Analysis and Comment

Evaluation of the biogas production potential in Cuba

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Abstract

In Cuba a significant potential for biogas production and utilization is observed, based on the diversity and volume of contaminating residues generated by the agricultural and agri-food sectors; however, this potential is not accurately known yet to utilize such information in the decision-making processes that contribute to national bioenergy development. In that sense, the objective of the paper is to offer an evaluation of the biogas production and utilization potential in the country. To facilitate the evaluation, the study was divided by sectors (MINAG, MINAL, AZCUBA); within the animal husbandry sector, it was subdivided into poultry, pig (state and cooperative producers) and cattle, but only the productive activity directly linked to MINAG was taken into consideration. In the case of the industry sector (MINAL and AZCUBA), data were taken from the 12 most contaminant industries and from the alcohol distilleries, respectively. The daily potential of biogas production is 674 609 m^3, in which the pig and poultry production stand out; this potential means an energy production of 1 477 394 MWh/year, equivalent to 132 856 t of diesel, whose import costs 48 615 065 USD Cuba according to the current prices. Likewise, if the intensity in CO_2 of diesel is considered, the emissions prevented due to the substitution of this fossil fuel by biogas are estimated in 440 778 t $CO_{2\ eq}$/year.

Keywords: bioenergy, pollution, residues

Introduction

Anaerobic digestion constitutes a good alternative to treat residues with high biodegradable organic matter (Deng *et al*., 2014; Sosa *et al*., 2014; Rota and Sehgal, 2015; Sosa, 2017). Thus, this treatment is indicated for agroindustrial residual waters, with high load of biodegradable organic matter: wastes from the production of sugar, alcohol, meats, paper, preserved food and distilleries (Rahayu *et al*., 2015); agricultural residues, such as purines, manure (Girard *et al*., 2014; Sosa *et al*., 2014; Pérez *et al*., 2016; Bansal *et al*., 2017); and urban residues that comprise the organic fraction of solid residues (Biogas Association, 2015; Mang and Shikun, 2015) as well as sludge from urban sewage treatment plant (Biogas Association, 2015; Frankiewicz, 2015).

This treatment is also indicated for mixtures of organic residues from different origin and composition, taking advantage of the synergy of the mixtures and compensating the shortage of each residue separately, in what is known as anaerobic co-digestion (Lijo *et al*., 2014; Agostini *et al*., 2015; Biogas Association, 2015).

Biogas production through fermentation or anaerobic digestion is widely known, and there are diverse systems and technologies for the treatment of residual waters and organic residues that allow to capture the gases they emanate, such as: fixed-dome and floating drum biodigesters (Chinese and Indian models), plastic tubular or polyethylene tube digester (Taiwan model), plug flow biodigesters; covered lagoon biodigesters with geomembranes of high density polyethylene (HDPE), M-class ethylene propylene diene (EPDM) and polyvinyl chloride (PVC); second-generation digesters (sludge ascendant flow UASB, fixed film, expanded bed and fluidized bed); and third-generation or second-generation hybrid biodigesters, a mixture of several digesters in one unit, among the main ones (La Bioguía, 2013; Carreras, 2013). Their importance lies not only on their capacity to turn organic residues into fuel, but on the fact that such systems prevent the release to the atmosphere of gases such as methane (CH_4), which generates 21 times more greenhouse effect than carbon dioxide (CO_2) –gas used as reference (IPCC, 2007).

In Cuba, in the early eighties of the 20th century, the introduction of this technology was focused

mainly on solving the environmental impact generated by distilleries and large pig production and cattle fattening centers; but it reached its peak among the productive entities, especially dairy farms and pig production facilities. Later, as time passed, a high number of these systems were neglected, until most of the installed plants stopped working; which was largely due to the low prices of electricity at that moment and the little motivation of entities towards the utilization of renewable energy sources (Blanco *et al*., 2012).

