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An overview on the Irish Breweries and distilleries potential for generating bioenergy through the anaerobic digestion of the wastewater

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Abstract: This work presents an overview on the potential for generating bioenergy through the anaerobic digestion of the Irish breweries and whiskey distilleries effluents. The results showed that it would be possible to generate 28,210,958 Nm^3/year of biogas or 154,846 MWh of thermal heat with 110,715 tonnes of CO_2 savings in a year. The electricity generation potential and CO_2 savings were also calculated. It was possible to conclude that the anaerobic digestion of the wastewater from the brewery and distillery industries stand out as a feasible option to increase the share of renewable energies in Ireland.

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Introduction

It is known that globally fossil fuels are still widely used to generate most of the energy consumed worldwide. But, it is also known that they are a finite resource and release high amounts of CO_2 into the atmosphere over their life cycle when used as a fuel. A large range of renewable energy sources have been object of study recently, e.g. solar, wind and biomass energy. However, more alternatives need to be sought in order to be able to replace fossil fuels.

According to the last three years Irish Beer Market Reports available [1]–[3] beer is Ireland's favorite alcoholic beverage, followed by wine and spirits. Irish breweries produced 768 million liters of beer in 2016 and in the same period 77.7 million liters of Irish whiskey were sold. Alcoholic beverages production leads to the generation of effluents with high organic load, which need to be treated before disposal. Anaerobic digestion is a feasible alternative in order to treat these effluents while generating valuable bioenergy in means of biogas. Thus, it is possible to reduce CO_2 emissions due to the use of fossil fuels while treating an effluent and avoiding its improper disposal on water bodies.

This work aims to present an overview on the potential for generating bioenergy, in means of biogas, and reduce CO_2 emissions, through the anaerobic digestion of the Irish breweries and whiskey distilleries effluents

Methodology

The overall beer market in Ireland was assessed between 2006 and 2016, and the trends on beer consumption were assessed, in order to delimitate the importance of this work. To stablish some delimitations for this work, only the whiskey market was studied regarding the distilleries production. The volumes of beer produced and whiskey sold in 2016 were used for the biogas calculations. The wastewater from breweries and distilleries was characterized regarding its chemical oxygen demand (COD). A literature research on the different strategies for treating these effluents as well as the COD removal efficiency was conducted.

Based on the information found on literature, the COD generated per year was calculated and this value was multiplied by the UASB efficiency, to obtain the COD removed per year. Considering that one mole of methane requires two moles of oxygen to oxidize it to CO_2 and water as shown in the Equation 1, each kg of methane produced corresponds to the removal of 4 kg of COD, or 1 kg of COD is equivalent to 250 g of methane. Thus, knowing that the molar mass of methane is 16 g/mol, 250 g of CH_4 represent 15.62 moles.

$$CH_4 + 2O_2 -> CO_2 + 2H_2O \quad (1)$$

At the normal temperature and pressure conditions, 1 mol is equivalent to 22.4 l, therefore 15.62 moles represent 0.3 m^3. So, in this work it was considered that at normal temperature and pressure each kilogram of COD removed will yield 0.35 Nm^3 of gas. This value was multiplied by the COD removed per year and the methane yield was obtained. It was assumed that the biogas is a mixture of 65% methane and 35% CO_2 for the estimation of the biogas yield. According to [4] the calorific value of Methane is 38 MJ/Nm^3. Thus the calorific value of biogas, constituted of 65% of methane is 24.7 MJ/m^3 of biogas. This value was used for the estimation of the gross energy generated by the biogas production. Losses due the heating of the biodigestor or process losses were not considered.

