IOP Conf. Series: Materials Science and Engineering **1318** (2024) 012016 doi:10.1088/1757-899X/1318/1/012016

Greenhouse Gas Mitigation Potential of the Enhanced Rice Straw Biogas System in the Philippines

C C Gomez[1,4], R B Demafelis[1,5], B T Magadia[1], A E D Matanguihan[1], E P V Estante[1], C J E Nuñez[1], J V Sumague[1], K Chong[2], M Roeder[2] and C Jamieson[3]

[1] Department of Chemical Engineering, College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños, College, Laguna, 4031 Philippines

[2] Energy and Bioproducts Research Institute, Aston University, Aston Triangle, Birmingham B4 7ET, United Kingdom

[3] Straw Innovations, Lawes Open Innovation Hub, Rothamsted Research, West Common, AL5 2JQ, United Kingdom; with operations in Laguna, Philippines

E-mail: [4]ccgomez2@up.edu.ph; [5]rbdemafelis@up.edu.ph

Abstract. Rice straw is an agricultural waste produced abundantly every rice cropping cycle. Its disposal or removal from the field is a problem to rice farmers every start of the next cropping cycle due to its labor-intensive collection from the field. One traditional practice is soil incorporation; however, rice straw does not degrade easily, and this management practice releases significant amount of greenhouse gas emissions to the environment. An attempt to solve this issue is to utilize rice straw with cattle manure as feedstock for biogas production and use the energy generated for rice post-harvest processing such as grain drying and milling. An Enhanced Rice Straw Biogas facility was constructed in Victoria, Laguna, Philippines and a trial lagoon run was conducted from June to October 2021. The data from the initial run was used as input to the modified Aston-developed Mass Energy Balance Model to determine the biogas production potential of rice straw and cattle manure as bioenergy feedstocks. The proposed system can produce 8,803,567.99 L (296.19 L/kg VS) of biogas which can be converted to 19,502.97 MW electricity and 84,512.86 MJ heat. From the energy generated per batch, 18,417.21 kg rice grain (dry season) or 15,752.79 kg rice grain (wet season) can be dried and milled, with an excess of equivalent kerosene (696.93 L for dry season or 248.46 L for wet season) and electricity (3,745.12 kWh for dry season or 6,182.23 kWh for wet season). Due to biogas utilization, an estimated 3,351 L of fossil-based kerosene and 12,185.91 kWh of electricity equivalent can be avoided. This low GHG emission rice production system (Aston Model) has a theoretical annual carbon footprint of 153,134 kg CO_2e and a 28.21% reduction of greenhouse gas emissions compared to the conventional rice production system.

Keywords: Biogas, Greenhouse gases, Carbon footprint, Life cycle assessment, Rice straw, Cattle manure

1. Introduction

The climatic changes in the environment are intensifying through time as the global greenhouse gas (GHG) emissions continuously reach record high levels. Extreme weather conditions such as super

IOP Conf. Series: Materials Science and Engineering **1318** (2024) 012016 doi:10.1088/1757-899X/1318/1/012016

typhoons, massive wildfires, and strong tornadoes encountered are expected to occur at a more frequent and more destructive magnitudes. Glacial retreats and shrinking ice sheets caused by increase in global temperatures result to sea level rise while high carbon dioxide amounts in the atmosphere leads to ocean acidification. These events threaten both flora and fauna into a possible extinction. Impacts of these events greatly cost numerous lives, scarcity in food, water insecurity, as well as disruption on worldwide peace and security due to increased competition on resources. According to scientists, future environmental disasters may still be prevented if the global GHG emissions, in which more than half comes from anthropogenic sources (55.46% of total global GHG emission in year 2016 [1]), will be reduced at an acceptable level.

