Food Research International 73 (2015) 226–233

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Biochemical methane potential of livestock and agri-food waste streams in the Castilla y León Region (Spain)

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ARTICLE INFO

Article history:
Received 23 October 2014
Received in revised form 16 December 2014
Accepted 23 December 2014
Available online 3 January 2015

Keywords:
Agri-food waste
Anaerobic digestion
Buswell and Muller's equation
Methane potential
Valorization strategies

ABSTRACT

An inventory of agri-food industry organic waste streams with potential for biogas production was carried out in a logistically viable area of Castilla y León (Spain). The potential for methane production from 23 wastes and their mixtures was evaluated theoretically and in laboratory batch assays. Obtained methane yields ranged from 290–725 mL CH_4 g $VS^{-1}{}_{waste}$, and the methane content in biogas ranged from 46–72% for raw wastes. The estimation of the regional fluxes of waste and methane potentials suggests anaerobic digestion in a centralized plant as a sustainable solution for the valorization of the organic wastes generated in this area, where up to 5% of the primary energy demand can be covered by the calculated total biogas energy potential. Sector-specific waste streams (livestock and agri-food industry) could cover up to 24% of regional total energy demand. Logistical aspects are critical in Castilla y León due to the high dispersion of the population and the industrial facilities.

1. Introduction

Households, agriculture, and industry generate large amounts of waste products that, when managed improperly, cause tremendous environmental impacts. Over the years, a range of ideas for the utilization of these wastes has been put forward; however, anaerobic digestion of organic wastes to produce energy in the form of biogas is the most likely option to be of commercial interest, provided that the economics are favorable. As a result, during recent years, anaerobic digestion of organic matter from different sources has been presented as a suitable technology used for treatment of organic wastes and production of energy from combustion of biogas (Kiran, Trzcinski, Jern Ng, & Liu, 2014; Weiland, 2010; Zhang, Su, Baeyens, & Tan, 2014), as well as greenhouse gases reduction (Liebetrau et al., 2013). In addition, a material use of the digestates (fermentation residues) in the sense of a recycling economy is possible and thus can contribute to the agronomical value of soils (Hidalgo, Martín-Marroquín, Gómez, Aguado, & Antolín, 2014).

Due to these advantages, energy recovery from biogas has taken a leap forward in the EU during the last years. Primary energy production grew by 15.7% in 2012 compared to 2011, which is a 1.6 Mtoe increase (12 Mtoe produced in 2012) (EurObserv'ER, 2013). In Spain, where a common practice, for example, is the burning of agricultural waste on the field (Avendano, 2009), the waste concept is also still in its infancy compared to countries as Germany or The Netherlands (Lorenz, Fischer, Schumacher, & Adler, 2013). The Spanish waste production is continuously growing, and has climbed to about 1.35 t/inhabitant/year in 2010 (EUROSTAT, 2013). Around 47% of this waste is estimated to be organic matter (Lorenz et al., 2013).

Treatment plants specifically designed for energy recovery (decentralized agricultural plants, municipal solid waste treatment plants, methanization plants, co-digestion and multi-product plants) dominate the biogas production in the EU, generating more than two-thirds of the primary energy (66.5% in 2012), a long way ahead of landfill biogas (23.7%) and biogas from sewage plants (9.9%). The situation is totally different in Spain. In 2012, primary production of biogas in Spain was 0.26 Mtoe (a 0.026 Mtoe decrease compared to 2011). 50.6% of the biogas was produced from landfill, 11.1% from sewage sludge and the remaining 38.3% from other sources (EurObserv'ER, 2014). Landfill is the main biogas source in Spain due, in part, to the fact that the proportion of fermentable waste consigned to landfill remains high. In 2006, only 3% of total organic waste was recycled in this country (Lessner, 2009). The separate collection of biowaste is only broadly established in northern Spain, especially in Catalonia (Giro, 2013).

But the situation in Spain has to change in the medium term since there are two directives of EU legislation dealing with these problematic aspects. The first is the Landfill Directive (1999/31/EC), which requires the reduction of biodegradable waste going to landfills (Article 5). This request is reinforced in the second instrument, the Waste Framework Directive (2008/98/EC). The Waste Directive includes also the Article 22, which requires Member States to take measures to encourage separate collection of biowaste.

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http://dx.doi.org/10.1016/j.foodres.2014.12.044
0963-9969/

Castilla y León, located in the middle of the northern half of Spain and covering an area of 94,223 km^2, is not only the largest region of Spain, but as well one of the largest regions of all the European Union. Castilla y León faces several demographic challenges, among them sparseness, meaning low population density together with a great dispersion of population and industrial spots. Until recently, agriculture and livestock were its major economic sectors (agricultural production in this region represents 15% of Spain's primary sector). On the other hand, the agri-food industry represents the majority of Castilla y León's specialized industry. As a consequence, Castilla y León has a huge potential in biogas production (Table 1).