At present, the scenario in Cuba is very different, but not less complex. With the increasing delivery of lands to small farmers, the increase of small and medium pig production farms –with the subsequent rise in water contamination– and the high prices reached by energy in the country, the utilization of biogas is shown as an adequate alternative. Farmers are motivated and the environmental regulations are more rigorous, for which the demand for digesters increases, only limited by costs and availability of materials; all this has created a favorable environment for the development of biogas, which is an intelligent solution for the treatment of the generated animal excreta.

In this sense, the objective of the paper is to provide an evaluation of the biogas production and utilization potential in Cuba.

Materials and Methods

The evaluation was conducted as part of the formulation of the international project BIOENERGÍA, presented by the Cuban State to the Global Environment Found –GEF–, which is coordinated by the Pastures and Forages Research Station Indio Hatuey (EEPFIH) and is focused on developing policies to support bioenergy, building capacities of construction and utilization of biogas and biodiesel production systems, as well as developing institutional and human capacities on these topics. Information of the closing of 2013 was used.

To facilitate the evaluation the study was divided by sectors (Ministry of Agriculture, MINAG; Ministry of the Food Industry, MINAL; Sugar Production Group, AZCUBA); within the animal husbandry sector (MINAG), the subdivision was made into poultry, pigs (state and cooperative producers) and cattle; in the case of the industry sector (MINAL and AZCUBA), the data were taken from the 12 most contaminant industries and the alcohol distilleries, respectively. In cattle production only the productive activity directly linked with MINAG was considered.

The available information for conducting this analysis only allows to make a preliminary evaluation of the biogas production potential and of the number of facilities required to utilize it. The coefficients and indicators used to determine the biogas production volumes and their equivalent in conventional fuel are the ones proposed by Guardado (2007), Guardado and Flores (2008), Guardado and Vargas (2008) and Díaz-Piñón (2009), which are accepted in this type of studies at national level.

The indicators used in the calculation of the potential in the poultry, pig and cattle sectors are shown in tables 1, 2 and 3.

Table 1. Indicators used in the calculation of the potential in the poultry sector.

Indicator	Value
kg of excreta-day/animal	0,15
m^3 of biogas/kg of excreta per day	0,06

Source: Montalvo y Guerrero (2003), Sosa (2007), Guardado (2007), Guardado y Vargas (2008), Guardado y Flores (2008) and Díaz-Piñón (2009)

Table 2. Indicators used in the calculation of the potential in the pig production sector.

Indicator	Value
kg of excreta-day/animal	2,3
m^3 of biogas /kg of excreta per day	0,07

Source: Montalvo and Guerrero (2003); Sosa (2007 2014.)

Table 3. Indicators used in the calculation of the potential in the dairy cattle sector.

Indicator	Value
kg of excreta-day/animal	10
m^3 of biogas/kg of excreta per day	0,04

Source: Montalvo and Guerrero (2003).

The annual energy production was calculated through equation 1:

Energy production/year = biogas production/day x 365 days x energy content of 1 m^3 de biogas (1).

Where: energy content of 1 m^3 of biogas (expressed in heat) is 6 kWh/m^3 (EEPFIH/Cubaenergía, 2014).

Likewise, considering that the intensity in CO_2 of diesel is 3,135 kg CO_{2eq} per liter, the potential of emissions to be prevented due to the substitution of this fossil fuel is calculated through equation 2:

Emission potentials to be prevented = diesel liters / year x intensity in CO_2 of diesel (2).

In this analysis, the handbook for calculating benefits of the projects of energy efficiency and energy renewable sources for GHG emissions was used (GEF, 2008), as well as the results of EEPFIH/ Cubaenergía (2014).