World Resources Institute Climate Analysis Indicators Tool reported that Philippines emitted 157.6 metric tons of carbon dioxide equivalent ($MtCO_2e$) in the year 2012 [2]. This accounts to 0.33% of the world's total GHG emissions (World emission 47,599 $MtCO_2e$ [2]). From the emissions from the Philippines, 54% originates from energy sector while 33% comes from agriculture sector [2]. These emissions were high due to the dependency on burning fossil fuels, and use of synthetic fertilizers, substrates, and processes with high carbon footprint. In addition, the anthropogenic GHG emissions are projected to increase to provide for the demand of growing population.

Focusing on the Philippine agriculture sector, the main GHG emitter is the rice cultivation. This accounts to 60% of the total emission from agriculture or around 20% of the total GHG emissions of the whole country based on the 2012 statistics [2]. In 2020, Philippines ranked 8th largest rice-producing country in the world with an annual production of 19.44 million metric tons [3]. The country is expected to increase its rice production with the Department of Agriculture targeting a higher yield to cope with the high demand in rice. Unfortunately, high rice production entails not only large amount of rice grain but also massive quantities of by-products such as rice straw, rice husk and rice bran. The ratio of rice straw to rice grain is from 0.7 to 1.4, depending on the variety and cultivation conditions [4]. Hence, an estimated 13.61 to 27.22 million tons of rice straw was produced from the rice production in 2020. Unlike rice husk and rice bran, there is no current economic value for rice straw. The most common practice of farmers to dispose this waste is by incorporating it on soil which releases around 3,500-4,500 kg CO_2e/ha [5]. Adding this to the other emissions during rice cultivation, harvest and post processing worsens the GHG emission from this agricultural sector.

As an initiative to solve this growing concern on GHG emission and rice straw management, Straw Innovations Ltd. constructed an enhanced biogas system utilizing rice straw and cow manure to produce methane and convert it to energy. This industrial research project (March 2020-March 2022) funded by Innovate UK entitled "Enhanced Rice Straw Biogas" was in collaboration with Aston University for the social analyses and with University of the Philippines Los Baños for the environmental analyses. The aim of this paper is to extend the results of the trial lagoon digester run and determine the GHG mitigation potential of the system.

2. Methodology

The methodological framework for the determination of GHG emission mitigation potential of the enhanced rice straw biogas system is shown in Figure 1. Data gathered includes farm data collected from key informant interviews (KIIs) and surveys with rice farmers, biogas production data from the trial research run conducted by Straw Innovations in 2021, and other necessary values obtained from literature.

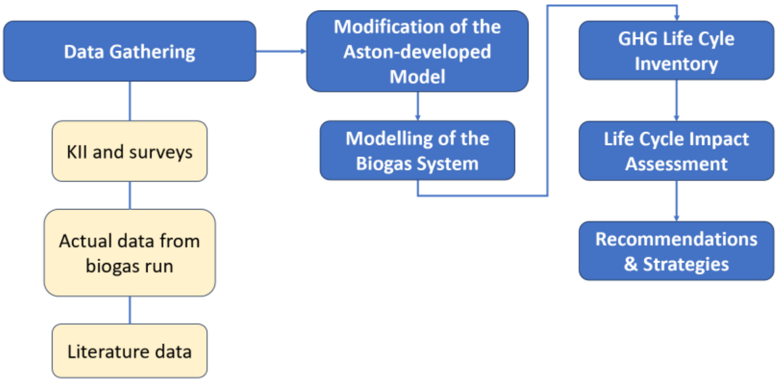

Figure 1. Methodological framework.

2.1. *Bioenergy Mass-Energy Balance Model developed in Aston University*

A scoping tool designed by a team in Energy and Bioproducts Research Institute (EBRI), Aston University, UK to evaluate the viability of various biomass as feedstocks to the commercially available bioenergy technologies was used in this study This tool allows modelling of typical plant configurations to fit selected feedstock and target energy output range of 10 kW_e to 5 MW_e [6]. This is a part of a project entitled "*Bioenergy for Sustainable Local Energy Services and Energy Access in Africa Phase 2 (BSE-AA2)*", funded by the UK foreign, Commonwealth and Development Office (FCDO) under the Transforming Energy Access (TEA) program.

