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Study of the energy recovery of slaughterhouse waste. The case of Tenerife

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Abstract. Tenerife is one of the main islands of the Canary Islands, which, due to its characteristics as outermost region, has a high energy dependence as well as a limitation on available territory; in addition, as it has been designated as a *Remote Area*, the elimination of Animal By-Products (ABPs) in landfills is permitted. This treatment does not contribute to the current trend of a circular economy and negatively harms the environment. The energy recovery of this waste through anaerobic digestion to produce biogas would enhance the use of renewable energies, contributing to the meat industry's energy independence and better management of the waste generated by this industry in Tenerife, promoting an energy transition towards cleaner energies. The study of the potential for biomethanization has been carried out both separately and in co-digestion in search of the best biogas production. Of the samples studied, only biogas was obtained in the anaerobic digestion of the rumen content, sewage sludge and for the co-digestion of viscera (cattle, pigs, goats, sheep, and rabbits) with raw blood and sewage sludge. The latter produces 128 mL of biogas per gram of volatile solids (VS) of the mixture, resulting in a total of 4,800 kWh_e of electrical energy for Tenerife's estimated waste in 2019.

Key words. waste-to-energy, anaerobic digestion, animal by-products, slaughterhouse waste

1. Introduction

Higher population growth, globalization and technological developments produce an increase in energy demand, waste generation and anthropogenic emissions [1]. The energy production scenarios are very polluting because the majority use fossil fuels, which are non-renewable fuels. In Spain, only the 37.5% of the electric energy comes from renewable sources [2]. In 2017, for example, 73.9% of the fuel needed for generating primary non-renewable energy was obtained from Algeria, Saudi Arabia, Nigeria, Mexico and Peru, among others [3].

On the other hand, waste management is particularly important because the landfill uses up a large amount of land that could be used for other productive activities such as agriculture. The Spanish discharge rate on landfill was higher than 50% in 2019 [3], [4]. In addition, landfills cause environmental problems such as bad smells and methane emissions, one of the most polluting gases. It is not the best treatment for waste because they do not follow the circular economy, where waste is transformed into a resource to be used again in the same process or in other processes. One of the most widely used treatments today is to transform this waste into energy, known in the literature as waste-to-energy (WTE). There are different alternatives to produce energy from biomass sources, grouped into thermochemical processes and bioconversion processes. Adequate technology is dependent on the characteristics and properties of the biomass. Anaerobic digestion, a bioconversion process, is more appropriate for biomass sources containing more than 50% moisture [5].

The high nutritional value of meat, i.e. high protein, bioavailable minerals and vitamins content, results in an increasing demand for livestock products and consequently, in increasing animal by-products generation originating in slaughterhouses [6]. Management of animal by-products for food industry is particularly important to ensure the safety of the human and animal food chain [7]. The animal by-products (ABPs) in slaughterhouses are waste from the process of the meat industry. Meat production is growing, according to the Food and Agriculture Organization (FAO) in 2029 there will be an 8% increase in developed countries when compared to the average values of the 2017-2019 series. Therefore, the amount of waste produced will also rise.

The Canary Islands are one of the outermost regions of the European Union in Spain. They face persistent and combined difficulties that hinder their socio-economic development: great remoteness, insularity, small area, complex orography and economic dependence on a small number of products. For this reason, the Canary Islands are called "*Remote Area"* from 1 March 2012 [7] and it has been extended several times, most recently until June 15, 2022 [8]. This name was declared by the Canary Islands Administration because of the special orographic conditions of the Canary Islands for the operations of withdrawal, transport, handling, and storage of animal by-products, together with the remoteness and insularity of the territory. Then, animal by-products can be taken to the landfill whenever environmental complexes have environmental authorization and the removal and transfer of such by-products from generating activities to environmental complexes are carried out by companies authorized for the purpose according to BOC - 2018/112 [8].

Each island that composes the Canary Islands forms an isolated energy system with an external energy dependence on fossil fuels and a territory limitation. Each energy system must tend to energy transition towards a cleaner one, favouring the penetration of renewables with manageable renewable energy like biogas. This is in line with the goal of the Sustainable Development Goal (SDG) number 7, "Ensure access to affordable, reliable, sustainable and modern energy for all". Likewise, complying with the law 7/2021, published the 21 May 2021, called "Climate Change and Energy Transition Law", which highlights the steps for a clean energy transition.