Results and Discussion

In Cuba many studies about biogas have been conducted, with emphasis on its production but much less on its utilization. Recent examples are the following: in pig production (Suárez *et al*., 2013, 2014; Sosa *et al*., 2014; Pérez *et al*., 2016; Suárez, 2017), in animal production with different species (Savran, 2005; López *et al*., 2006), in agricultural residues (Martínez *et al*., 2014), and in the sugar production industry (López *et al*., 2006; ICIDCA, 2008, 2011). However, the biogas production potential at national scale, with a multisectoral approach, has not been evaluated yet.

Production potential in the poultry sector

Poultry production in the country is carried out, mostly, by the Animal Husbandry Entrepreneurial Group (GEGAN, for its initials in Spanish), state-owned, whose organizational structure for poultry is the following:

- 11 enterprises for the production of concentrate feeds,
- 19 poultry production enterprises,
- one goose production enterprise,
- the Poultry Genetics Enterprise,
- the Enterprise of Technical-Material Supply,
- the Enterprise of Supplies, and
- the Poultry Research Institute.

The poultry production enterprises are subdivided into farms, which are classified as: laying, replacement and breeding hens.

Considering table 1 and the quantity of existing animals at the end of 2013 in each of the farms, table 4 shows the biogas potential and its expression in tonnes of oil equivalent in one year (TOE).

It is important to emphasize that in the poultry facilities in the country the excreta is collected once the cycle is finished; because if different people enter, the hens get scared and do not lay eggs.

In order to eliminate the odors calcium carbonate (lime) or other substances is added, which prevents that the excreta can be used for biogas production. To achieve its energy utilization through anaerobic technologies, a technological change that allows the daily collection of excreta and prevents the use of lime is essential. One of the authors of this paper visited a poultry farm with 80 000 laying hens, in which conveyor belt mats are used under each cage row; these mats extract the dry poultry dung with a frequency lower than 24 hours, to be used in two covered lagoons biodigesters of 500 and 900 m^3, which supply electricity to the farm through a Caterpillar biogas motor generator of 70 kW.

Production potential in the pig production sector

The pork production in Cuba is concentrated by GEGAN, directly responsible for 60 % of the production delivered to slaughter; while the rest is assumed by small and medium private farmers, according to ONEI (2013). This same source states that 70 % of the pig stock existing in the country belongs to the private sector; one of the link mechanisms between the state and the private sectors are the production contracts signed between private farmers and state enterprises (called «pig production contracts»). This approach for non-specialized pork production in the cooperative-farmer sector, transformed such sector into the largest food production industry in Cuba; for such reason, the information is divided into pig production contracts and state farms.

Table 4. Biogas potential in the Cuban poultry sector and its equivalent in tonnes of oil equivalent (1 TOE = 1 931,18 m^3 of biogas, for its caloric value).

Farm type	Quantity of animals (thousands)	Biogas (m^3/ day)	TOE
Laying hens	11 636	104 724	19 793
Replacement hens	2 227	20 043	3 788
Breeding hens	71	639	120
Total	13 934	125 406	23 701

Source: Elaborated from information of the National Union of Combined Poultry Enterprises (UECAN).

TOE: tonnes of oil equivalent in one year, is an energy unit; its value is equivalent to the existing energy in one ton of oil, and a conventional value of 11,63 kW.h was considered.

The organizational structure of the pig production chain in 2013 is shown in figure 1. Cuba has 14 state provincial pig production enterprises and 160 municipalities with territorial units linked to these enterprises, which belong to GEGAN. The state farms are classified into: breeding, genetic, multiplying and integral ones.

According to data estimated by GEGAN, in 2013 there were 14 000 farmers with contracts. The quantity of pigs varies from 30 to 2 000, but the most common range is 100-120 animals (Sosa *et al*., 2014). However, only 5,5 % (negligible value) of these contracts had biodigesters as treatment system; this proves the huge existing potential and does not include the state sector, with a higher animal concentration.