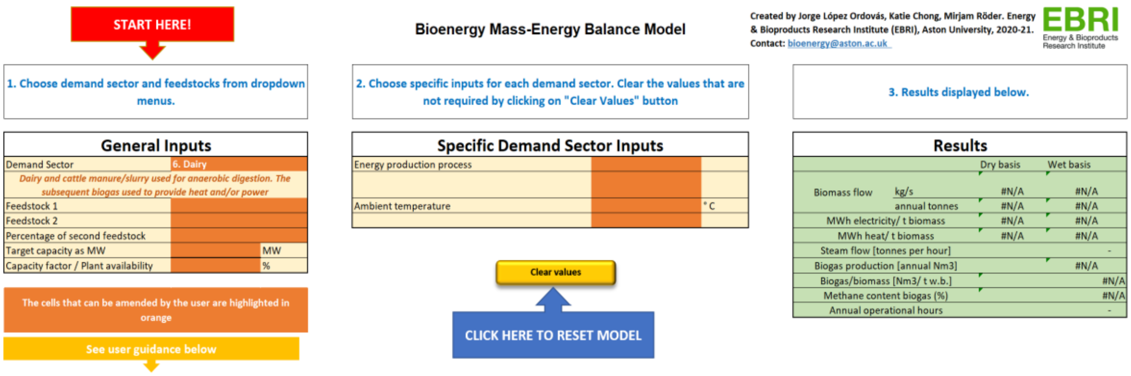

Figure 2. Bioenergy Mass-Energy Balance Model developed in Aston University, UK.

This bioenergy model uses the 1977 modification of Boyle [7] on the Buswell and Mueller equation [8] (shown in Equation 1) to back-calculate the amount of biomass needed to produce a target methane output. Since Equation 1 stoichiometrically provides the chemical conversion of biomass to biogas based on the feedstock elemental composition, the amounts of products can be determined.

$$C_cH_hO_oN_nS_s + \frac{1}{4}(4c - h - 2o + 3n + 2s)H_2O \rightarrow \frac{1}{8}(4c - h + 2o + 3n + 2s)CO_2 + \frac{1}{8}(4c + h - 2o - 3n - 2s)CH_4 + 2NH_3 + sH_2S \quad (1)$$

The Buswell equation is widely used in the calculation of theoretical maximum methane potential, however, the calculated amount cannot be achieved since a complete breakdown of feedstock cannot be achieved [9]. With this, the reaction efficiency was adjusted to 40% [10] to simulate the conversion of rice straw and cattle manure into biogas. This is based on the degree of degradation in seven farm-scale biogas plants utilizing cattle manure with organic substates [10]. Feedstock properties such as

IOP Conf. Series: Materials Science and Engineering **1318** (2024) 012016 doi:10.1088/1757-899X/1318/1/012016

elemental composition of cattle manure and rice straw, shown in Table 1, were based on the studies of Font-Palma [11] and Sumagang *et al* [12], respectively. Adjustments on feedstock type and properties, conversion conditions, and processing units were made on the model to simulate the constructed rice straw biogas facility in Victoria, Laguna, Philippines.

Table 1. Feedstock properties of rice straw and cattle manure.

	Moisture content (wt%)	Ash content (wt%)	Volatile matter (wt%)	Fixed carbon (wt%)	Carbon (wt%)	Hydrogen (wt%)	Nitrogen (wt%)	Oxygen (wt%)	Sulfur (wt%)
Cattle manure[11]	70.70	37.20	52.00	10.80	31.01	4.06	2.09	24.98	0.66
Rice straw[12]	5.73	21.00	61.40	17.60	35.50	4.62	0.99	37.83	0.06

2.2. GHG Life Cycle Inventory and Life Cycle Assessment

Life Cycle Assessments were simulated using SIMAPRO 9.4.0.2 version. The functional unit used in the study is 1 kg milled rice grain while the impact method used is the Intergovernmental Panel on Climate Change 2021 Global Warming Potential climate factors for 100 years timeframe that includes CO_2 uptake and biogenic CO_2 emissions (IPCC 2021 GWP100-incl. CO_2 uptake). The values obtained from the data gathering conducted and from the modified Bioenergy Mass-Energy Balance Model were used in the life cycle assessment of the low GHG emission rice production system. The conventional rice production system was also evaluated for comparison. System boundaries of the two rice production systems are shown in Figures 2 and 3.

