from two departments in Colombia: Antioquia (a farm located in Santa Rosa de Osos) and Valle del Cauca. Data from the characterization is presented in Table 2.

The variation in the results of the physicochemical characterization between these two samples corresponds to various factors such as, condition at the time of collection, the climate of the geographical site, quality of the food provided to animals, transport needs, herd size, manure recover facilities, among others (Jiménez Vásquez, 2021).

Table 1. Characteristics of cattle manure and pig manure

No.	Dry Matter DM kg DM kg manure^{-1}	Volatile solids kg VS kg DM^{-1}	Biochemical methane potential Nm^3 CH_4 kg VS^{-1}	Reference
	Characteristics of cattle manure			
1	0.27	0.81	0.32	(Arango Osorio et al., 2019)
2	0.17–0.26	0.71–0.87	0.17	(Pham et al., 2017)
3	0.16–0.22	0.88	0.19–0.22	(André et al., 2019)
4	0.18	0.80	0.21	(Ramírez Balaguera & Barrera Ojeda, 2017)
5	0.17	0.55	0.13	(Zhao et al., 2018)
6	0.17	0.77	0.27	(Martí Herrero, 2008)
7	0.17	0.61	0.20	(Krishna Kafle & Chen, 2016)
8	0.16	0.87	0.11	(Herrero Garcia et al., 2019)
9	0.15–0.16	0.85	0.32	(McVoitte & Clark, 2019)
10	0.16	0.84	0.33	(Li et al., 2014)
11	0.12	0.85	0.243	(Luna-Derisco et al., 2011)
	Characteristics of pig manure			
11	0.36	0.99	0.15	(Herrero Garcia et al., 2019)
12	0.28–0.33	0.71–0.76	0.32	(Galvis Pinzón & Acevedo León, 2008)
13	0.32	0.78	0.15	(Liang et al., 2020)
14	0.31	0.77	0.13	(Cabeza et al., 2016)
15	0.31	0.73	0.32	(Ramírez Balaguera & Barrera Ojeda, 2017)
16	0.31	0.87	0.32	(Krishna Kafle & Chen, 2016)
17	0.30	0.89	0.25	(Liang et al., 2017)
18	0.28	0.78	0.26	(Yang et al., 2019)
19	0.28	0.80	0.29	(J. Zhang et al., 2019)
20	0.28	0.78	0.31	(Xiao et al., 2019)
21	0.23	0.73	0.16	(Wang et al., 2018)
22	0.24–0.29	0.75–0.77	0.26–0.35	(W. Zhang et al., 2014)
23	0.3-0.8	0.7–0.8	0.175–0.35	(Luna-DelRisco et al., 2011)
24	0.19	0.77	0.35	(Li et al., 2014)

Table 2. Characterization of the residual biomass of the porcine sub-sector

Department	% Moisture	% DM	DM kg DM kg manure^{-1}	% VS	VS kg VS kg DM^{-1}
Antioquia	67.18	32.83	0.33	24.98	0.76
Valle	71.9	28.11	0.28	19.87	0.71
Average	69.54	30.47	0.31	22.42	0.73

Source: Centre for Environmental Studies and Research – CEIAM.

In Eq. 2, the mathematical model for the estimation of the technical-energy potential from RLB for the porcine and specialized milk cattle subsectors is presented.

$$EP_{RLB} = \sum_{i=1}^{n} \cdot RLBPi \cdot \%DM.VS \cdot Bo_i \cdot LCV_{CH4} \qquad (2)$$

where EP_{RLB} – Technical-energy potential of residual livestock biomass (TJ year^{-1}); RLB – kg manure year^{-1}; $\%DM$ – % Dry Matter (kg DM kg manure^{-1}); VS – Volatile solids (kg VS kg DM^{-1}); *Bo* – Biochemical methane potential (Nm^3 Biogas kg VS^{-1}); LCV_{CH4} – Methane Lower Calorific Value (TJ Nm$^{3-1}$).

RESULTS AND DISCUSSION

Estimation of exploitable residual livestock biomass in the Department of Antioquia for the porcine and specialized dairy subsectors

It is estimated that manure production by the porcine sub-sector in the Department of Antioquia is approximately 1,223.056 tons per year (Table 3). From this amount, 72.13% is generated in large scale and technified systems that warranties animal confinement by physiological state and age. The remaining 27.87% is produced by backyard pigs, which are in family farms and small-scale production systems (UPME, 2011).

