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Biogas production from *Sargassum ilicifolium*: Solution for the golden tides in Quintana Roo, Mexico

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ABSTRACT

With fossil fuels being the primary source of energy in today's world, different types of biofuels and bioenergy have been proposed to reduce our reliance on them. In recent years, Mexico has been suffering from the overaccumulation of the macroalgae species known as *Sargassum* on its Caribbean coastal shoreline. The purpose of this study is to investigate the usage of Sargassum as feedstock for an anaerobic digestion system. First, batch experiments were conducted to understand the methane yield of the *Sargassum*. The results showed that the *Sargassum ilicifolium* has a low methane yield. According to other studies, food waste can show up to 410 NmL/g-VS while *Sargassum* shows 177 NmL/g-VS. We chose thermal and ultrasound pretreatments for this research to increase the methane yield. Both thermal and ultrasound pretreatments showed a 10% and 43% increase in methane yields. Mexico has a vast production of agricultural products. Therefore, we tried co-digestion with corn. Results showed that methane yields of corn, *Sargassum,* and co-digestion are 268, 177, and 211 NmL/g-VS, respectively. These results may lead to a better understanding of the utilization of Sargassum as biomass in Mexico.

Keywords: Sargassum, golden tides, anaerobic digestion, pretreatment, co-digestion

INTRODUCTION

Fossil fuels are the main resources for energy production globally, currently, and following the COVID-19 breakout, a 5% increase in worldwide energy consumption in 2021 was observed (**Figure 1**), with 14,221 Mtoe consumed, and rebounding after a 4.5% dip during 2020. As a result, the 2021 consumption is higher than 2019—the year before the pandemic began (Enerdata, 2022). In 2021 the CO2 emissions, related to energy, reached 36.6 Gt CO2, which is the largest yearly increase reported by the International Energy Agency (IEA, 2022). With the continuous increase in the global population (United Nations Department of Economic and Social Affairs, Population Division, 2022), energy demand and greenhouse gas emissions grow with it.

Biomass is generally known as renewable organic matter that comes from plants and animals. The energy contained in biomass is denominated as biomass energy. During the past decade, the amount of seaweed causing inundations in different parts of the world has been increasing, causing the "seaweed tides" phenomenon and problems in different economic sectors like tourism and fishery (Smetacek & Zingone, 2013). Seaweed tides' names will depend on the color of the seaweed Macroalgae are eukaryotic organisms that can be divided into three taxonomical groups depending on their pigmentation: green, red, and brown algae. Macroalgae are suitable biomass for biofuel production, because of their advantage over terrestrial crops; even though their growth rate varies upon season, temperature, nutrients in the water, pH, and salinity, among other factors (Milledge & Harvey, 2016).

Golden tides are a phenomenon caused by the overpopulation of Sargassum, and pelagic seaweed; these, happen mostly in the Caribbean, South American, and African countries. Pelagic Sargassum, is mostly a combination of two species of brown macroalgae (*Sargassum natans* and *Sargassum fluitans*), these species are commonly found on the surface of the Sargasso Sea and drift with ocean currents (Franks et al., 2016). In the past years, an inundation occurred on the Mexican Caribbean coasts, with the seaweed Sargassum, every year in season washed ashore.

This research aims to increase the methane yield of brown macroalgae, specifically Sargassum. In the Mexican Caribbean and many other countries, the phenomenon known as golden tides is causing environmental and economic concerns. As a result of the need to find solutions to this problem, we've concluded that, because Sargassum has a lot of potential as a feedstock for methane fermentation, using it could be a great

