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## *On the valorization of Azorean meat industry by-products: Opportunities for green energy generation*

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### **Abstract**

The present work focuses on the valorization of slaughterhouse wastes produced by the Azorean meat industry. An estimation of the potential of biogas and organic biofertilizer production through anaerobic digestion of beef and pork by-products was carried out. Yearly, over 150,000 livestock units (cattle and pigs) are slaughtered in the Azores, generating over 5,284 t of animal waste. Anaerobic digestion of the waste can potentially generate 324,842 Nm<sup>3</sup> of biogas (189,383 Nm<sup>3</sup> CH<sub>4</sub>) and be used to produce either thermal (1,886 MWh) or electrical energy (660 MWh). Expected benefits include the reduction of CO<sub>2</sub> emissions and the production of organic biofertilizers, contributing to lowering the carbon footprint associated with the meat industry.

**Keywords:** *anaerobic digestion, Azores, biogas, environmental sustainability, green economy, slaughter waste*

### **Introduction**

The global climate change along with the recent European energetic crisis are pressing for further investments and policies promoting renewable energy sources and zero net emissions. However, ultraperipheral regions of the European Union (EU), such as the Azores, have always had a small-scale economy and a limited number of key sectors (Valente, 2007) which impose an even greater challenge in decarbonizing industries and meeting EU targets for cuts in greenhouse gas (GHG) emissions (European Commission Secretariat-General, 2019). In 2020, only Graciosa had a production of energy from renewables of over 50%, followed by São Miguel and Flores which registered  $\approx 49$  and 47% of total electricity generation, respectively. Terceira, the second highest energy consumer, generated  $\approx 37\%$  of its energy from renewables, whereas in the remaining islands that share represented less than  $\approx 13\%$ . Nonetheless, 2020 registered the lowest values of electricity production from fossil fuels of the last 10 years, with a decrease of  $\approx 8$  and 1% for oil and diesel, respectively, and an increase of wind and geothermal energy,

correspondingly, of  $\approx 3$  and 2% (SREA, 2022a) (Fig 1).

The use of biogas, a biofuel naturally produced from the decomposition of organic matter, for electricity production has increased slightly over the last 10 years but is still restricted to the island of São Miguel. The production of biogas encompasses anaerobic digestion of substrates e.g., food, agricultural and animal waste, allowing an abatement of its polluting potential and a recovery of two valuable products, energy and natural fertilizers. The fact that livestock farming is one of the most important sectors of the economy of the Azores, renders exploring strategies for the valorization of animal waste a great opportunity to build a more resilient business for the future. Indeed, meat consumption shows no signs of slowing down, as pork and beef slaughter has increased, in the region, respectively, by 12% and 25% in the last decade (SREA, 2022b). The production of beef generates tons of waste yearly, as on average, up to 60% of cattle animal weight is inedible. In large animal slaughtering facilities, by-products consist mainly of whole or parts of rejected carcasses, blood, wool, leather, hair, skins, horns, hooves,