2.2.1. Conventional Rice Production System. The conventional rice production system in Victoria, Laguna was considered in the study. This system includes rice production from land preparation until milling of rice grain. Hand tractors and hydrotiller powered by diesel were used for the plowing and harrowing of rice fields while levelling was done using a wooden plank pulled by a carabao. Seeds were initially grown in wet beds before transplanting to the field 14 days after germination. Fertilizers were manually scattered by farmers on the field at a specific growth stage of rice plant. For the pesticides and herbicides, farmers spray it on the field if need arises. Water supplied to rice paddies may either be from the National Irrigation Administration (NIA) sourced from river or from deep well. Harvesting was done using combine harvester. Rice grains were collected in sacks and were transported to drying and milling facilities for post-harvest processing while rice straws that were left on the field will be incorporated on soil upon land preparation for the next cropping cycle Amounts of seeds, fertilizer, pesticides, insecticides, and fuel used for irrigation pump and machineries for land preparation and harvesting were accounted from the KII and surveys with seven rice farmers in the area.

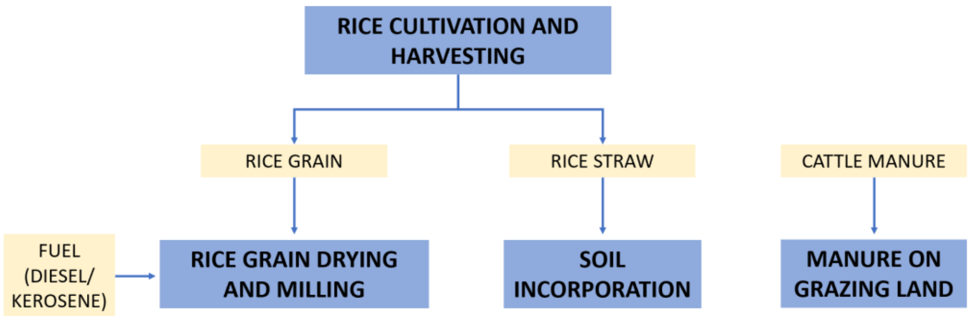

Figure 3. Conventional Rice Production System Boundary.

Calculations for the GHG emissions of rice cultivation is similar with the study of Estante *et al* [13] which was adapted from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse

Gas Inventories was used in the calculations of rice field GHG emissions for methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2). Energy usage (fuel and electricity) for the drying and milling of rice were obtained from KII with drying and milling facility owners while other values were based on literature.

To balance the inputs of conventional system with the low GHG emission system, the equivalent amount of manure used for biogas production were accounted in the conventional system as cattle manure applied on grazing land. GHG emissions of cattle manure was estimated based on the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

2.2.2. Low GHG Emission Rice Production System. Rice cultivation from land preparation until harvesting for the low GHG emission system is similar with the conventional system. Rice straws were collected and co-digested with cattle manure for biogas production. Batch anaerobic digestion trial run by Straw Innovations was conducted in a lagoon digester for 120 days. Fuel usage such as diesel used during the collection of rice straw from nearby rice fields and collection of cattle manure from nearby dairy farm were accounted. Biogas produced was used to generate heat and electricity via Combined Heat and Power (CHP) engine operating at 15% electricity efficiency and 65% heat efficiency conversion. The heat and electricity produced from the biogas substituted the fossil fuel-based energy used to operate rice grain dryer and mill. Wet palay were dried at 13% moisture content at 70% dryer efficiency and while dried rice grains were milled at 70% milling efficiency. Basis for the calculations for drying and milling of rice grain is shown in Table 2. Digestates produced were utilized as soil conditioner and fertilizer.