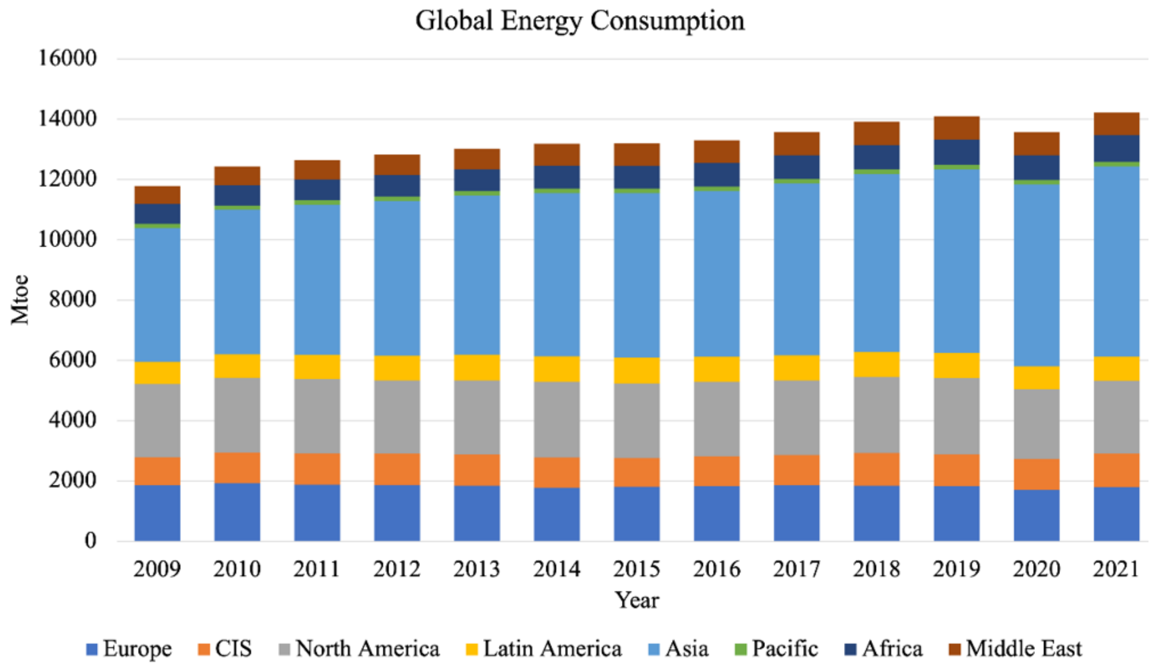

Figure 1. Global energy consumption (Chart data compiled from Enerdata Yearbook 2022 (Enerdata, 2022))

way to not only provide a solution, but also to bring a more sustainable and ecological approach to energy generation in Mexico, which is still dependent on fossil fuels as a main source of energy with almost 60% of its energy production coming from this sources (González-López & Ortiz-Guerrero, 2022).

Although it was difficult to get Pelagic Sargassum from Mexico for this study, Kochi University graciously provided the research team with *Sargassum ilicifolium*, a species of Sargassum found around the Japanese coast and some parts of South Korea.

In this research paper, knowing the challenges of using this biomass, we concentrate on the main issue: the methane yield, which is the plant's ability to generate biogas; to achieve this, pretreatment methods hold great promise for maximizing the plant's true potential. This study proposes two methods to improve the methane production of the plant, according to earlier research studies (Thompson et al., 2019), there are not many papers discussing the use of pretreatments in relation to optimizing the methane yield of brown macroalgae (Thompson et al., 2020). Starting with lab-scale experiments, thermal and ultrasound pretreatments were tested. From the methods studied, thermal pretreatment using a conventional oven showed an increase in the methane yield of the plant, and due to its worldwide utilization could be a more acceptable methodology for scalability. Finally, this study included a feasibility assessment on how to take benefit from natural resources (cropland) wastes in Mexico. Combining maize, one of the most widely planted and farmed products in the area, according to SAGARPA´s latest report in 2020 Mexico planted a total of 7,481,137 ha of maize (SAGARPA, 2020), and with Sargassum, provides an opportunity to assist the country's recycling and waste management culture. While continuing research has shown that lab-scale initiatives produce excellent outcomes, additional data is needed to assess their sustainability on a biorefinery scale.

Figure 2. *Sargassum ilicifolium* (Source: Authors' own elaboration)

MATERIALS AND METHODS

Substrate Collection and Inoculum

In July 2019, samples of *Sargassum ilicifolium* seaweeds, **Figure 2**, were harvested and provided by the Kochi University at Kochi Prefecture, Japan. The fresh biomass was received and cleansed for the removal of extra sand and pollutants, then stored for its later usage. The inoculum for biogas production was fermented sludge, that was starved for four weeks after

Table 1. *Sargassum ilicifolium* chemical characteristics

Sample	M	TS	VS	C:N	P	Fat	C	Ash (dry)
SI	77.5%	22.5%	13.9%	21:2	2%	0.6%	11.3%	8.6%

Note. *SI: Sargassum ilicifolium*; M: Moisture; C: Carbohydrates; & P: Protein

being conditioned using nori with a 10 L jar fermenter with sewage sludge collected from a sewage treatment plant in Hyogo, Japan; the jar was set to 35 °C. *Sargassum ilicifolium* chemical characteristics are shown in **Table 1**.

Anaerobic Digestion

The process that involves biomass conversion to produce biofuels is called biorefinery; these biomass feedstocks are the biodegradable portion and residues from biological materials (biomass). One way to take advantage of this marine biomass is by converting it into energy through anaerobic digestion (AD). The purpose of AD is the production of biogas, which is a mixture of gases mainly conformed by methane and carbon dioxide with small quantitates of hydrogen sulfide and ammonia. These results can be burned for the obtention of heat and power generation (electricity). Macroalgae have several advantages for biogas production, due to their high carbon-nitrogen ratio, which is 30% depending on the harvested season (Aparicio et al., 2020). It is known that the methane generation from brown macroalgae is low and that the use of a pretreatment method to enhance its methane yield is beneficial (Montingelli et al., 2015); therefore, in this study we will focus on applying two different pretreatment methods to the Sargassum, expecting to see an increase in the methane yield of the plant.

Pretreatment Methods

In this study, we focused specifically on two pretreatment methods, ultrasound and thermal pretreatments, which have not been studied towards macroalgae and specifically into Sargassum, but the experiments implemented have shown great results in the increase of methane yield in the micro-algae (Rodriguez et al., 2015).

Ultrasound pretreatment is acoustic energy in the form of waves, that are applied in frequencies above the human listening range. This high frequency of sonic waves causes a rapid pressure variation and generates cavitation inside cell walls, this effect is caused because of micro-bubbles. These micro-bubbles are formed by the interaction of liquid molecules in the caustic waves. Low-frequency ultrasound (in the order of kHz) and high amplitude induce cell rupture. This activity promotes chemical reactions that destroy organic matter due to high local temperatures and pressures, creating extreme shear stress in the liquid and leading to the formation of reactive radicals (H+ and OH-). The hydrolysis of the biomass is accelerated and subsequently Volatile Fatty Acids are more easily generated and transformed into methane (Rodriguez et al., 2015). Ultrasonication has been applied to brown algae for different research purposes; but no study has explored yet, the effect of this pretreatment method on brown macroalgae, far more *Pelagic Sargassum* methanation (Thompson et al., 2019).

