



Maejo International Journal of Energy and Environmental Communication

Journal homepage: <https://ph02.tci-thaijo.org/index.php/MJEEC>



ARTICLE

Exploring biogas feedstocks *Glyceria maxima* and *Phalaris arundinacea* with cow dung co-digestion

Macdonald Tatenda Muronda¹, Vadzanayi Mushayi², Obey Gotore^{3,*}

¹Department of Engineering and Physics, Bindura University of Science Education, Bindura, Zimbabwe

²Department of Civil Engineering, Harare Polytechnic College, Harare 407, Zimbabwe

³Department of Biological Environment, Akita Prefectural University, Akita 011-0195, Japan

ARTICLE INFO

Article history:

Received 17 November 2023

Received in revised form

24 December 2023

Accepted 28 December 2023

Keywords:

Wetland grasses

Glyceria maxima

Phalaris arundinacea

Cow dung co-digestion

Biogas production

Sustainable wetland management

ABSTRACT

The digestion of marsh grasses *Glyceria maxima* and *Phalaris arundinacea* with and without cow manure is examined for biogas production. This study investigates biomass sources for biogas production to address these issues. Anaerobic digestion investigations were conducted for 30 days with four feedstock combinations: 100% *G. maxima*, 100% *P. arundinacea*, 70% *G. maxima*, 30% cow dung, and 70% *P. arundinacea* and 30% cow dung. The simultaneous digestion of cow manure significantly boosted biogas output for both grass kinds. The highest biogas yield was 0.55 m³/kg VS from *G. maxima* and cow dung, followed by 0.50 m³/kg VS from *P. arundinacea* and cow dung. The grass-only combinations had 58% methane, while the co-digestion mixtures had 60%. *G. maxima* and *P. arundinacea* produced similar biogas and methane, suggesting they could be renewable energy crops. The reactor pH and VFA levels indicated stable digesting conditions. Total solids and volatile solids decreased more in co-digestion mixes. The results show that marsh grasses and cow manure improve biogas generation efficiency and profitability. This technique increases energy output and sustainably manages marsh grasses and cow manure, reducing dependence on conventional energy crops, greenhouse gas emissions, and biodiversity loss. This integrated strategy has the potential to greatly enhance the utilization of renewable energy and the management of wetlands. The addition of biogas to biomass resources enhances the production process.

1. Introduction

Environmental issues caused by the depletion of natural resources, increased emissions of greenhouse gases (GHG), the loss of biodiversity, and the growing need for energy, food, and space are among the most significant environmental difficulties humanity is currently facing in the 21st century (Bhuyar et al., 2021). One of the most significant contributors to GHGs is the combustion of fossil

fuels, which in turn causes enormous and rapid changes in the atmosphere, ocean, cryosphere, and biosphere. These alterations have a significant influence on the occurrence of extreme weather events and the patterns of climate in every locality around the globe (Angalika et al., 2022). Using biomass as an energy source is one approach that can be taken to combat climate change and the shrinking of biodiversity (Chuanhai et al., 2019). At the moment, there is an increasing need for biomass all over the world. Despite this, the European Union's (EU) emphasis on the Green Deal and

* Corresponding author.

E-mail address: gotore_o@akita-pu.ac.jp (Gotore O.)

2673-0537 © 2019. All rights reserved.

green recovery may significantly impact the biomass business, which will need the industry to make adjustments to conform to environmental, social, and economic sustainability criteria in Europe and abroad.

Recently, energy crops have been reevaluated as potential energy sources that are considered environmentally sustainable (Pradechboon & Junluthin, 2022). It has been demonstrated that the increased cultivation of energy crops like maize (*Zea mays*), sorghum (*Sorghum* spp.), sugarcane (*Saccharum officinarum*), switchgrass (*Panicum virgatum*), and willow (*Salix viminalis*) may lead to a reduction in biodiversity and an increase in competition for land that is necessary for the production of food and animal feed (Pinho & Mateus, 2023). Despite the fact that energy crops account for more than half of the biogas production, the cultivation of these crops is associated with many potential risks, including increased erosion, emissions of nitrogen oxides, and eutrophication (Chuanchai & Ramaraj, 2018). Cultivating maize that produces high yields requires a significant quantity of nutrients, most notably nitrogen, and vast amounts of external energy inputs, most of which are obtained from fossil fuels (Dussadee et al., 2017). As a consequence of the aforementioned problems, society has resistance to producing biogas from maize. This opposition highlights the importance of expanding the variety of materials utilized in biogas facilities to increase public support.