Considering the indicators shown in table 2, the quantity of existing animals at the end of 2013 in each of the farms, the pig contracts and amount of excreta, the biogas potential and its expression in tonnes of oil equivalent in one year are shown (table 5). The average weight of the pigs under the conditions of Cuba is 50 kg, taking into consideration the starting and finishing weight in fattening of 80 kg (Sosa, 2007).

Concerning the biogas production and utilization perspectives in the Cuban pig production sector, in the investment plan of GEGAN foreseen for the 2013-2020 period (Sosa *et al*., 2014), the following items are included:

- 1 000 biodigesters of 22 m^3 to treat the residues of 100-120 pigs, in the cooperative-farmer sector.

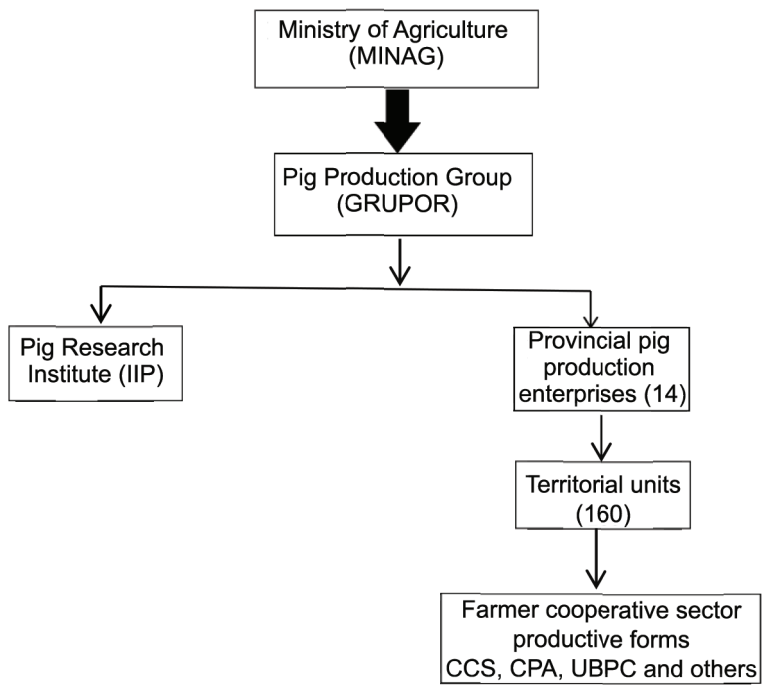

Figure 1. Organizational structure of the pig production chain in Cuba (EEPFIH/Cubaenergía (2013).

Table 5. Biogas potential in the Cuban pig production sector and its equivalent in tonnes of oil equivalent.

Type	Quantity of animals	Excreta (kg/day)	Biogas (m^3/day)	TOE
Private	833 175	1 916 303	134 141	25 353
State	286 693	659 394	46 158	8 724
Total	1 119 868	2 575 697	180 299	34 076

Source: Elaborated from the information reported by GEGAN.

TOE: tonnes of oil equivalent in one year, is an energy unit; its value is equivalent to the existing energy in one ton of oil, and a conventional value of 11,63 kW.h was considered.

- 36 medium-size biogas plants in state farms.
- Utilization of biogas for generating electricity.

To the actions of GEGAN for the treatment of pig effluents and the generation of energy, the ones carried out by other actors (farmers, cooperatives, state farms and international projects) are added. In the case of the two international projects coordinated by the EEPFIH, which prioritize pig farmers due to the high environmental impact, the results are the following: AGROENERGIA, funded by the European Union and the Portuguese NGO Oikos, built 28 biodigesters in the Martí municipality (Matanzas); while the project BIOMAS-CUBA, with funding from the Swiss Development and Cooperation Agency (SDC), has constructed 179 biodigesters –including three covered lagoons, one of them of 5 000 m^3– (Suárez, 2017). Additionally, other private, public and cooperation actions have allowed the construction and operation of other 539 small biodigesters.