Thermal pretreatment has temperatures ranging from 50-250 °C being applied directly to the biomass, via heat exchange, with the purpose of breaking the hydrogen bonds that maintain mechanical strength, promoting cell wall disintegration. This change to the substrate improves the enzymatic hydrolysis of organic matter and results in higher biogas yields. Thermal pretreatment can be subdivided into low temperatures (<110 °C) and high temperatures (>110 °C). High temperatures have been shown to optimize biomass solubilization and energy extraction. Even so, temperatures beyond 180 °C promote formation of inhibitory compounds such as furfural and phenols, which reduce the efficiency of the bioconversion (Thompson et al., 2019).

Experimental Procedure

Thermal pretreatment

For the thermal pretreatment experiments, a batch of 12 samples was put in 100 mL vial bottles, which were used to perform a methane fermentation experiment in which different levels of energy after the thermal pretreatment were applied, and by analyzing the generated biogas we could compare the effect of different pretreatment methods impacted the plant methane yield. The procedure for this pretreatment method was decided based on (Thompson et al., 2019), where they proved and presented a study with 121 °C applied to a species of brown algae, did potentialize the methane yield, that after washing the plant, it would be pretreated at 120 °C in an oven for 30 minutes.

Starting this batch of experiments, 60 mL of sludge was added to each of the vial bottles, three bottles were used as blank; continuing with the organic loading rate being 3.0 g-Vs/L of Sargassum was added to three of the bottles, this resulting in 1.71 g of Sargassum as substrate, three were fed with the Sargassum post Thermal pretreatment, for these ones it was considered that after being taken out of the oven the Sargassum has lost only moisture weight and the organic mass (volatile solids) remain the same; being this, the sample was introduced into the vial bottles. The experiment was set up at mesophilic conditions, and, after filling the bottles with the inoculum, they were filled with nitrogen and kept at a temperature of 37 °C, and constantly stirred at 130 rpm using a magnetic stirrer. From the 1st to the 7th day of the fermentation process, the measure of gas produced was measured, the analysis process for the experiments is shown in **Figure 3**.

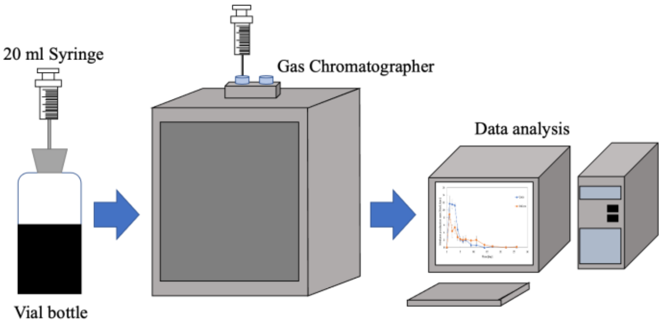

Figure 3. Schematic diagram experiment analysis process (Source: Authors' own elaboration)

The generated biogas was measured with a syringe. The biogas composition was analyzed using a TCD-gas chromatograph (SHIMADZU GC-2014).

Ultrasound pretreatment

The ultrasound pretreatment in this study was conducted by using a Branson Sonifier 750 model in three different energy ranges (40%, 50%, and 60%) from its total capacity and, at a constant frequency (20 kHz). The sample (Sargassum) was treated in distilled water (which was the conductor) and the heat produced by the system was not considered, therefore no cooling system is described. During this experiment, a batch of 12 samples was put in 100 mL vial bottles, which were used to perform a methane fermentation experiment, and by analyzing the generated biogas we could compare the effect of this pretreatment in the methane yield of the plant. The seed sludge used in the experiment has the same conditions as the previous experiment.

Starting this batch of experiments, 60 mL of sludge was added to each of the vial bottles, three were used as blank, and the rest were fed with the different Sargassum post-ultrasound pretreatment because the ultrasound has a tendency to destroy organic matter, we decided that after the ultrasound pretreatment was applied, the Volatile Solids of the plant should be measured again resulting in a new amount of substrate to be added to the vial bottles, 60%, 50%, and 40% were now 1.9 g, 2.1 g, and 2.2 g of wet-mass respectively. Filling and measuring are the same as in the previous subsection.

Corn co-digestion

In these experiments, a batch of nine samples was put in 100 mL vial bottles, which were used to perform a methane fermentation experiment in which the methane potential of the corn was measured and also the addition of corn; whereas with corn we refer only to the “ear of the corn,” which is the part inside or underneath the corn grain; to the Sargassum was performed to see the behavior of both biomass in an anaerobic digestion process, and by analyzing the generated biogas we could compare the effect of different pretreatment methods impacted the plant methane yield.

Starting this batch of experiments, 60 mL of sludge was added to each of the vial bottles, three of them were used as blank, another three were fed with corn, and the last three were fed with Sargassum and corn with a feeding ratio of 1:1 for the possible available amount of this biomass in Quintana Roo area. Filling and measuring are the same as in the first subsection.