In the present study, the available data on waste generated by the slaughterhouse on the island of Tenerife has been collected and analysed. Subsequently, it is experimentally determined with samples supplied by the slaughterhouse how much energy it is possible to obtain from the wasted by-products. This information will make it possible to determine the self-sufficiency capacity available in this type of industrial activity using its own animal by-products.

2. Case of Study

A. Quantification of animal by-products in Tenerife

The Canary Islands government has a quantification of the number of animals (heads) slaughtered in Tenerife, which includes bovine, porcine, goats, ovine, and rabbits. This study was carried out with data collected during the year 2019, the last year within normality given that in 2020 because of the COVID-19 pandemic the data are not representative [9].
the amount of animal by-products is estimated taking into account the bibliographic data of $kg \cdot head^{-1}$. For bovine and porcine, the parameters of the head studied by Sagastume et al. [10]. In the case of goats and ovine, they are considered as small ruminants with a median weight of 40 kg, 50% of viscera and 3% of blood [11], [12]. Finally, the rabbits have a median weight of 2.30 kg and a 40% waste rate [13]. The sewage sludge is the real production of the slaughterhouse.
According to this, in 2019 the quantity of ABPs estimated was 828.09 t of viscera (329.01 t of bovine, 326.41 t of porcine, 133.64 t of goats and ovine and 39.03 t of rabbits), 223.8 t of blood and sewage sludge has a real production of 240.30 t.
The total amount, in metric tonnes, of viscera, blood and sewage sludge generated per month in Tenerife for 2019 are shown in Table I.

Table I. Total of animal by-products in Tenerife. Year 2019.

Month	**Viscera (t)**	**Blood (t)**	**Sewage sludge (t)**
January	63.10	16.59	16.80
February	63.98	16.49	16.80
March	63.84	16.33	19.20
April	70.40	19.58	15.00
May	64.41	18.56	22.50
June	63.95	17.04	22.50
July	64.65	18.31	22.50
August	58.39	16.52	22.50
September	63.30	17.61	15.00
October	70.90	18.83	37.50
November	67.25	18.50	15.00
December	113.93	29.43	15.00

In agreement with these total quantities, the proportion of each animal by-products is 64.1%, 17.3% and 18.6%, viscera, blood and sewage sludge, respectively. Viscera are in a very high proportion, then it is crucial to improve the valorisation of this kind of waste.

The total quantity of 1,292 t of animal by-products (bovine, porcine, ovine, caprine and rabbit) was generated according to the estimation for 2019 in Tenerife.

B. Anaerobic digestion

Anaerobic digestion, a technology that converts waste into biogas and biofertilizer, is an ideal method for recovering these types of waste [14].
In Tenerife, to send animal by-products to the landfill, the slaughterhouse must pay to an authorized manager to transport them to the landfill. And only solid waste must be eliminated from the landfill. Therefore, blood is dehydrated using steam at 180ºC for 40 minutes before being sent to the landfill. Consequently, the effect of raw and dehydrated blood on biogas production is investigated in this study.
Before this waste is used in anaerobic digestion, according to Regulation (EU) 142/2011, a pre-treatment is necessary. The pre-treatment used in this study was pasteurisation for 24 hours at 85 ºC to ensure that a temperature of 70 °C is reached inside the sample for one hour. Also, animal by-products must be cut into pieces smaller than 12 mm before pretreatment.
The animal by-products used were a mix of viscera of different animals (bovine, porcine, goat, ovine and rabbit), and a mix of blood and sewage sludge of all animals. The viscera proportion was determined according to the distribution of viscera quantity of each animal.
In order to improve biogas production from samples such as viscera, co-digestion is important to compensate for anaerobic digestion inhibitors [15]. Therefore, samples with a mix of animal by-products as well as by-products alone were studied to seek energy recovery from all animal by-products converting waste into resources.
The gas production from anaerobic digestion of ABPs was obtained by a batch system (Figure 1).

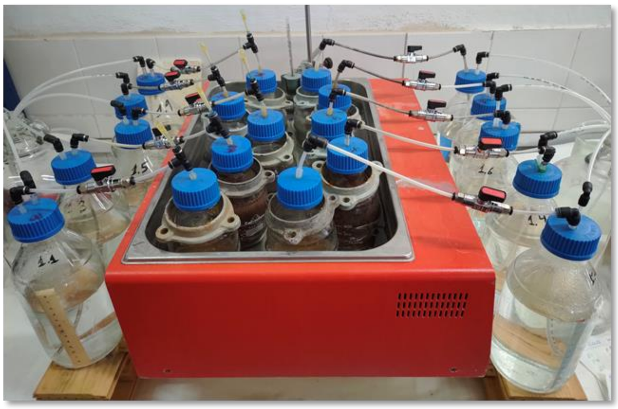

Figure 1. Experimental batch system.