Table 3. Estimation of Residual Livestock Biomass (RLB) of the porcine sub-sector in the Department of Antioquia

Physiological Status	Age (days)	Number of Animals	Manure Production Rate (MPR) (kg animal year^{-1})	RLB[1] (ton manure year^{-1})
Piglets	1–60	583,145	102.2	59,597,419
Weaners	61–120	488,909	445.3	217,711,178
Growers	121–180	423,867	799.35	338,818,086
Reproducers	-	5,704	2,051.3	11,700,615
Females	120–240	21,187	1,971	41,759,577
Breeding females	> 240	78,916	2,693.70	212,576,029
Backyard pigs	-	253,677	1,343.81	340,893,267
Total		1,855,405	-	1,223,056,171

Source: Adapted from (UPME, 2011); [1]Technically available biomass from pigs.

According to Table 4, livestock farming operations in the Department of Antioquia, including beef cattle, specialized dairy, and dual-purpose cattle, produces a total of 13,683,706.920 tons of manure per year.

Table 4. Estimation of Residual Livestock Biomass (including beef cattle, specialized dairy and dual-purpose cattle) of the livestock farming operations in the Department of Antioquia

Livestock age (months)	Number of Animals	Manure Production Rate (MPR) (kg animal year^{-1})	RLB[1] (ton manure year^{-1})
< 12 months old	536,460	1,460	783,231
12–24 months old	756,146	3,285	2,483,939,610
24–36 months old	723,165	5,110	3,695,373,150
> 36 months old	1,023.008	6,570	6,721,162,560
Total	3,038.779	-	13,683,706,920

Source: Adapted from (UPME, 2011).

According to data reported in 2018 by the Agricultural Assessments by Consensus, the Municipal Agricultural Technical Assistance Units (UMATAS) and the Ministry of Agriculture, in the Department of Antioquia (MinAgricultura, 2018), there are approximately 182,166 cows destined to specialized systems of milk production with a manure production rate of 6,570 kg animal^{-1} year for a total of 1,196,830 tons of manure per year. Table 5 presents data related to manure production by the specialized dairy subsector in the Department of Antioquia.

Table 5. Municipalities with the highest manure production by the specialized dairy subsector

Municipality	Manure production (ton year^{-1})	RLB specialized dairy subsector[1] (ton manure year^{-1})
Santa Rosa de Osos	515,554	128,889
Entrerrios	166,208	41,552
Don Matías	98,550	24,638
Yarumal	90,975	22,744
Belmira	84,024	21,006
Sonsón	29,802	7,450
Medellín	24,894	6,223
Abejorral	19,881	4,970
El Carmen de Viboral	19,382	4,845
Frontino	19,283	4,821

Source: Adapted from (UPME, 2011); [1]Technically available.

Data shows that Santa Rosa de Osos and Entrerríos are the municipalities with the highest production of manure from the specialized dairy subsector with 515,554 tons and 166,208 tons per year respectively. The municipalities of Santa Rosa de Osos, Entrerrios, Don Matías, Yarumal and Belmira located in the northern sub-region of the Department of Antioquia contribute to the 79.82% of the total manure generated in the Department of Antioquia. The historical main activity of these municipalities is milk related products (Rios & Botero, 2020).

Although the specialized dairy subsector generates 1,196,830 tons of manure per year, only 25% of the manure generated in the dairies during milking can be recovered, which is approximately 299,208 tons per year of technically available manure (Ministerio de Agricultura, 2020; UPME, 2011). On the other hand, the porcine subsector in the Department of Antioquia reported a total production of 1,223,056 tons of manure per year. The available amount of this substrate has a higher technical potential than livestock manure because its productive system usually uses the confinement of the animals (Londoño et al., 2017).

The approximate sum of manure produced by the porcine sub-sector (1,223,056 tons per year) and the technically usable manure produced by the specialized dairy sub-sector (299,208 tons per year), represents a residual biomass of 1,522,264 tons per year of technically usable manure due to its collection possibilities.

Technical-energy potential of manure generated by the porcine and specialized dairy subsectors in the Department of Antioquia

Manure produced by the porcine subsector in the Department of Antioquia has a technical-energy potential of 1,896 TJ year^{-1} with a statistical variation from 1,611 to 2,186 TJ year^{-1}, corresponding to a 95% confidence interval. Backyard pigs accounts for the 27.9% of the total energy potential while the technified porcine systems represent the 72.1% (Londoño et al., 2017).