RESULTS AND DISCUSSION

Thermal Pretreatment

Figure 4 and **Figure 5** show the generation rates of methane and carbon dioxide, respectively. The methane generation rate on the first nine days shows being more stable and with higher levels on the plant with no pretreatment, due to the strong changes in the methane generation on the pretreated mass, there was more generation coming from the Sargassum. Coincidentally, from day 10 we can start seeing a more controlled methane generation in the pretreated mass, that stabilization allowed the pretreated plant shows an increase in the methane yield of the plant.

Figure 6 shows the cumulative amount of methane and carbon dioxide generated at the end of the fermentation. This figure shows the gas generated from both, pretreated and non-pretreated biomasses. Methane generated in thermal (pretreated plant) and Sargassum (non-pretreated) is 35.09

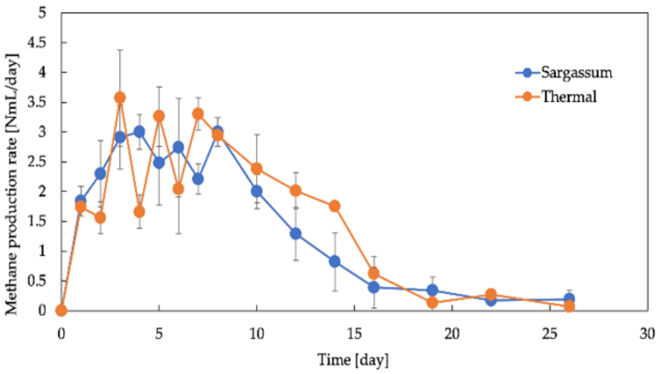

Figure 4. Thermal pretreatment CH_4 production rate (Source: Authors’ own elaboration)

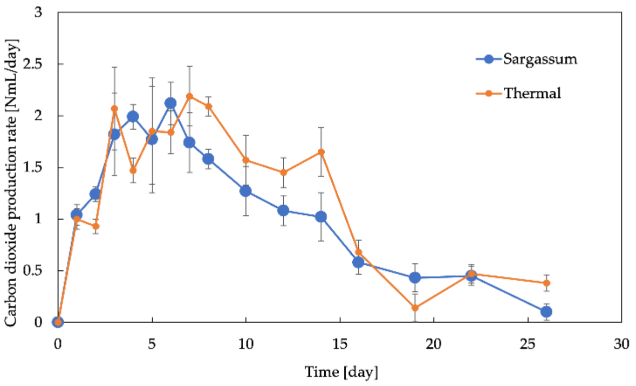

Figure 5. Thermal pretreatment CO_2 production rate (Source: Authors’ own elaboration)

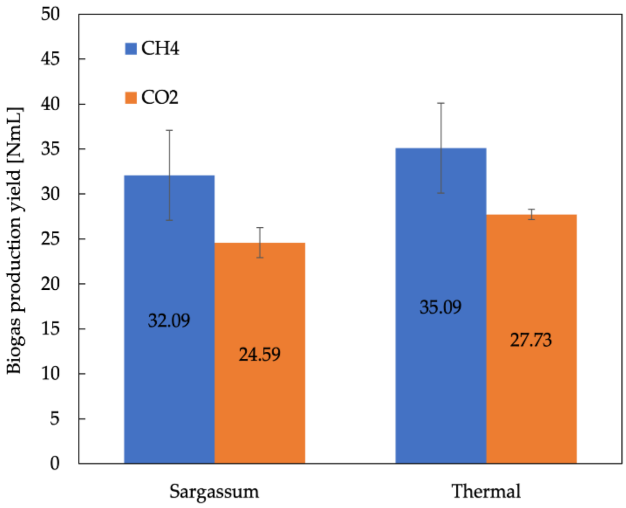

Figure 6. Thermal pretreatment biogas production rate (Source: Authors’ own elaboration)

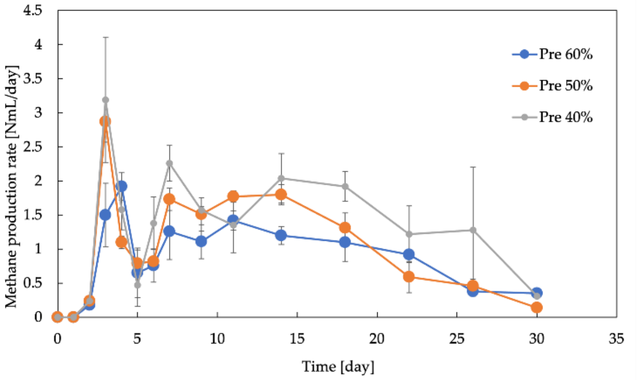

Figure 7. Ultrasound pretreatment CH_4 production rate (Source: Authors' own elaboration)

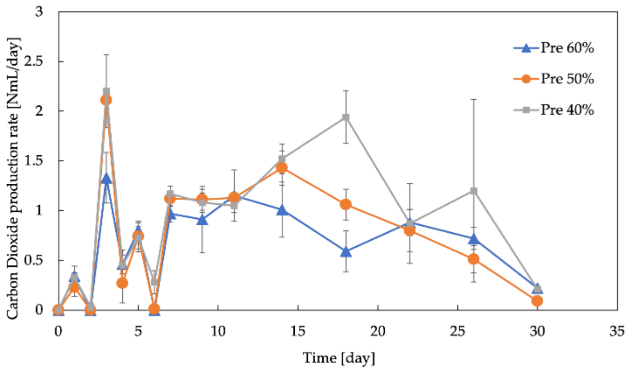

Figure 8. Ultrasound pretreatment CO_2 production rate (Source: Authors' own elaboration)

NmL and 32.09 NmL, respectively. Carbon dioxide-generated gas was 24. 59 NmL on thermal (pretreated plant) and Sargassum at 27.73 NmL, having almost a 10% increase in Biogas generation, and it can be noticed that the amount of CH_4 and CO_2 generated had almost the same increase.