The samples were rumen content, sewage sludge, raw blood, dehydrated blood and viscera alone. After that, the co-digestion of wastes was studied viscera with raw blood, viscera with dehydrated blood and the last sample was a mix of all kinds of wastes (viscera with raw blood and sewage sludge).

In the experimental system, ISO bottles were used as biodigesters. In each digester, 60 g of pasteurized animal by-products were placed, except in the biodigester with rumen content, where due to its low density only 15 g were placed. Then, 290 mL of distilled water was added, then the content was shaken and the pH was measured. After that, 4.8 g NH_4Cl (purity 99.5 %) were added to provide the medium with a nitrogen source, 540 mg of $CaCO_3$ (purity 99.0 %) and 10 mL of buffer solution (pH=7.0 (20ºC)) were subsequently added to act as a buffer and pH was measured again. In the case of the rumen content, 2.4 g NH_4Cl, 270 mg of $CaCO_3$ and 10 mL of buffer solution 7.0 pH were added. A 4M NaOH solution (purity 99.0%) was added if necessary to achieve a pH in the range of 7.5-8.5. After that, biodigesters were hermetically sealed with a GL45 cap and vacuum was made. Afterwards, biodigesters were filled with nitrogen and purged three times to avoid oxygen inside the biodigester. Each sample was duplicated because one digester is disturbed to extract gas volume for composition analysis in the chromatograph and the other was used only for gas volume measurements. Finally, the biodigesters were introduced into thermostatic water baths at a temperature of 32 ºC and connected to the metering system.

1) Quantification of gas production

One of the products of anaerobic digestion is gas production. Gas produced by biodigesters was measured by volume displacement in a one-litre ISO glass bottle. In this way, each bottle was calibrated with a scale of 12 centimetres on which it was possible to measure the difference in height. Then, the volume of the cylinder displaced is proportional to the volume of biogas produced.

The volume measurement was taken at the same time, depending on gas production, at average intervals of two days. The content of the bottle was stirred to facilitate the release of the gas dissolved in the solution and then the value of height is taken. The value of gas volume was converted to normal conditions.

To characterize each sample and its potential for biogas conversion, a solid analysis (total, volatile and fixed solids) has been carried out according to standard methods [16]. Volatile solids are susceptible to being transformed into biogas. Therefore, samples were analysed before and after the process of anaerobic digestion, relating the amount of volatile solids consumed to the volume of biogas produced (Table II).

Table II. Volatile solids analysis in the anaerobic digestion (AD).

Volatile solids before AD	Volatile solids after AD	Volatile solids consumed in AD
86.0%	10.5%	75.5%
77.6%	11.3%	66.3%
21.4%	5.9%	15.5%
24.9%	9.0%	15.9%
41.2%	25.9%	15.3%
37.2%	21.7%	15.5%
38.3%	34.8%	3.5%
40.9%	17.2%	23.7%

The quantification of gas produced by grams of volatile solids fed (Table III).

Table III. Gas production per sample.

Sample	Gas production (ml · g VS^{-1})
Rumen content	32.73
Sewage sludge	252.13
Raw blood	62.13
Dehydrated blood	37.40
Viscera	27.57
Viscera and raw blood	47.47
Viscera and dehydrated blood	35.19
Viscera, raw blood and sewage sludge	127.71

2) Composition of gases

The composition of gases in each sample was measured with a gas chromatograph (Agilent 7820A GC) and a thermal conductivity detector (TCD) with two capillary columns working in parallel, CP-Molsieve 5 Å (30 m, 0,53 mm DI, 0,53 µm) and CP-PoraBond Q (packed column), which allow measurement of CH_4, CO_2, CO, O_2 and N_2. The analysis was realized with operating conditions as follows: oven temperature isothermal at 40ºC; injector temperature at 175ºC; TCD temperature at 180ºC and helium as carrier gas with a flow rate of 36 mL min^{-1} and at 9 psi pressure.

The composition analysis was carried out on a gas sample volume of 1 ml.