Production potential in the cattle production sector

The beef and cattle milk production is mainly carried out by the private sector, which has more than 80 % of the existing heads of this livestock. At present there is the Cattle Production Entrepreneurial Group, which coordinates and supports the performance of state enterprises, as well as cooperatives and farmers.

The information about the quantity of existing heads, in the state as well as the private sector, is found at the level of enterprises, which report the data to the National Center of Livestock Control (CENCOP) and to the Ministry of Agriculture (MINAG).

Although cattle in Cuba is mostly semi-confined, with concentration of the animals in night hours, for the calculations only the milking cows were considered (ONEI, 2013), because it is guaranteed that they are going to be confined at least five hours per day for milking and in this period the excreta is collected. Likewise, it was estimated that 5 kg of excreta per animal per day are collected.

Taking into consideration the indicators shown in table 3, the quantity of existing animals at the end of 2013 in each one of the dairy farms and the quantity of excreta, the biogas potential and its expression in tonnes of oil equivalent in one year are shown in table 6.

Production potential in the food and sugar production industry

Within the food industry of MINAL, the 15 meat enterprises, five breweries, 15 dairy product enterprises and four alcohol distilleries are considered as more contaminant or of higher environmental impact; from these 39 enterprises 12 (31 %) were selected, due to their high impact on the environment: one distillery, three dairy product enterprises, six meat enterprises and two breweries. The main residues that are generated in this sector are liquid, and include vinasses, wort and residues from the production of dairy and meat products.

In the sugar production industry there are two types of basic residues that can be treated through anaerobic technologies, they are: sugarcane filter cake (residue in the juice filters from sugarcane production) and the vinasses generated in alcohol distilleries. In this analysis no data are included about sugarcane filter cake, due to the little available information about its potential for biogas production and the viability of this treatment.

In the case of distilleries in the sugarcane industry, they are 12 and are disseminated throughout the country. These are the most contaminating facilities within AZCUBA. Table 7 shows the biogas production potential in the food and sugar production industries, and its expression in tonnes of oil equivalent in one year.

Summarizing, the potential of daily biogas production is 674 609 m^3/day with 127 563 tonnes of oil equivalent per year.

The annual energy production would be calculated as:

Table 6. Biogas potential in the Cuban dairy cattle sector (private, cooperative and state) and tonnes of oil equivalent.

	Quantity of animals	Excreta (kg/day)	Biogas (m^3/day)	TOE
Milking cows[1]	501 200	5 012 000	200 480	37 898

[1]40 % of the total existing cows in 2013, which was 1 253,0 heads, according to ONEI (2013), was assumed as milking cows

TOE: tonnes of oil equivalent in one year, is an energy unit; its value is equivalent to the existing energy in one ton of oil, and a conventional value of 11,63 kW.h was considered.

Table 7. Biogas potential in the food industry and AZCUBA, and its expression in tonnes of oil equivalent.

Sector	Facilities	Biogas production (m^3/day)	TOE
MINAL	12	25 959	4 896
AZCUBA	12	142 465	26 992

Source: Elaborated from the information provided by MINAL and AZCUBA.

TOE: tonnes of oil equivalent in one year, is an energy unit; its value is equivalent to the existing energy in one ton of oil, and a conventional value of 11,63 kW.h was considered.

674 609 m^3/day x 365 days x 6 kWh/m^3 = 1 477 393 710 kWh/year = 1 477 394 MWh/year.

Likewise, when considering the 127 563 TOE, that one TOE is equivalent to 41 868 MJ and that diesel has a calorific value of 40 200 MJ/t, it is calculated that the 127 563 TOE mean 132 856 t of diesel, whose import costs Cuba 48 615 065 USD – without including freight and unloading– considering the price of West Texas Intermediate (47,57 USD/barrel) of September 4, 2017 (Precio del Petróleo, 2017); and that due to density, the weight of one barrel of 159 liters is 130 kg. This amount would allow the Cuban government to import, with the prices of that date, any of the following amounts:

- 13 914 t of whole powder milk (3 494 USD/t; ODEPA, 2017);
- 128 611 t of ground rice (378 USD/t; FAO, 2017a);
- 150 511 t of soybean meal (323 USD/t; Ámbito, 2017); or
- 360 112 t of yellow rice (135 USD/t; FAO, 2017b).