To calculate the energy potential, two scenarios were assumed. In the scenario A it was considered the conversion of biogas using power to heat usage. According to the Sustainable Energy Authority of Ireland report [5] the main fuel used in heating is oil, which is responsible for 13.8% of the supply. Thus it was assumed the displacement of oil, in the generation of heating. An efficiency of conversion of 80% was assumed as proposed by [6]. According to [7] the life cycle emission of CO_2 for using oil as a fuel is between 530-900 $kgCO_{2eq}$/MWh. For this work an average of this value was used what corresponds to 715 $kgCO_{2eq}$/MWh. For the CO_2 savings calculation biogas was assumed to be a carbon-neutral resource, once the CO_2 released during its utilization is captured from atmosphere during biomass growth via so-called "closed carbon loop" [8], thus the savings were solely based on the CO_2 emissions to what was displaced.

Scenario B that was proposed assumed that the biogas was converted through combined heat and power (CHP) system, what would allow slightly higher efficiency. An efficiency of 33% for electricity conversion and 50% for heat conversion related to CHP systems using biogas is suggested by [9], and those were the values assumed for this work. SEAI report [5] shows that the highest share of the electricity supplied in Ireland is produced using natural gas. Thus this was considered as fuel displaced in the electricity generation on the CO_2 emission calculation. It is mentioned by [7] that its life cycle emissions go from 380 to 1000 $kgCO_{2eq}$/MWh , thus an average of 690 $kgCO_{2eq}$/MWh was used in this work.

Results

Market analysis

The analysis of the Irish beer market between 2006 and 2016 showed that after a trend of reduction in the beer production between 2006 and 2009 it has maintained a stable market with some fluctuations over the period (Table 1). Regarding the number of active breweries, a significant increase starting from 2013 is observed. It is due to the emergence of craft beers on the Irish beer scenario. It is possible to observe that the number of craft breweries has quadrupled over the period studied, thus showing the importance to pay attention to this arising market, its possible impact on the environment and its ability to contribute in the generation of renewable energy.

Regarding the spirits market, much less information is available. It was chosen to use the Irish whiskey in this work due to the volume produced in Ireland, it is understood that it is more significant than other spirits. The Irish Spirits Association report [10] mentions that the number of active distilleries increased from 4 in 2013 to 18 in 2017. The overall volume of sales of Irish whiskey increased by 54% between 2011 and 2016. A very substantial increase that also represents an increase in the volume of effluents released and thus in potential of generating biogas.

Table 1: Irish Beer market (2006-2016)

Year*	Total Production (1000 hl)	Total Consumption (1000 hl)	Consumption per capita (l)	Number of active breweries	Number of craft breweries**
2006	9,337	5,508	106.0	n.a.	n.a.
2007	9,270	5,451	105.5	n.a.	n.a.
2008	8,846	5,193	98.6	n.a.	n.a.
2009	8,042	4,832	91.0	n.a.	n.a.
2010	8,249	4,814	90	26	n.a.
2011	8,514	4,721	86	26	n.a.
2012	8,195	4,677	86	26	15
2013	8,008	4,328	79	30	23
2014	7,288	4,481	81	50	32
2015	7,755	4,414	79.9	64	48
2016	7,680	4,576	81	90	62

* Source from 2006 to 2009 data:[11]
Source from 2010 to 2016 data:[12]
** Source:[13]

For this work a volume of 768 million litres of beer and 77.7million litres of whiskey, relative to 2016 production/sales were used in the calculations of the bioenergy generation in means of biogas.

Effluent characterization and treatment

Aiming to obtain accurate information for the biogas yield estimation, the characteristics of brewery effluent from different authors were used to calculate an average COD that was used in the bioenergy estimative. In addition, it is important to know the amount of effluent that is generated per litre of beer produced, in order to determine the amount of wastewater generated per year. This information was also sourced from the available literature. A summary of the values from literature can be found on Table 2.