The maximum methane composition was chosen for each sample (Table IV).

Table IV. Maximum methane composition.

Sample	Methane composition
Rumen content	64.74 %
Sewage sludge	68.92 %
Raw blood	16.46 %
Dehydrated blood	0.18 %
Viscera	0.32 %
Viscera and raw blood	32.29 %
Viscera and dehydrated blood	28.31 %
Viscera, raw blood and sewage sludge	69.19 %

Only rumen content, sewage sludge, and the co-digestion of viscera and raw blood with sewage sludge produced biogas because its methane composition was higher than 55%. Therefore, they have the potential to be used to obtain electrical or thermal energy, due to the high energy potential of methane. Currently, the rumen content with a high vegetal biomass composition is used in aerobic digestion as compost, and then as a biofertilizer in agriculture. Although with anaerobic digestion, the by-product generates energy as well as the same as biofertilizer.

Others, like raw blood, co-digestion of viscera with raw blood or co-digestion of viscera with dehydrated blood, methane concentration is lower than 55%. Therefore, this gas rich in carbon dioxide can be used to transform this CO_2 into other products with higher energy values, such as dimethyl ether (BioDME), where the gas could be converted to methanol by a catalytic process before BioDME production. Additionally, biomethanol (Bio-MeOH) can also be obtained.

C. Energy potential

From the point of view of energy recovery from biogas, as mentioned above, the samples used produce a gas with a methane composition greater than 55% which can be used to obtain thermal and electrical energy through cogeneration. In the case of slaughterhouses, both types of energy are necessary, and the biogas generated could be used. The energy can be estimated by equation (1):

$$E_{biogas} = C \times CH_4 \times P \times \eta \quad (1)$$

where E_{biogas} is the quantity of electricity or heat energy produced (kWh/year); C represents the lower calorific value of methane, which was considered as 36 MJ (or 10 kWh) per cubic meter of methane; CH_4 represents the methane content; P is the amount of biogas produced per year or the biogas potential (m^3/year); and η represents the efficiency of the conversion of biogas (%) [17]. It is noted that the η values (η_e or η_c) were considered as η_e = 37% (conversion efficiency of electricity) and η_c= 53% (conversion efficiency of thermal energy), respectively, for electric and thermal energies [18].

In this work, the result from each sample was analysed to estimate the energy production using equation (1). Table V shows the estimation of electrical and thermal energy produces by co-generation, electrical and thermal energy. The samples mixture of the principal animal by-products (viscera, sewage sludge and raw blood) has the highest energy production transforming in a suitable alternative to reduce the waste generated in the slaughterhouse, allowing the generation of 4,800 kWh/year and 24,753 MJ/year electrical and thermal energy in 2019, respectively. It is necessary to compare this estimation with the real energy demand of the slaughterhouse industry and calculate the self-sufficiency rate like Ireland case [19].

Table V. Energy estimation.

Sample	Electrical energy (kWh/year)	Thermal energy (MJ/year)
Sewage sludge	3,331	17,176
Raw blood	50	259
Viscera	3	16
Viscera and raw blood	617	3,180
Viscera, raw blood and sewage sludge	4,800	24,753

One way to compare different wastes is given by the energy potential in MJ/kg of waste (Table VI).

Table VI. Energy potential.

Sample	Energy potential (MJ/kg of ABPs)
Sewage sludge	6.3
Raw blood	0.37
Viscera	0.0032
Viscera and raw blood	0.55
Viscera, raw blood and sewage sludge	3.2

3. Conclusion

The animal by-products have a potential for energy recovery through anaerobic digestion. As a result, this process is an approach to the treatment of waste dumped in landfills that avoids transport and landfill emissions and the financial expenses of paying an agent to carry out the transport of the goods. In addition, the blood does not have to be submit to a thermal process because it doesn't improve the co-digestion of ABPs and energy would be wasted.

A mixture of most animal by-products generated in Tenerife, with an estimation of 1,292 tonnes for 2019, and the proportion analysed in this work generates a biogas production of 127.71 mL g VS^{-1}. Furthermore, animal by-products will generate an average of 4,800 kWh $year^{-1}$ of electrical and 24,753 MJ $year^{-1}$ thermal energy.

Overall, this alternative treatment of animal by-products converts this waste into a resource as energy recovery to supply the meat industry's energy demand, turning this industry into a more sustainable and self-sufficient industry, favouring the circular economy.

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