Ultrasound Pretreatment

Figure 7 and **Figure 8** show CH_4 and CO_2 generation rates, respectively. The methane generation rate on the first 9 days showed being more stable and with higher levels on the plant with no pretreatment, due to the strong changes in the methane generation on the pretreated mass, there was more generation coming from the Sargassum during this period of time. Coincidentally, from day 10 it starts noticing a more controlled methane generation in the pretreated mass, that stabilization allowed the pretreated plant shows an increase in the methane yield, and the batch treated with less energy (40%) showed a better gas production than the others, making us think that the plant may react better to low energy exposures, as a result, more in-depth research needs to be done to understand better the intensity energy effect to the plant.

Figure 9 shows the cumulative amount of CH_4, and CO_2 generated at the end of the fermentation.

Corn Co-Digestion

Figure 10 and **Figure 11** show CH_4 and CO_2 generation rates, respectively. From past experiments, we can notice that the CH_4 generation from corn is extremely fast and high. The first five days of both experiments showed a fast biogas conversion from the only corn batch and its gas production was stable, but it rapidly decreased and reached its highest production before day 10 of fermentation. One interesting reaction from combining Sargassum and Corn is that from the first 10 days most of the gas tends to be approximately half the production from the corn, as mentioned above the ratio was 1:1 being this 50% of the corn's actual Organic Loading Rate (ORL) was input in the bottles, and opposite from the corn from day nine we can see an increase in daily methane

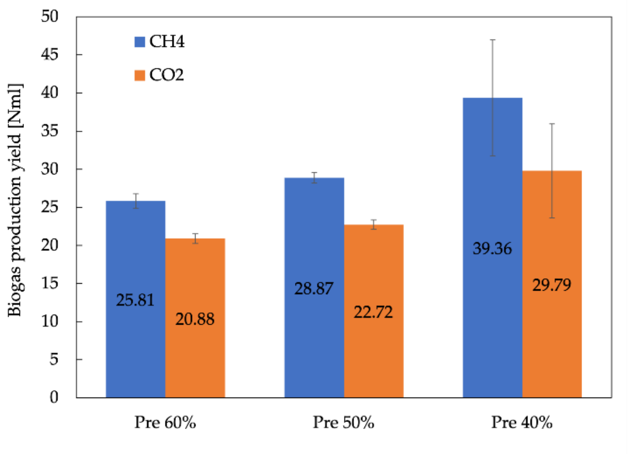

Figure 9. Ultrasound pretreatment biogas production rate (Source: Authors' own elaboration)

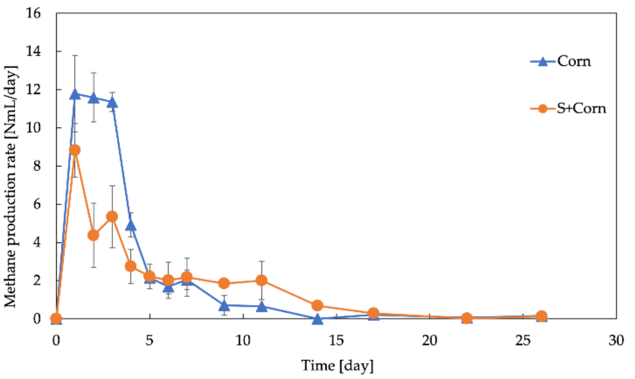

Figure 10. Corn co-digestion CH_4 production rate (Source: Authors' own elaboration)

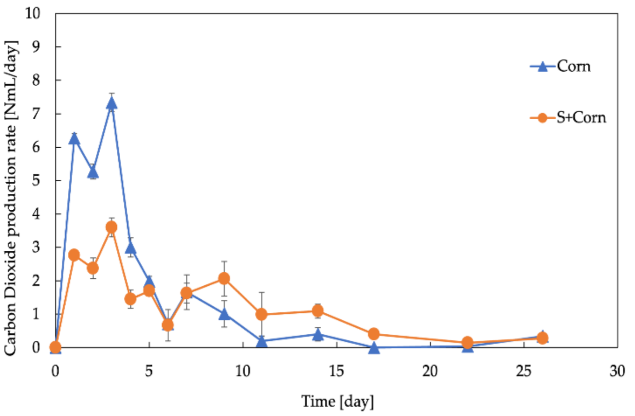

Figure 11. Corn co-digestion CO_2 production rate (Source: Authors' own elaboration)