When the process of producing renewable energy is carried out on peatlands or organic soils that have been drained, the negatives of this method become substantially more apparent. A considerable amount of carbon dioxide (CO₂) is released into the atmosphere due to the process of mineralizing the aerated peat in these situations (Nurzakiah et al., 2020). The requirement of shifting energy sources from biomass to include waste from industrial and municipal processes, sewage sludge, and biomass obtained from landscaping and vegetation management in protected natural areas and restored peatlands has been highlighted by several studies. An extremely promising alternative is biomass, which is obtained from biotope management and plasticulture. Paludiculture encompasses agricultural and forestry techniques implemented on peatlands undergoing repeated wetting and rewetting. Implementing rewetting and transitioning to plasticulture substantially reduces GHG emissions, leading to a considerable overall decrease in emissions (Tanneberger et al., 2022).

Peatland harvesting depletes nutrients, hence decreasing the presence of contaminated runoff water. Nevertheless, the challenging topography necessitates the use of specialized harvesting technology. Consistent mowing and removing biomass are crucial for safeguarding these areas and fostering the growth of adaptable plants. The utilization of paludal-biomass in fen peatlands enables the utilization of gramineous biomass such as reeds, reed canary grass, and sedges. This biomass possesses a significant calorific value and is well-suited for thermal utilization through the use of efficient combustion technologies (Hartung et al., 2020). There is a significant market demand for gas, heat, and electricity production using paludi, particularly in places that already have district heating networks. Biogas production can utilize fresh biomass or silage obtained from wetlands. The biogas and power or heat options can be seamlessly incorporated into distribution

networks. Efficient utilisation of gathered biomass is essential, as naturally occurring wetland ecosystems generate less biomass than rewetted peatlands (Lupascu & Wijedasa, 2021).

Several different approaches can be utilized to extract energy from biomass. In light of the fact that our civilization is extremely dependent on energy, it is necessary to replace fossil fuels with renewable energy sources to accomplish sustainable development (Junluthin et al., 2021). Wind power, tidal and wave energy, dam energy collectors, and biomass produced by autotrophic organisms are all examples of renewable energy sources (Dussadee et al., 2022). Solar energy can be created using thermal and photovoltaic methods; thus, it is included in this category. The heat from the earth, which is often referred to as geothermal power, is a source of energy that is both sustainable and long-lasting despite the fact that it is not considered a renewable resource (Ramaraj & Dussadee, 2015). Biomass, which can be comprised of living or extinct organisms, is commonly referred to as plants or other photosynthetic organisms such as bacteria and algae (Ramaraj et al., 2016). These organisms can operate as a reservoir of biomolecules or energy. Plant biomass, which has traditionally been utilized as a source of energy for heating, is increasingly being recognized as a viable source of biofuels that are also favorable to the environment (Ramaraj & Unpaprom, 2016). It has the advantage of having a nearly neutral influence on carbon dioxide production and other gases contributing to climate change. This is a significant advantage (Nong et al., 2022a,b). Most types of plant biomass can be utilized in one of two ways: either by directly burning them as a source of heat or by converting them into biofuels such as bioethanol, biodiesel, biogas, and biohydrogen. Both of these methods are viable options.

Constructed wetlands (CW) are engineered systems that use natural wetland treatment mechanisms to manage wastewater efficiently. Plants are essential components of these CW systems. The CW vegetation, more popularly called macrophytes, consists of rooted or floating species that differ in their characteristics depending on the wetland and substrate (Gotore et al., 2021). These plant species provide a direct contribution to the process of absorbing nutrients and contaminants from the water. The fixation of biofilm, the transmission of oxygen, and the management of pH are all indirect ways in which they contribute (Muronda & Gotore, 2023). Microorganisms can successfully ingest and transform contaminants as a result of the conditions that are created by these activities. In addition, they offer thermal insulation, prevent obstructions, allow for the creation of habitats for wildlife, and enhance the aesthetic attractiveness of the CW system. In order to prevent the depletion of nutrients at the end of the growing season, it is essential to harvest the vegetation that grows in wetland areas. This vegetation can then be utilized as biomass for a variety of uses, including the production of bioenergy. To develop plant biomass for bioenergy production, this technique significantly contributes to the interaction between water and energy (Gotore et al., 2022). This is accomplished through the utilization of built wetlands (CW). In addition to this, it eliminates the need for fertile land, fertilizers, and freshwater, which is an additional advantage.