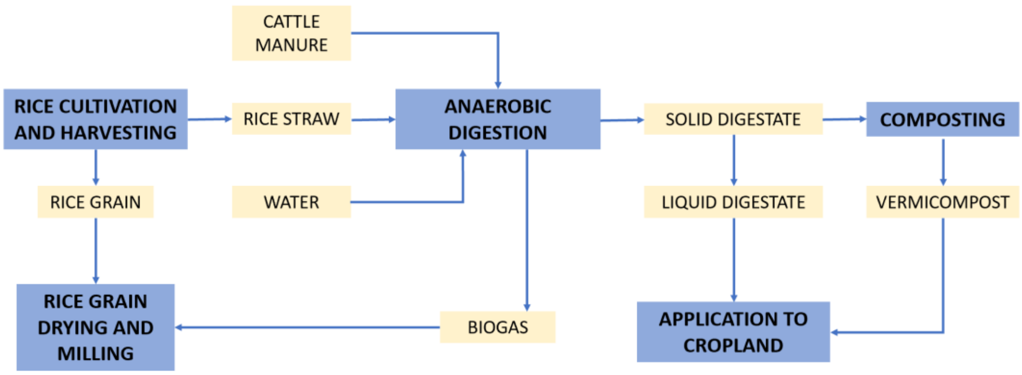

Figure 4. Low GHG Emission Rice Production System Boundary.

Table 2. Rice grain moisture content and energy requirements of recirculating vertical bin dryer and grain milling unit.

	Recirculating vertical bin grain dryer		Rice grain milling unit	
	Dry season	Wet season		
Rice Grain			Unit	6LN-15/155D
Initial moisture (%)	17.00	29.00	Rated output, kg/h	600-800
Target moisture (%)	13.00	13.00	Power requirement, kW	19.87-24.62
Inputs			Efficiency, %	68-72
Wet palay, kg/batch	7,000.00	7,000.00		
Fuel (kerosene), L/batch-unit	120.00	175.00		
Electricity for pumps, kWh/batch-unit	17.90	26.86		
Drying time, h	8.00	12.00		

GHG emissions in CO_2 equivalent were accounted and the environmental hotspots in the rice production systems were identified based from the values obtained per process stage. To determine the GHG reduction potential of the low GHG emission rice production system from the conventional system, Equation 2 was used.

$$GHG\ Reduction\ (\%) = \frac{GWP_{conventional} - GWP_{low\ GHG}}{GWP_{conventional}} x100\% \tag{2}$$

3. Results and discussion

Straw Innovations conducted a trial lagoon digester run in 2021 to test the viability of rice straw and cattle manure as feedstocks for biogas production. Since the study was in experimental stage, the digestion process was not optimized. To determine the potential of the rice straw biogas system as bioenergy source and for mitigating GHG emissions, the same system inputs were used as feedstock amount basis in the Aston Bioenergy Mass-Energy Balance Model (Aston Model). Amounts of feedstocks and the projected biogas and digestates are shown in Table 3.

Table 3. Biogas production inputs and outputs of the actual trial run and the simulated model using Aston Bioenergy Mass-Energy Balance Model.

Models	Input				Output		
	Rice Straw, kg	Cattle Manure, kg	Water, kg	Total, kg	Biogas, L	Solid Digestate, kg	Liquid Digestate, kg
Straw Innovations Run	39,950.00	10,000.00	52,033.43	101,983.43	1,409,744.48	56,841.80	53,970.02
Aston Model	39,950.00	10,000.00	52,033.43	101,983.43	8,803,567.99	47,956.63	53,956.99

The calculated biogas produced, shown in Table 4, was upgraded to meet the CHP biogas composition requirement. With the 8,803,567.99 L biogas produced using the Aston Model, an equivalent of 19,502.97 MW electricity and 84,512.86 MJ heat can be generated. This energy can be used to process the harvested rice grain in the rice fields considered in the system boundary. Since moisture content of harvested palay is higher during wet season, the amount of dried and milled rice grain in this season is lower compared to dry season. Around 18,417.21 kg (dry season) and 15,752.79 kg (wet season) dried and milled rice grain can be processed using the same biogas yield per batch. The generated heat and electricity from the biogas conversion in the Aston Model has excess amounts which can be used to process more rice grain or for other purposes.