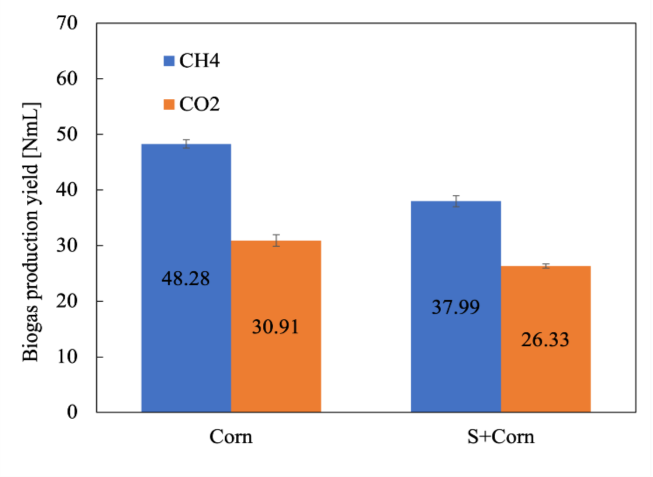

Figure 12. Corn co-digestion biogas production rate (Source: Authors' own elaboration)

production, supposed to be from the Sargassum methane fermentation process. This production presented in **Figure 9**, can give us an idea, that when in an AD reactor both biomasses can have different digestion timing and bring the opportunity to take advantage of the feeding windows for the reactor.

Figure 12 shows the cumulative amount of methane and carbon dioxide generated at the end of the fermentation; clearly showing that the "ear of the corn" has a great methane potential, there was no pretreatment performed for this biomass.

BIOGAS SYSTEM IN CANCUN QUINTANA ROO

Biogas Production Potential in Mexico

Mexico has around 8% of the biomass used in bioenergy projects coming from the cane of sugar and wood; also, the utilization of renewable energies in Mexico is extremely low, even though Mexico's biomass energy potential is around 3,000 PJ/year and 4,000 PJ/year. This value expresses around 54% and 81% of the actual basic energy, which comes to around 5,647 PJ. However, Mexico's actual bioenergy usage comes to around 400 PJ, which is only 8% of the total, having this data given, we can say that is extremely below its technical potential (Mercado, 2012).

Agriculture in Mexico is more than an important productive sector. Beyond its participation in the national GDP, which is roughly 4%, the multiple functions of agriculture in economic, social, and environmental development determine that its incidence in development is much greater than that indicator would imply. One of the long-term national goals is environmental sustainability and the conservation of natural resources. In a world where the new challenges derived from climate change are added to the secular problems of depletion, pollution, and deterioration of natural resources, Mexico needs to put more effort into the preservation of aquifers, soils, biodiversity, forests, the density of marine life and interior waters, and the other elements of environmental sustainability; it needs to be stated as a national priority have better guidelines and modalities of agricultural development.

In the agricultural sector, the annual amount of agricultural waste is around 45 million tons of dry matter from the ten main crops (corn, sorghum, wheat, beans, rice, barley, soybeans, cotton, safflower, and sesame); corn stubble and cob (25,500,000 tons), sorghum straws (6,600,000 tons) and wheat (4,500,000 tons) represent little more than 81% of the crop residues. These materials are very important to feed livestock in times when traditional foods are limited. Corn cultivation stands out for occupying the largest area of crops in Mexico; stubble is obtained from it, the yield of which ranges between three and five tons per hectare (SAGARPA, 2015).

A study made in Italy shows that biogas production is mainly based on the anaerobic digestion of cereal silages, and among these the corn silage is the most utilized. They specifically mention that "maize hybrids are the most used crops for energy production; they can be grown as a single crop system (monoculture) or, after the harvesting crops as a double crop system". Regarding biogas production, the most important part of the plant is the ear of the corn. The corn ear represents a very good feedstock for biogas production because of its high starch content, it is characterized by a higher biogas production compared to the silage of the whole plant. From a study in Italy (Negri et al., 2014) we could know, that the whole plant provides a higher methane yield, but this is including the corn, which is usually used for consumption, and the ear of the corn, that can be considered a waste, shows great results in the methane yield with roughly 7,800 m^3/ha of methane production. Having this data and knowing that in the study they produced around 22.48 t/ha of the ear only, we can say that its methane production comes to be around 346 m^3/t from only the ear of the corn.

When it comes to the Sargassum, we know that the most severe consequences come when it reaches the coasts of Quintana, Roo. The inadequate disposal of the *Sargassum* threatens marine life, but not only that, but it is also the only source of local freshwater, filling it with nutrients, salt, metals, and other contaminants; **Figure 13** shows how big the impact of the seashore Sargassum.

The maximum amount of *Sargassum* recorded in the past years was in September 2018, with 22,900 ha, In the peak months of 2018 (usually March to August), 4.5×10^3 m^3/km was removed on average per month, and quantities varied among beach section from 0.7×10^3 to 31.5×10^3 m^3/km, these amounts were collected per month during those peak months. Annual averages were 3.2×10^3 and 1.7×10^3 m^3/km monthly (Chávez et al., 2020). Sargassum influx is not constant but its abundance and threat to society with a non-sustainable approach is undeniable. The focus of our research will be done in a city named Puerto Morelos, in Quintana Roo. This is one of the most important touristic places; also, is nearby the most important touristic places in the state. Which will allow us to transport the collected sargassum without having to interrupt the local touristic activities.