Considering the 127 563 TOE and that 0,1418 t of diesel are equivalent to a barrel of 159 liters, these TOE represent 884 273 barrels, that is, 140 599 467,9 liters of diesel. Likewise, the potential of emissions to be prevented due to the substitution of this fossil fuel is estimated in 440 779 t CO_{2eq}/year, calculated as follows: 140 599 467,9 liters diesel/year x 3,135 kg CO_{2eq}/L = 440 779 339 kg CO_{2eq}/year or 440 779 t CO_{2eq}/year.

Conclusions

There is significant potential for biogas production in Cuba, through the application of technologies which allow to utilize economically diverse agricultural and agrifood residues, highly contaminant and GHG emitters.

The results of this evaluation can support with information the decision-making processes that contribute to the national development of bioenergy, focused on substituting imports of fossil fuels and on eliminating the environmental impact; on it lies their importance for national, sectoral, provincial and local decision-makers.

Bibliographic references

Agostini, A.; Battini, F.; Giuntoli, J.; Tabaglio, V.; Padella, Monica; Baxter, D. *et al.* Environmentally sustainable biogas? The key role of manure co-digestion with energy crops. *Energies.* 8 (6):5234-5265, 2015.

Ambito. *Harina de soja internacional*. Buenos Aires: Nefir S.A. http://www.ambito.com/economia/mercados/granos. [09/02/2017], 2017.

Bansal, V.; Tumwesige, V. & Smith, J. U. Water for small-scale biogas digesters in sub-Saharan Africa. *GCB Bioenergy.* 9 (2):339-357, 2017.

Biogas Association. *Municipal guide to biogas*. Ottawa, Canada: Biogas Association. https://biogasassociation.ca/resources/municipal_guide_to_biogas. [09/02/2017], 2015.

Blanco, D.; Cepero, L.; Suárez, J.; Savran, Valentina; Díaz, M. & Martín, G. J. *Manual para el diseño, montaje y operación de digestores plásticos de bajo costo. Una alternativa para Cuba*. Matanzas, Cuba: EEPF Indio Hatuey, 2012.

Carreras, Nely. *Biogás*. Brasilia: ONUDI, 2013.

Díaz-Piñón, M. R. *Apuntes para convertir la producción animal en una forma segura y eficiente para producir energía y alimentos*. Las Tunas, Cuba: Grupo Provincial de Biogás, CITMA, 2009.

EEPFIH/Cubaenergía. Clean energy technologies for the rural areas in Cuba (Clean Energy Cuba). La Habana: GEF-PNUD; 2014.

FAO. *Grains. Trade and markets*. Rome: FAO. http://www.fao.org/economic/est/est-commodities/grains/en/#.WuHnXOfB_IU,[09/02/2017]. 2017b.

FAO. *Rice. Trade and markets*. Rome: FAO. http://www.fao.org/economic/est/est-commodities/rice/en/. [09/02/2017], 2017a.

GEF Council. *Manual for calculating GHG benefits of GEF projects: energy efficiency and renewable energy projects*. Washington D.C: Global Environment Found, 2008.

Guardado, J. A. *Diseño y construcción de plantas de biogás sencillas*. La Habana: Editorial Cubasolar, 2007.

Guardado, J. A. & Flores, J. A. Manual del constructor de pequeñas plantas de biogás de cúpula fija. *Taller Demostrativo. Proyecto GEF-PNUD CHI/00/G32 "Remoción de barreras para la electrificación rural con energías renovables", VII Región*. Maule, Chile. p. 13, 2008.