Table 2: Brewery wastewater generation and COD

Author	l of wastewater/l of beer	COD (mgCOD/l)
Fang et. al. (1990) [14]	5-9	2,692
Chen et. al. (2016) [15]	3-10	8,400 – 13,800
Shao et. al. (2008) [16]	n.a.	5000
Bakare et. al. (2017) [17]	n.a.	2,280 – 10,210
Brewers association (2012) [18]	2-8	1,800 – 5,500
Kanagachandran et. al. (2006) [19]	3-10	1,000 – 4,000
Braeken et. al. (2004) [20]	4-10	592 – 3,692
Oktem et. al. (2006) [21]	n.a.	870-5,065
Enitan et. al. (2014) [22]	n.a.	2,005

For this work an average generation of 6 litres of beer per litre of effluent and average value of 4,200 mg COD/l were used. Next, the techniques for treating this kind of effluent and their respective efficiency were assessed. Table 3 presents a summary of the literature studied.

Table 3: Type of reactor used for brewery wastewater treatment and efficiency

Author	Type of reactor	Volume of Reactor (l)	Operating Temperature (°C)	OLR (kgCOD/ m^3.day)	HRT (h)	Removal efficiency (% COD)	Biogas yield (Nm^3/kg COD_{rem})
Fang et. al. (1990) [14]	UASB	1170	26.1	4.9	13.3	89	0.45
Chen et. al. (2016) [15]	Anaerobic membrane bioreactor	15	35	3.5 - 11.5	44	98	0.53
Shao et. al. (2008) [16]	ASBR (anaerobic sequencing batch reactor)	45	32 - 34	1 - 5	24	90	0.48
Oktem et. al. (2006) [21]	UASB	30	35-37	7	84	95	n.a.
Enitan et. al. (2014) [22]	UASB	1.7×10^6	35 - 39	n.a.	8 - 12	79	n.a.

OLR: organic loading rate; HRT: hydraulic retention time; COD_{rem}: COD removed

As the most of the studies used UASB rectors with good COD removal, this type of reactor was chosen for this. An average efficiency of 87% was calculate from the authors studied, and used in this work.

Regarding the whiskey distillery wastewater, an average from the literature values showed in Table 4 of 40,000 mgCOD/l was used. It is possible to notice that the distillery activity generates much stronger wastewater when compared with breweries.

Table 4: Distillery wastewater COD

Author	COD (mgCOD/l)
Uzal et. al. (2003) [23]	37,060 - 50,700
Akunna and Clark et. al. (2000) [24]	16,600 -58,000
Tokuda et. al. (1999) [25]	48,200
Goodwin et. al. (2001) [26]	2,860 – 32,830
Barrena et. al. (2017) [27]	57,100

In relation to the volume of effluent generated per litre of whiskey produced, [28] mention an amount of 8 $e_{ffluent}/w_{hiskey}$ while [29] cite 20 $e_{ffluent}/w_{hiskey}$ and [30] between 10 and 15 $e_{ffluent}/w_{hiskey}$. Thus an average of 13 litres of wastewater per litre of whiskey was used in this work. For the treatment, Table 5 presents literature works using different types of reactor. Again, a UASB, this time with an efficiency of 88%, was chosen for the treatment.

Table 5: Type of reactor used for distillery wastewater treatment and efficiency

Author	Type of reactor	Volume of Reactor (l)	Operating Temperature (°C)	OLR (kgCOD/ m^3.day)	HRT (h)	Removal efficiency (% COD)
Uzal et. al. (2003) [23]	UASB	0.245	33 - 37	19.4	25.8	96
Akunna and Clark et. al. (2000) [24]	GRABR (granular bed anaerobic baffled reactor)	35	35 - 39	2.37	96	92
Tokuda et. al. (1999) [25]	AF (upflow anaerobic filter)	2,000	37	20	2 - 5	70
Goodwin et. al. (2001) [26]	UASB	1.05	35	5.46	50.4	80

Using the data afore mentioned and the methodology described in the previous section, the gross energy for both wastewaters and the total gross energy were calculated. Table 6 shows a summary of the calculations and the results.