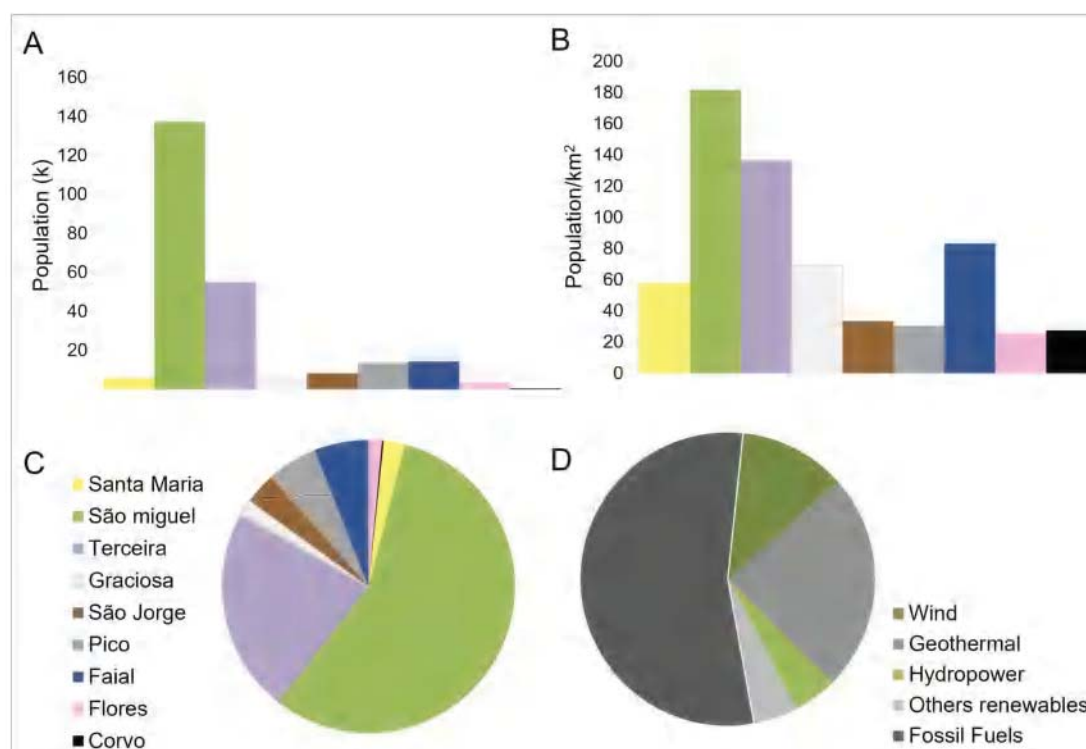


**Figure 1** - Infographics of the Azores: (A) population per island, (A) density of population per island, (C) energy consumption per island, and (D) sources for electricity generation in the archipelago. Data referring to 2020 was obtained from Statistics Azores, SREA website (Srea, 2022)

the content of gastrointestinal compartments, inedible red and white offal, which are classified into three categories (M1, M2, M3), according to their origin and potential risk for the health of both humans and animals. M1 by-products must be incinerated, whereas M2 and M3 might be used for different purposes, including biogas production if previous processing is applied to minimize the health risks involved, e.g., particle size reduction followed by pressure sterilization (SREA, 2022c).

## Results and Discussion

In 2021, just under 79,000 units of beef and 76,000 units of pork were slaughtered and approved for human consumption in the Azores (SREA, 2022c). São Miguel, Terceira, and Pico produced, respectively, 49, 28, and 9% of beef, followed by São Jorge, Faial ( $\approx 5\%$ ), Santa Maria, Graciosa, Flores ( $< 2\%$ ) and Corvo ( $< 0.1\%$ ). Regarding pork meat production, São Miguel stood out with 64%, followed by Terceira (18%), and the other seven islands responsible for  $< 17\%$  of slaughter units of pork (European Parliament,

2009). The estimation of waste produced per unit slaughtered was carried out for pork and beef, using average body part weights obtained in Terceira slaughtering facility for the following age categories: 1) piglet, 2) fattening pig, 3) bulls and cows, 4) heifers and bullocks, and 5) calves. High-risk materials such as rejected carcasses (whole or parts) and other classified M1 products were not considered, as they are not authorized for biogas production.

The pork meat industry generates a lower amount of waste since a greater percentage of the carcass and offals are suitable for human consumption. Therefore, despite the number of pork and beef units slaughtered in the region being similar, the amount of waste generated is largely affected by the second. On the other hand, the cattle slaughter on each island varies throughout the year, due to socio-cultural reasons. The analysis of cattle slaughter data in the last 10 years (SREA, 2022b) shows that the monthly animal waste production is relatively constant on the islands of São Miguel, Terceira, São Jorge, and Pico. Contrarily, on Faial, but especially, on Santa Maria, Graciosa, Flores, and

Corvo, monthly variations from 5 to 20% occur. This is a key point, as not only the gross substrate production must be considered but also its availability to feed the biodigester that operates continuously.

Slaughterhouse waste produced in the whole year was estimated to be 5,284 t, 4,806 t from beef, and 478 t from pork, unevenly distributed across the nine islands. Anaerobic digestion of the waste potentially has a gross methane yield of 189,383 Nm<sup>3</sup> equating to 324,842 Nm<sup>3</sup> of biogas (58.3% CH<sub>4</sub>; (Biogas, 2022), which corresponds to 37,1 Nm<sup>3</sup> biogas per hour. Biogas might be used to generate thermal energy (1,886 MWh) for self-consumption, namely, to produce steam for several operations (clean, scalding) and heat the biodigester ensuring the self-sufficiency of the system. Alternatively, biogas can be used to generate electricity (660 MWh) for self-consumption or be sold back to the grid for revenue. To place perspective on these figures, the electric potential generated corresponds to roughly 20% of the electricity demand of the slaughtering facilities (3,168 MWh/year in 2021). In terms of savings, it is expected to represent

over 180,000 euros per year, which will, eventually, cover the costs of the biogas plant installation and maintenance. Moreover, replacing this share of energy from fossil fuels with an equal share produced from a renewable source will prevent the release of 557 kg of CO<sub>2</sub> into the atmosphere. Importantly, this estimation does not account for the impact of waste incineration, thus the reduction in GHG emissions associated with anaerobic digestion is expected to be even higher. Environmental sustainability can also be improved by the production of natural fertilizers. Indeed, the anaerobic digestion of the waste was estimated to allow the recovery of 15,582 kg of N that can be applied as organic fertilizer in an agricultural area of 93 ha (Kefalew & Lami, 2021), thus contributing to lowering the dependence on chemical fertilizers. The availability of organic fertilizers might be relevant for farmers that are now implementing organic farming practices to become eligible for receiving government financial incentives intended to push for more sustainable and ethical agriculture in the region.