Case Study in Quintana Roo

This study is based on four case scenarios, **Figure 14** shows the schematic representation for the anaerobic digestion system proposed for all four scenarios. The planned anaerobic

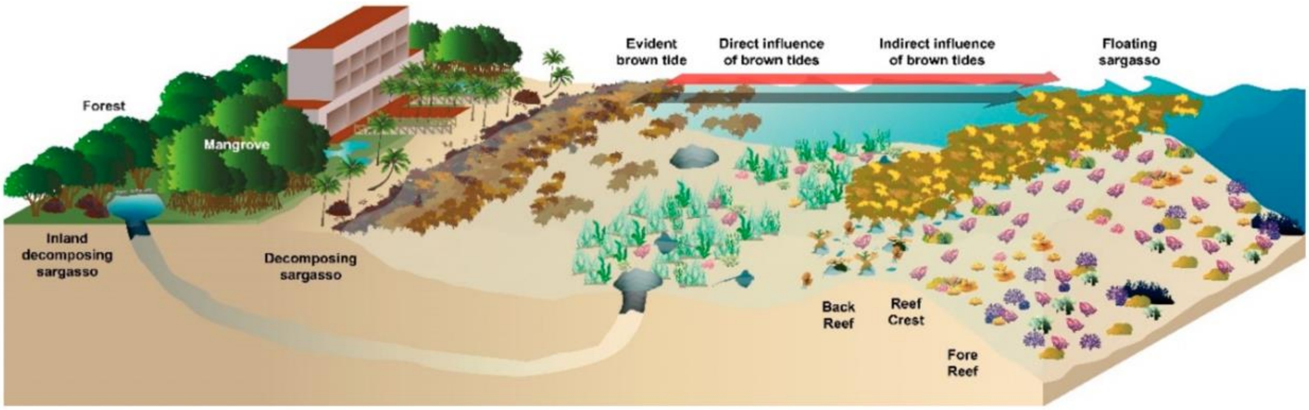

Figure 13. Representation of the Mexican Caribbean coast and the impacts of Sargassum on the coast (Chávez et al., 2020)

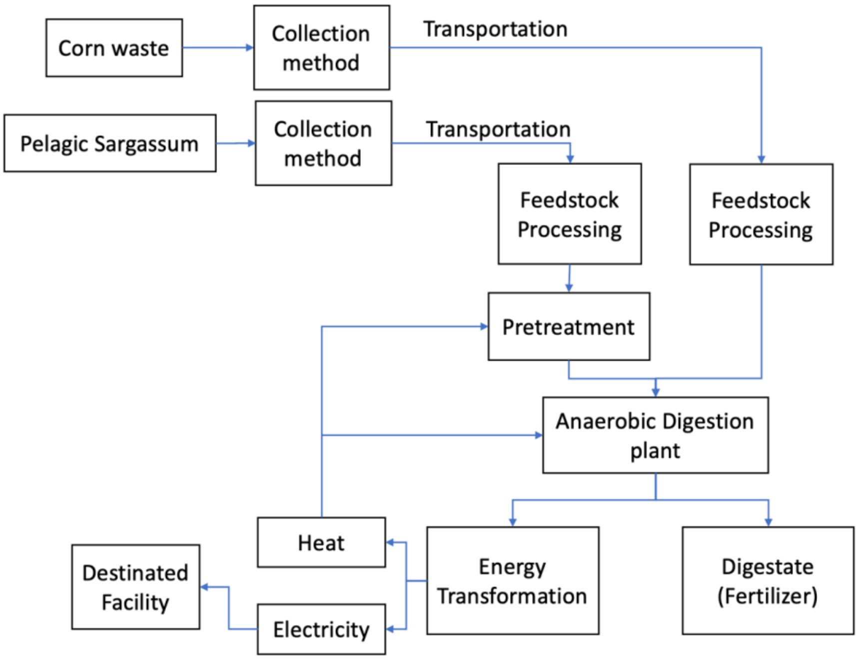

Figure 14. Schematic representation of anaerobic digestion system (Source: Authors' own elaboration)

digestion system includes corn waste and sargassum as feedstock. Biogas will be generated from the Anaerobic digestion process. This will be transformed into energy in the form of gas and electricity. The generated gas will be recycled in the form of heat to support the feedstock's pretreatment. The electricity will be supplied to the commercial facilities located in the Puerto Morelos area. The digestive sludge produced as a by-product of the digestion process could be possibly used as a fertilizer (Kuroda et al., 2014).

Four cases were investigated. Costs incurred throughout the operation, OC, are made up of the following costs: CS for collecting seaweed, CF for collecting maize waste, and CP for operating the plant:

$$OC = CS + CF + CP, \tag{1}$$

where CS is the cost of labor for harvesting seaweed. Labor costs are calculated using the number of employees over the course of a year, the labor cost per hour, and the number of working hours each day. CF consists of the cost of the fuel (light oil) and the labor necessary to collect the waste from maize. Depreciation, interest, labor expenditures for maintaining the plant, and upkeep make up CP.