Table 6: Calculation Gross Energy Generation

	Unit	Brewery	Distillery	Total
Production/Sales	l/year	768,000,000	77,697,000	845,697,000
Effluent generated	$l_{effluent}/l_{beverage}$	6	13	-
Effluent generated	$l_{effluent}$/year	4,608,000,000	1,010,061,000	5,618,061,000
COD effluent	$mg_{COD}/l_{effluent}$	4,200	40,000	-
COD effluent	$kg_{COD}/m^3_{effluent}$	4.20	40.00	-
kgCOD generated	kg_{COD}/year	19,353,600	40,402,440	59,756,040
Efficiency UASB considered	-	0.87	0.88	-
COD removed	$kgCOD_{rem}$/year	16,837,632	35554147.2	52,391,779
Methane yield	Nm^3 CH_4/year	5,893,171.2	12443951.52	18,337,123
Methane in the biogas	%	65	65	-
Biogas yield	Nm^3 biogas/year	9,066,417.231	19144540.8	28,210,958
Methane Calorific Value	MJ/m^3	38	38	-
Biogas Calorific Value	MJ/m^3	24.7	24.7	-
Gross Energy generated biogas	MWh/year	62,205.701	131,352.832	193,559

From the calculations is possible to notice that even though the volume of beer produced in Ireland is much higher than the volume of whiskey, the chemical oxygen demand released by the second is much more significant, leading to a gross energy generation from the whiskey effluent 111% greater than the energy generated from the brewery effluents.

Given the values for the gross energy generated, in the following section an analysis of two scenarios of the usage of this energy potential will be performed.

Assessment of proposed scenarios

It is known in this work that the biogas calorific value used was 24.7 MJ/m^3. However, there are energy losses when converting the biogas into heat, electricity or fuel for transportation. The losses are going to depend on the method of conversion that is used. A study was carried out by [6] aiming to address what is the most energy efficient route for biogas utilization. The authors looked at the use of biogas for heat, electricity and transport means, and found out that the conversion efficiencies vary from 8% to 54% for electricity generation, 16% to 83% for heat, 18% to 90% to combined power and heat generation. To narrow down the possibilities, and having a clear way of predicting the potential to generate energy in the Irish context, two scenarios are proposed in this work.

For the scenario A it was considered that the biogas would be converted solely into heat, using a boiler. Considering a conversion efficiency of 80% it would be possible to generate 154,846 MWh/year. As oil was chosen as the displaced fuel for heating source, for scenario A and using the averaged values from the oil CO_2 emissions (715 $kgCO_{2eq}$/MWh) it was possible to conclude that the use of biogas produced from the wastewater generated by the Irish breweries and distilleries would lead to the saving of 110,715 tonnes of CO_{2eq}.

In the scenario B the combined production of heat and power (CHP) was assessed. It was considered a conversion efficiency of 33% for electricity production and 50% for heat generation, leading to the generation of 63,874 MWh/year of electricity and 96,779 MWh/year of heat. Again the values for the oil emissions were used in the CO_2 saving calculation for the heat generation. For the electricity generation, the values from the average of CO_2 emissions for natural gas were used (690 $kgCO_{2eq}$/MWh). The total CO_2 savings in this scenario was 113,270 tonnes of CO_{2eq}.

In this context, it is possible to notice higher CO_2 savings in scenario B (2.3%), given that the efficiency is higher and two fossil fuels with similar CO_2 emission were used in the study. The SEAI report [5] emphasizes that in 2016 there was an increase in the Irish CO_2 emissions, mainly due to the increase in the gas share in fuel transports and the decrease in hydro and wind generation. Thus, the proposed energy generation from biogas could be an option to reduce this value.

Conclusions

The report issued by the Sustainable Energy Authority of Ireland [5] mentions that the Irish energy production reached the highest level ever recorded in 2016, however the share of renewable remains low, only 8%, a value 12% lower that the target set by the Europe Union for 2020. Given the data presented in this work it is possible to conclude that the anaerobic digestion of the wastewater from the brewery and distillery industries stand out as a feasible option to increase the share of renewable energies in Ireland, focusing on meeting the targets proposed at the National Renewable Energy Action Plan (NREAP). In addition, it would allow Ireland to reduce its carbon emissions, once biogas is considered a carbon-neutral resource

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