Referring operating biogas plants, the possibilities of biogas production in Castilla y León mainly comes from two kinds of resources: sewage sludge and organic urban waste. However, the potential of the region in biogas production from manure and agri-food industry wastes (>250 ktoe/y) (IDAE, 2011) is one of the highest in Spain (Fig. 1). In biogas plants of recent construction, the substrate input streams consist predominantly of a manure mixture, which can contribute in some cases more than 95% of the total biomass digested in the reactor. In contrast, the use of food waste as well as industrial organic waste is still of minor importance (EREN, 2009).

A common fact is that, whatever the considered waste stream, characterization is a key task for designing and operating anaerobic digesters, as it affects biogas production and process stability (Zhang, Cai, & He, 2007). The main parameters include moisture, volatile solid content, nutrient contents, particle size, and biodegradability. The biodegradability of a feedstock is indicated by biogas production or the BMP (biochemical methane potential) (Labatut, Angenent, & Scott, 2011) and percentage of solids that are removed in the anaerobic digestion. The objective of a BMP test is to measure the maximum methane production of a specific substrate. Several batch methods exist for measuring biochemical methane potentials of waste, however their technical approaches vary significantly among the published methods (Angelidaki et al., 2009; Raposo, de la Rubia, Fernández-Cegrí, & Borja, 2011).

In this study an inventory of animal and agri-food industry organic waste streams with a high potential for biogas transformation was performed in a logistically viable area of the central part of Castilla y León (Spain) of 4000 km^2. Some of the industries studied were livestock, meat industry, dairy, animal feed, fruit industry, and processing industry of used edible oils.

The main objective of this study was to characterize the waste collected from that area with the aim of evaluating the feasibility of converting the waste into biogas energy in a centralized plant. Furthermore, a calculation of biogas energy potentials was carried out for defined waste fractions which are most suitable for anaerobic digestion.

2. Materials and methods

2.1. Waste selection

23 different waste streams from the main livestock and agri-food industries, among others, located in a logistically viable area of the Castilla y León region were chosen for this project: pig manure (diluted with high loaded wash water) (PM), cattle manure (CM), sheep manure (SM), poultry manure (PoM), potato waste (PW), waste sludge from a potato residue treatment plant (WSP), waste sludge from a fruit residue treatment plant (WSF), oily waste sludge (OWS), non-refine glycerin (G), diluted used vegetable oils (dUVO), waste sludge from used vegetable oil processing (WS-UVO), used vegetable oil decanted fraction (DF-UVO), waste sludge from an animal feed residue treatment plant (WSA), pet feed waste (PFW), fish feed waste (FFW), straw (S), strawberry bed pruning waste (SBPW), leek waste (LW), FeCl coagulation sludge (CS), pasteurized blood (PB), organic matter from animal intestine (OMAI), wafer waste (WW) and sewage sludge (SS).

Although agri-industrial wastes traditionally are the most convenient co-substrates for manures (Mata-Alvarez et al., 2014), the need to overcome its seasonality and further improve the digester methane production have raised interest over other industrial wastes and substrates rich in biodegradable organic matter, as it is the case in this work of streams as G, S, CS and SS.

The selection criteria for all the waste streams relied upon aspects such as the geographical relative distance between each producer to a hypothetical (planned but not already constructed) centralized plant and theoretical information related to biomethane generation per kg of organic waste.

In this study, the quantities of waste, as well as current waste streams of organic residues generated by the selected industries and farms were mainly determined by means of interviews. Based on these data, the usable quantities of respective waste fractions for anaerobic digestion, as well as the technical potentials for the energy production via biogas, were calculated. The quantity of waste usable for anaerobic digestion is the waste fraction remaining after other alternative uses already established in the area, as animal feed, composting, or recovery of active compounds. On the other hand, the technical potential means the part of the present biomass (theoretical potential) that can be used for biogas production by current technical possibilities, that is, only the biomass available at the source for collection and transport. Manure from extensive livestock farming would not be considered, for example, an available waste. Possible structural and ecological restrictions (e.g., established utilization paths) were not taken into account.

Samples were weekly collected. Enough amounts of the different waste streams were taken for each time in order to guarantee the same sample to be used for digestion and then stored in a 4 °C fridge.

2.2. Waste characterization

Total and volatile solid concentrations (TS, VS) were determined following Standard Methods (APHA, 2005) recommendations. C, N, H and S contents were determined by UNE-CEN/TS 15104 EX with a LECO Truspec CHN(S) elemental analyzer. Oxygen content was not measured directly but was estimated assuming that no other elements (apart from the measured C, H, N and S) were present in the wastes. In all the cases, analysis was performed just after sampling.

Table 1
Organic resources in Castilla y León.

Waste origin	Waste type	Current estimation		
		Available waste production (t y^{-1})	Primary energy (ktoe y^{-1})	Source
Agriculture	Including straw	6,063,405	1003.1	Own
Farms	Manure	7,239,493	207.2	IDAE (2011)
Agri-food industry	Animal	1,334,293	28.6	IDAE (2011)
	Vegetal	478,307	14.8	IDAE (2011)
Urban	Organic fraction	231,000	2	EREN (2009)
	Sewage sludge	42,296	7.6	IDAE (2011)
Energy crops	Herbaceous	295,000	42	EREN (2009)