Table 2. Costs assumptions for case studies 1 to 4

Labor cost of seaweed removal	
Number of employees per year	3,200
Labor cost per person per hour	5 USD/h
Working hours per day	8 h/D
Fuel cost of transportation on land	
Diesel cost	1 USD/L
Number of employees per year	5
Labor cost per person	7,000 USD/y
Operation and maintenance cost	
Maintenance	5% of the construction fee
Number of employees per year	5
Labor cost	11,000/y
Depreciation	60% of the construction fee
Interest	3%

The cost presumptions are given in **Table 2** and **Table 3** (Kuroda et al., 2014). Cases 1 through 4; these show an

Table 3. Calculation results for case studies 1 to 4

	Case 1	Case 2	Case 3	Case 4
Sargassum (t/y)	4,500	4500	4,,500	4,500
Corn waste (t/y)	2,500	2,500	2,500	2,500
Heat surplus (MJ)	14,534.09	16,061.52	16,061.52	16,061.52
Electricity surplus (MJ)	3,767.12	4,461.4	4,461.4	4,461.4
CO_2 Emission (t)	4,004	4,004	4,004	4,004
CO_2 Reduction (t)	59,338	59,338	68,560	68,560
20-year cost (10^6 JPY)	2,139.33	3,469.33	3,469.33	2,349.33
20-year revenue (10^6 JPY)	2,051.05	2,051.05	1,737.28	2,524.27

anaerobic digestion plant that works with sargassum and corn biomass as feedstock, is necessary to be mentioned that the only factor that changes within cases 1 and 2 is the cost of the corn waste for the case 2; case 3 shows an approach where the heat surplus is not sold and recycle into the system to support a thermal pretreatment, and case 4 shows the results in where the pretreatment process also occurs, but the project has support from the Government allowing the plant to sell the generated electricity at a higher price. The construction cost in case 1 through case 4 is 680 (10^6 JPY).

The construction cost per mass of daily waste decreases with increasing weights of daily waste, but because in both scenarios the same amount of daily weight is obtained, both cases keep the same cost (refer to **Table 2**), **Table 2** summarizes the costs assumptions for the seaweed cultivation, cost of transportation and operation and maintenance, for both cases 1 and 2.

DISCUSSION

For case 1 there is a scenario where corn waste, thrown away by the farmers, could be disposed of for free. It is known that in Mexico nearby 85% of the total amount of corn waste is used for animal feeding and the resting 15% is treated like waste or for soil recovery processes (Reyes-Muro et al., 2013), in the Quintana Roo State there was around 47,303 tons of corn waste disposed of in (2008-2011), as the last published report of the country, coming this to around 15,000 tons of available waste each year; and supposing that there is only 15% available for this research purposes, it would be possible to work with around 2,500 tons of corn waste each year.

Table 3 shows case 1 and the factors dictating its feasibility study results; this case is environmentally sustainable, but the revenue expected is lower than the cost, making it not economically feasible. For case 2 there is a payment for the amount of waste that is going to be disposed of, anyhow, this scenario is still using the 15% that is not used for cattle feeding purposes. The revenue comes primarily from the incineration of waste and the supply of electricity. Case 2 factors dictate its non-economically feasibility. In case 3, there is a need to pay for the corn to be disposed and then all the surplus from heat will be recycled into the system to support the pretreatment; unfortunately, this case is also non-economically feasible due to the loss in the income coming from the surplus of heat, and then, the methane generated from the Sargassum not adding enough to the final revenue. Finally, case 4 supposes that there is no need to pay for the disposed of corn, and then, the project has support from the Government, and its probability to increase the price of the electricity, allowing the plant to compete with the fossil fuels energies in the Country, going from 3 JPY/kWh to 10 JPY/kWh; even though this is the most ideal scenario, it shows the Feasibility of the project in Quintana Roo, Mexico. The result shows that only case 4, of all scenarios, is economically feasible. This is because, for the other three cases, the projection cost for 20 years of operation time of the plant, exceeds the revenue. Anyhow, it's necessary to keep in mind that all the proposed scenarios have shown that the plant is environmentally feasible, this is an important factor in this study due to the low reliance on clean energies from Mexico and promoting the use of this bioenergy being one of the objectives of this project. Finally, it is necessary to improve methane production by considering new feedstock biomass and other processes like pretreatments that can improve amount of methane produced (Kuroda et al., 2014).

CONCLUSIONS

This study is focused on the methane fermentation process from the *Sargassum ilicifolium* and its response to two pretreatment methods. In the thermal pretreatment method, it was found that an exposure of 30 min with a temperature of 120 °C, promotes the cumulative amount of biogas generated. For the ultrasound pretreatment, it was found that for the *Sargassum,* lower ultrasonic power exposures have a better reaction in the plant, increasing its methane yield by almost 23%; it is to be noticed that the start of methane and carbon dioxide was retarded, and its production was lower than the non-treated plant until after day 15 of the process. For the feasibility study, it was proved that the corn waste (ear of the corn) is suitable for the process of co-digestion with the *Sargassum*; in the fermentation process, corn waste shows a faster methane production than the *Sargassum*. The proposed case scenarios show that an anaerobic digestion plant in Quintana Roo is only feasible in the conditions presented for case 4, for the other scenarios these conditions caused the expenses to surpass the revenue in a frame time of 20 years. Finally, *Sargassum* still needs to be tested in continuous systems to understand its behavior during the process, and still, different case scenarios should be reviewed before it is determined whether an AD plant is feasible or not feasible in Quintana Roo, Mexico.

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Ethical statement: Authors stated that ethics committee approval is not required since information that was used in the study is freely available in the public domain, for example, published biographies, newspaper accounts of an individual's activities and published minutes of a meeting, whilst still personal data under the Data Protection Act would not require ethics review.

Data sharing statement: Data supporting the findings and conclusions are available upon request from corresponding author.

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