Municipalities with the highest technical-energy potential from pig manure are Don Matías (166.67 TJ year^{-1}), Medellín (144.73 TJ year^{-1}), Ebejico (129 TJ year^{-1}), Santa Rosa de Osos (121.26 TJ year^{-1}), Santo Domingo (72.13 TJ year^{-1}), San Pedro de los Milagros (68.21 TJ year^{-1}), Barbosa (64.78 TJ year^{-1}), Concordia (53.04 TJ year^{-1}), Entrerrios (49.60 TJ year^{-1}) and Angelopolis (45.08 TJ year^{-1}) (UPME, 2011).

In the Department of Antioquia, there are 182,166 cows destined for specialized milk production systems with a production of 1,196,830 tons of manure per year and an energy potential of 749 TJ year^{-1} by means of anaerobic digestion. However, since the specialized dairy farming subsector gathers milking cattle twice a day, only 25% of the total manure produced can be collected. This amount has a technical-energetic potential (anaerobic digestion) of available manure of 187 TJ year^{-1} with a variation from 156 to 236 TJ year^{-1}, corresponding to a 95% confidence interval.

For the specialized dairy subsector, the highest technical-energetic potential by means of anaerobic digestion was identified in the municipalities of Santa Rosa de Osos (80.68 TJ year^{-1}), Entrerrios (26.01 TJ year^{-1}), Don Matias (15.42 TJ year^{-1}), Yarumal (14.24 TJ year^{-1}) and Belmira (13.15 TJ year^{-1}), all located in the northern sub-region of the Department of Antioquia. The technical-energetic potential of manure produced in these municipalities is estimated at approximately 149 TJ year^{-1}, corresponding to 79.82% of the potential of the Department. The sum of the other municipalities represents less than 5 TJ year^{-1} each, where Sonson and Medellin present a potential of 4.66 TJ year^{-1} and 3.90 TJ year^{-1} respectively (Rios & Botero, 2020).

Considering data from the porcine and specialized dairy subsectors, the total exploitable technical-energetic potential is approximately 2,084 TJ year^{-1} with a statistical variation from 1,767 and 2,422 TJ year^{-1}, corresponding to a 95% confidence interval. From the estimated total technical-energetic potential, the porcine subsector represents 91.01% of the total while the specialized dairy sub-sector only presents the 8.99%. From the municipalities analyzed in this study, Santa Rosa de Osos showed the highest technical-energy potential with 201.94 TJ year^{-1}, where 60.05% is contributed by the porcine sub-sector and 39.95% of the potential by the specialized dairy sub-sector.

Don Matias, Medellin, Ebejico and Santo Domingo presented an exploitable technical-energy potential from 73 TJ year^{-1} to 182.10 TJ year^{-1}. Energy potential is primarily attributed to the porcine sector of around 91% of the total, whereas only 9% is from the specialized dairy sub-sector. Entrerríos has a total technical-energy potential of 75.61 TJ year^{-1}, where the porcine sub-sector contributes with 65.6% of the total. In the case of the municipality of Yarumal, the porcine sub-sector contributes to the 74.15% and the specialized milk sub-sector contributes 25.85% of the total exploitable technical-energy potential, corresponding to 55.08 TJ year^{-1}. San Pedro, Barbosa, Concordia, Angelopolis, Caldas, Jerico, Tamesis, Angostura, Fredonia and Guarne have a total exploitable technical-energy potential from 40.24 TJ year^{-1} to 68.21 TJ year^{-1}, with a predominant contribution from the pig sub-sector, with percentages above 97% with a very low contribution from the specialized dairy sub-sector. Belmira has a total exploitable technical-energy potential of 21.25 TJ year^{-1} with a 38.13% contribution from the porcine subsector. Marinilla, Santa Bárbara, Rionegro, Envigado, Girardota, Bello, Gomez Plata, Amaga, La Ceja, Urrao, Yolombo, El Retiro, Turbo and Arboletes, have a total exploitable technical-energy potential from 15.99 TJ year^{-1} to 36 TJ year^{-1} with a high contribution from the porcine subsector with percentages above 92%.

In the other hand, municipalities such as Carolina del Príncipe, El Carmen de Viboral, Frontino, Sonson, La Union and Abejorral are highly influenced by the contribution of the specialized dairy subsector in percentages ranging from 16.66% to 63.98% (UPME, 2011).

In a study conducted by Contreras et al., 2020, there are 5 types of biomasses prioritized for biogas production in Colombia based on technical, environmental, and socioeconomic criteria (Table 6). Although, these biomasses do not represent a large energy source to fulfill the energy demand compared with other renewable energy sources (i.e., hydropower, fossil fuels), energy generation from them have great potential of development and integration on the national grid, specifically to support energy demands in rural areas nearby, as an energy source for cooking, heating, or local electricity generation at small scale.