**Table 1.** Estimation of animal slaughter waste (pork and beef, t/year), biogas (biomethane) potential (Nm<sup>3</sup>/year), potential thermal and electrical energy (MWh/year), biofertilizer (kg N/year), CO<sub>2</sub> abatement (kg/year), and savings (€/year) for each of the nine Azores islands, data from 2021.

|             | animal<br>waste | biomethane <sup>a</sup> | thermal<br>energy <sup>b</sup> | electrical<br>energy <sup>c</sup> | biofertilizer <sup>d</sup> | CO <sub>2</sub><br>abatement <sup>e</sup> | savings <sup>f</sup> |
|-------------|-----------------|-------------------------|--------------------------------|-----------------------------------|----------------------------|-------------------------------------------|----------------------|
| São Miguel  | 2,636           | 94,472                  | 941                            | 329                               | 7,907                      | 279                                       | 88,09                |
| Terceira    | 1,462           | 52,386                  | 522                            | 183                               | 4,385                      | 155                                       | 48,238               |
| Faial       | 269             | 9,643                   | 96                             | 34                                | 807                        | 29                                        | 8,653                |
| Pico        | 416             | 14,912                  | 149                            | 52                                | 1,248                      | 43                                        | 13,778               |
| São Jorge   | 275             | 9,864                   | 98                             | 34                                | 826                        | 28                                        | 13,175               |
| Santa Maria | 63              | 2,252                   | 22                             | 8                                 | 188                        | 6                                         | 2,522                |
| Graciosa    | 101             | 3,619                   | 36                             | 13                                | 303                        | 11                                        | 4,033                |
| Flores      | 58              | 2,075                   | 21                             | 7                                 | 174                        | 6                                         | 1,835                |
| Corvo       | 4               | 160                     | 2                              | 1                                 | 13                         | 0                                         | 124                  |
| Azores      | 5,284           | 189,383                 | 1,886                          | 660                               | 15,852                     | 557                                       | 180,449              |

<sup>a</sup>Coefficients used: average dry matter (DM%) 14.6; organic matter (OM%DM) 83.5; volume of CH<sub>4</sub> per t OM 294; and %CH<sub>4</sub> 58.3 [7]; <sup>b</sup>Heating value of CH<sub>4</sub> = 9,96 kWh/m<sup>3</sup>; <sup>c</sup>Assuming 35% electrical efficiency of biogas generators; <sup>d</sup>Assuming 3 kg N for t of waste [7]; <sup>e</sup>assuming a diesel factor emission of ≈600 CO<sub>2</sub> g/kWh; <sup>f</sup>Considering the billing information of the corresponding year.

Currently, animal waste produced in each of the nine slaughter facilities is shipped to Terceira to be treated and incinerated, which has both an economic and environmental impact that demands new solutions. The installation of a small-scale biogas plant adjacent to each slaughtering facility to avoid the costs of exporting residues is, at first sight, an attractive idea. However, it would require a coupled system to ensure the maceration, homogenization, and pasteurization of the slaughter waste before subjecting it to anaerobic digestion, which is likely only available in São Miguel and Terceira. Furthermore, according to projections of other authors [9], 50 kWe is the minimum capacity that biogas plants should have to be economically viable, which considering the assumptions made, requires 3500 t annual of waste annually. In this scenario, one possibility is continuing to channel the waste treatment to Terceira, though replacing the incineration by anaerobic digestion in a biogas plant with a volume of biodigester of 580 m<sup>3</sup> (assuming a retention time of 40 days). Another scenario, that would reduce the impact of waste transport, would be the installation of a biogas plant in São Miguel for the treatment of waste produced in the Oriental group, and another in Terceira for the waste produced in the Occidental and Central groups, with biodigesters volumes of 296 m<sup>3</sup> and 285 m<sup>3</sup>, respectively.

## Conclusions

The impact of meat production on GHG emissions is not limited to enteric methane emissions. Indeed, it involves a series of processes throughout production and distribution that are detrimental to the environment. Therefore, it is mandatory to take a holistic view of the entire meat supply chain, in which slaughter is placed, and find solutions aligned with the green economy and environmental sustainability scopes. The production of biogas from slaughterhouse waste in the Azores can

contribute to these objectives in, at least, two islands (São Miguel and Terceira), which justifies pilot studies in the field. On the remaining seven islands, the installation of biogas plants adjacent to the slaughter facilities will unlikely return the investment, unless co-digestion is considered. Nevertheless, following the current practices of shipping the waste to Terceira, treating it by anaerobic digestion instead of incineration already promises to lower the current carbon footprint.

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