Guardado, J. A. & Vargas, D. Apuntes sobre el biogás como fuente de energía. *Taller Demostrativo. Proyecto GEF-PNUD CHI/00/G32 "Remoción de barreras para la electrificación rural con energías renovables", VII Región*. Maule, Chile. p. 116, 2008.

ICIDCA. Investigación-desarrollo-innovación-producción industrial de biogás a partir de desechos de la agroindustria azucarera y sus derivados. *Reunión de la Red de Universidades Cubanas para el Biogás*. La Habana: ISPJAE. p. 30, 2011.

IPCC. *Cambio climático 2007: Informe de síntesis. Contribución de los Grupos de trabajo I, II y III al Cuarto Informe de evaluación del Grupo Intergubernamental de Expertos sobre el Cambio Climático.* (Eds. R. K. Pachauri and A. Reisinger). Ginebra, Suiza, 2007.

López, Lisbet M.; Contreras, Luz M.; Romero, O.; Cruz, O. de la & Barrera, E. *La producción de biogás a partir de desechos pecuarios y agroindustriales: una alternativa energética*. Sancti Spíritus, Cuba: Centro Universitario de Sancti Spíritus, 2006.

Martínez-Hernández, C. M.; Oechsner, H.; Brulé, M. & Marañón-Maison, Elena. Estudio de algunas propiedades físico-mecánicas y químicas de residuos orgánicos a utilizar en la producción de biogás en Cuba. *Rev. Cie. Téc. Agr.* 23 (2):63-69, 2014.

Montalvo, S. & Guerrero, Lorna. *Tratamiento anaerobio de residuos. Producción de biogás*. Valparaíso, Chile: Universidad Técnica Federico Santa María, 2003.

ODEPA. *Precios internacionales de lácteos*. http://www.odepa.gob.cl/precios-internacionales-de-lacteos. [09/02/2017], 2017.

ONEI. *Ganadería en cifras*. La Habana: Oficina Nacional de Estadísticas, 2013.

Pérez, Tania; Pereda, Ileana; Oliva, Deny & Zaiat, Marcelo. Anaerobic digestion technologies for the treatment of pig wastes. *Cuban J. of Agric. Sci*. 50 (3):343-354, 2016.

Precio del Petróleo. *Precio del petróleo hoy*. WTI. http://www.preciopetroleo.net.[09/02/2017], 2017.

Rahayu, A. S.; Karsiwulan, D.; Yuwono, H.; Trisnawa, I.; Mulyasari, S.; Rahardjo, S. *et al. Handbook Pome-to-Biogas. Project development in Indonesia*. Jakarta: Winrock International, 2015.

Savran, Valentina. *Una solución energético-ambiental para reducción de contaminantes agropecuarios, como contribución al manejo integrado de la cuenca Zaza*. Tesis de Maestría en Gestión Ambiental y Protección de Recursos Naturales. Matanzas, Cuba: Universidad de Matanzas, 2005.

Sosa, R. *Fundamentación de los biodigestores tubulares en el tratamiento de aguas residuales en pequeñas producciones porcinas*. Tesis en opción al grado científico de Doctor en Ciencias Técnicas Agropecuarias. San José de las Lajas, Cuba: Universidad Agraria de La Habana, 2007.

Sosa, R.; Díaz, Y. M.; Cruz, Tamara & de la Fuente, J. L. Diversification and overviews of anaerobic digestion of Cuban pig breeding. *Cuban J. of Agr. Sci*. 48 (1):67-72, 2014.

Sosa, R. Indicadores ambientales de la producción porcina y ganadera. *VII Seminario Internacional de Porcicultura Tropical*. La Habana: Instituto de Investigaciones Porcinas, 2017.

Suárez, J. *Informe final del proyecto BIOMAS-CUBA Fase II*. Matanzas, Cuba: EEPF Indio Hatuey, 2017 6.4. Report No., 2017.

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