Table 6. Biogas energy potential from different biomasses in Colombia

Biomass type	Energy potential (biogas) share (%)
Vinasse from sugar cane	22
Organic Urban Solid Waste (OUSW)	18
Palm oil	21
Pig manure	14
Poultry manure	25
Total biogas energy available	14,670 TJ $year^{-1}$

Source: Adapted from (Contreras et al., 2020).

As presented in Table 6, utilization of pig manure is an interesting residual biomass option for biogas production. In addition, Contreras et al., 2020 showed that Santander, Antioquia, Valle del Cauca, and Meta are the Departments with the greatest diversity of these biomasses. These results are in accordance with our findings. Pig manure availability in the Department of Antioquia and its bioconversion into biogas showed a great opportunity for energy diversification in rural areas.

Impact of residual biomass on the Colombian energy matrix

Biomethane stands as an important renewable energy for Non-interconnected Electrical Areas (NEA) which impacts 66% of the Colombian territory and 601,486 inhabitants mostly located in areas typically affected by the social conflict and infrastructure restrictions. In that matter, biogas as a non-conventional renewable energy source can offer energy solutions such as fuel gas and/or electricity, allowing the development of more efficient projects with social benefits (CREG, 2016).

Manure produced by the livestock industry (meat, double purpose, and specialized dairy) has a theorical energy potential of 8,566 TJ $year^{-1}$ by anaerobic digestion means. Most of this energy potential depends on the possibility of collection and centralization. In Antioquia, productive systems are based on extensive cattle raising in which dissemination of residual biomass in the pastures of the cattle farms makes it difficult to collect. On the other hand, the specialized dairy subsector has a theoretical energetic potential of 749 TJ $year^{-1}$. For this farming practice, approximately 25% of the available is collected with an estimated technical-energetic potential of 187 TJ $year^{-1}$.

There is a technical-energetic potential of 2,084 TJ $year^{-1}$ in Antioquia from the manure produced by the livestock (i.e., specialized dairy) and the porcine subsectors, in which more than 90% of the potential corresponds to the porcine industry.

Strategies such the one presented by Komasilovs et al., 2021 are crucial to enable national and international cooperation between the private sector and public sector with the participation of academic researchers. This will promote the proposal of residual biomass projects based on the technical-energy potential of specialized dairy systems and technified porcine farming.

Reported data on the primary energy supply share in Colombia consists of approximately 75% from non-renewable sources such as oil (39%), gas (27%) and coal (9%). The other 25% stands for hydropower (49%) and bioenergy (51%). By 2020, reported data from the total energy supply reached 1,610,929 TJ, from which 404,426 TJ are generated from renewable sources (International Renewable Energy Agency, 2020). In this research study, it was found an estimated technical-energetic potential from the specialized dairy and porcine subsectors of approximately 2,084 TJ $year^{-1}$ for the department of Antioquia, in which the total primary energy demand was found at approximately 35,298 TJ $year^{-1}$ (UPME, 2021). Technical energetic potential from studied residual biomass represents almost 6% of total energy demand for the department. In addition, it is estimated that there are almost 6,000 rural household without energy coverage in Antioquia, for which the results in this study could represent a sustainable source of energy (Departamento Administrativo de Planeación, 2016).

CONCLUSIONS

Residual biomass available in the Department of Antioquia from the pig and specialized dairy cattle subsectors provides a sustainable energy source that impacts on the economic, social, and environmental dimensions. For the bioconversion of this type of biomass residues, availability, conditioning, collection with efficient transportation mechanisms and centralization is highly recommended to maintain the supply chain for its bioconversion into biofuels.

This research validated the importance of porcine and livestock manure centralization and bioconversion into biogas for energy generation in the Department of Antioquia. Specialized dairy manure and porcine manure contributes with approximately 299,208 tons and 1,223,056 tons per year of technically usable manure respectively.

For the specialized dairy farming industry manure collection is more accessible than for the traditional extensive livestock production practices because livestock is commonly gathered twice a day in cattle housing for milking, where manure can be collected and stored for further treatment. Technified porcine farms based on pig confinement and intensive production systems is the most implemented farming practice in the Department of Antioquia. This practice that allows manure centralization could lead the government, the private sector, and entrepreneurs to invests on renewable projects at medium and large scale. This study approaches data from a technical availability point of view and not from a theoretical perspective and proposes the need to update the current studies available to improve the quality of data.

Although the technical energetic potential from residual biomass in this study represents only 6% of total energy demand for the department of Antioquia, there is an opportunity to provide a sustainable energy solution for approximately 6,000 rural household without energy coverage in Antioquia.

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