Table 4. Biogas composition based on modified Buswell equation (initial) and after upgrading and its equivalent energy conversion using combined heat and power (CHP) engine.

Component	Biogas Composition				Biogas Conversion Using CHP		
	Initial composition		After upgrading		Component	Energy generated, MW	%
	Volume, L	%	Volume, L	%			
CH_4	4,203,050.27	47.74	4,203,050.27	60.00	Electricity	19,502.97	15.00
CO_2	4,329,440.27	49.18	2,802,033.51	40.00	Heat	84,512.86	65.00
NH_3	255,800.03	2.91			Losses	26,003.96	20.00
H_2S	15,277.43	0.17					
Total	8,803,567.99		7,005,083.79		Total	130,019.79	

IOP Conf. Series: Materials Science and Engineering **1318** (2024) 012016 doi:10.1088/1757-899X/1318/1/012016

Table 5. Amount of rice grain processed and excess energy equivalent of biogas utilization.

Component	Conventional System		Aston Model	
	Dry Season	Wet Season	Dry Season	Wet Season
Dried and milled rice grain, kg	18,417.21	15,752.79	18,417.21	15,752.79
Excess kerosene equivalent, L	-	-	696.93	248.46
Excess electricity equivalent, kWh	-	-	3,745.12	6,182.23

Life cycle assessment of the Conventional Rice Production System and Low GHG Emission Rice Production Systems, namely, Aston Model and Straw Innovations System, revealed the carbon footprint of each product stages. The stage with the highest carbon footprint identified was during rice cultivation and harvesting. This is due to high fuel usage during land preparation, irrigation and harvesting, as well as high inputs of synthetic fertilizer. Farm emissions in the conventional system is higher than the low GHG emissions systems by around 25-39% due to emissions of incorporation of rice straw on soil. Although biogas production has an equivalent GHG emission due to fuel used in the transport of rice straw and cattle manure from farm to facility, the calculated amount is still less than the emissions when rice is incorporated in the soil. For the grain drying and milling, there is GHG emission reduction for the Aston Model due to the excess energy produced. GHG emission reduction was also achieved for the use of solid and liquid digestate as organic fertilizers. Shown in Figure 5 are the GHG emissions and GHG reductions per product stage.

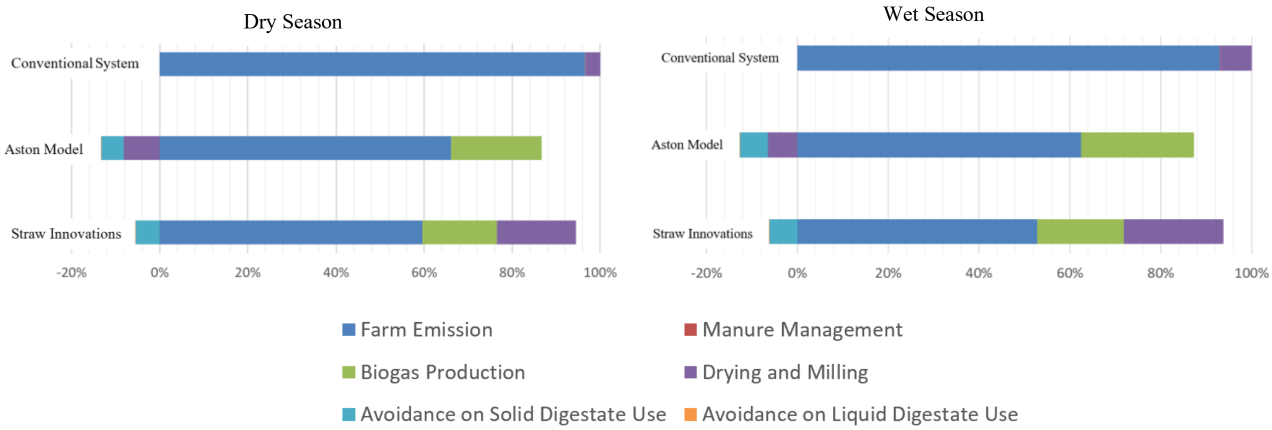

Figure 5. GHG emissions and savings of the three rice production systems.

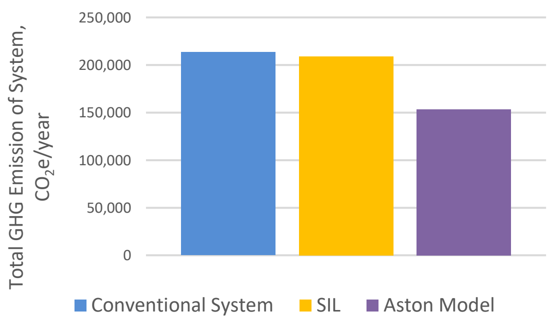

Figure 6. Annual GHG Emission of the rice production systems.

IOP Conf. Series: Materials Science and Engineering **1318** (2024) 012016 doi:10.1088/1757-899X/1318/1/012016

Combining the GHG emissions and GHG savings of the rice production systems for dry and wet seasons, an annual 28.21% GHG mitigation potential for Aston Model can be achieved. This is based on the GHG reduction from the conventional rice production systems. This GHG reduction potential is the theoretical maximum amount that can be achieved if the Straw Innovations rice straw biogas system will be optimized.

4. Conclusion

Findings in the life cycle assessment of the system utilizing rice straw with cattle manure to produce biogas proved the viability of these biomass in reducing GHG emissions in rice production system. With the abundant supply of rice straw generated as waste every cropping cycle in the country, its use for bioenergy production can sustain the energy requirement for rice post-harvest processing as well as supply the excess energy to the grid. However, this can only be achieved upon optimization of the anaerobic digestion and CHP to drying and milling units.

5. Acknowledgement

This paper and the research project it originated would not be possible without the exceptional support of United Kingdom Research and Innovation (UKRI) and our project collaborators in Straw Innovations and Energy and Bioproducts Research Institute (EBRI) in Aston University.

References

[1] Yue X L and Gao Q X 2018 *Adv. Clim. Chang. Res.* **9** pp 243-252
[2] World Resources Institute Climate Analysis Indicators Tool 2.0 2016
[3] International Rice Research Institute 2020 Philippine records its highest rice production in 2020 *Rice Today*
[4] International Rice Research Institute n.d. The value of sustainable rice straw management
[5] Nguyen V H, Topno S, Balingbing C, Nguyen V C N, Roeder M, Quilty J, Jamieson C, Thornley P and Gummert M 2016 *Enegy Rep.* **2** pp 117-122
[6] Chong K *et al* 2021 Bioenergy mass-energy balance model. Energy and Bioproducts Research Institute, Aston University, UK
[7] Boyle M 1977 *Microbial Energy Conversion* **(1)** pp 119-138
[8] Buswell A and Mueller H 1952 *Industrial & Engineering Chemistry* **44(3)** pp 550-552
[9] Zhang Y, Kusch-Brandt S, Salter A M and Heaven S 2021 *Processes* **9**, 1565
[10] Ahlberg-Eliasson K, Nadeau E, Leven L and Schnurer A 2017 *Biomass and Bioenergy* **(97)** pp 27-37
[11] Font-Palma C 2019 *Carbon* **5**, 27
[12] Sumagang M V P, Nguyen V H, Detras M C M, Alfafara C G, Borines M G, Capunitan J A and Gummert M 2020 *Renewable Energy* **148** pp 953-963
[13] Estante E P V, Demafelis R B, Matanguihan A E D, Magadia B T, Gomez C C, Nuñez C J E, Sumague J V and Jamieson C 2023 *Philipp. J. Crop Sci.* **48(1)** pp 41-53