Considering the aforementioned circumstances, the primary objective of the current research is to investigate the ability of *Glyceria maxima* and *Phalaris arundinacea* to generate biogas

(Banaszuk et al., 2020). These wetland grasses have substantial potential as feedstocks for biogas production because they generate a substantial quantity of biomass and are able to thrive in conditions that are saturated with water. As a result, they are suitable for cultivation in artificial wetlands made by humans (Czubaszek et al., 2020). Furthermore, the co-digestion of these grasses with cow dung, which is a commonly available and nutrient-rich substrate, has the potential to improve the process of producing biogas by delivering a balanced nutrient profile and enhancing the activity of microorganisms (Alfa et al., 2013). The objective of this study is to examine the physical and chemical characteristics of *Glyceria maxima* and *Phalaris arundinacea*, assess their biogas production and methane content through anaerobic digestion, compare the efficiency of biogas generation and gas composition between the two species, and evaluate the environmental and economic consequences of utilizing these grasses as feedstocks for biogas production with cow dung.

2. Material and methods

2.1 Collection and preparation of biomass

Glyceria maxima and *Phalaris arundinacea* specimens were gathered from their original wetland habitats at the conclusion of their growth cycles to guarantee maximum biomass production. Simultaneously, recently expelled cow dung was acquired from a neighbouring dairy farm. The entirety of the gathered organic material was conveyed to the laboratory for later processing. *Glyceria maxima* and *Phalaris arundinacea* were subjected to a 48-hour air-drying process in order to decrease their moisture content. Once the plant materials were dried, they were then sliced into minute fragments, measuring roughly 2-3 cm in size. This was done to increase the amount of surface area that could be accessed by microorganisms during the process of digestion. The plant components and cow manure were individually homogenized using a mechanical mixer to ensure a uniform and consistent texture.

2.2 Techniques used before treatment

The mechanical pre-treatment process entailed grinding and milling the dehydrated and chopped plant materials in order to decrease the size of the particles further and disintegrate the lignocellulosic structure. To perform chemical pre-treatment, the plant materials were immersed in a 2% sodium hydroxide (NaOH) solution for 24 hours. This process was carried out to degrade the lignin and hemicellulose components. A second set of ground plant materials underwent treatment with a 2% sulfuric acid (H₂SO₄) solution for 24 hours. This treatment aimed to break down hemicellulose and improve the solubility of the biomass.

2.3 Experimental configuration for anaerobic digestion

Batch reactors with a working volume of 2 liters were utilized to conduct anaerobic digestion tests. The reactors were maintained under mesophilic conditions, specifically at a temperature of 35±2°C. The anaerobic sludge utilized as the inoculum was obtained from a local wastewater treatment plant. It was exposed to the feedstock materials for a period of two weeks before the trials began.

Four unique combinations of feedstock were created for the experiments:

- Mixture 1: 100% concentration *Glyceria maxima* is the scientific name of a plant species.
- Mixture 2 consists of 100% of the substance. *Phalaris arundinacea* is the scientific name for a certain plant species.
- Composition 3: 70% The mixture consists of *Glyceria maxima* combined with 30% cow manure.
- Mixture 4 consists of 70% of the total composition. The combination of *Phalaris arundinacea* and 30% cow manure.

The reactor was filled with a total capacity of 2 liters, consisting of 1.5 liters of raw material combination and 0.5 liters of inoculum. The reactors were tightly sealed to preserve anaerobic conditions and linked to gas collection systems.

2.4 Surveillance and examination

The process of anaerobic digestion was observed over a period of 30 days. The subsequent variables were evaluated and documented, and all experimental procedures and analytical measurements were adopted from the Wannapokin et al. (2018) and Gotore et al. (2021):

- Biogas Production: The gas flow meter was used to measure the daily volume of biogas.
- The composition of biogas, including methane (CH₄), carbon dioxide (CO₂), and trace gases, was determined through the use of a gas checker.
- The pH and temperature levels were monitored on a daily basis to ensure that the circumstances were ideal for microbial activity.
- Volatile Fatty Acids (VFAs): The levels of VFAs in the liquid coming out of the reactor were measured.

The levels of Total Solids (TS) and Volatile Solids (VS) were determined in the initial feedstock mixtures and the effluents from the reactor using established protocols (APHA-AWWA-WPCE, 2015).

2.5 Data analysis

The biogas production efficiency was calculated by dividing the volume of biogas produced by the amount of volatile solids injected, given as m³/kg VS. The methane yield was determined by dividing the volume of methane produced by the number of volatile solids injected and expressing the result as m³ CH₄/kg VS. Statistical analysis, such as ANOVA, was employed to assess disparities in biogas production and composition across different combinations of feedstock.

3. Results and discussion

3.1 Feedstock properties

The moisture, volatile matter, ash, and fixed carbon of *G. maxima*, *P. arundinacea*, and cow dung differ proximally (Table 1). *G. maximum* has 10.5% moisture, and *P. arundinacea* 12.0%. Cow dung is higher in moisture at 75.0%. *P. arundinacea* has the most

volatile substance, 70.0%. With 65.0% volatile matter, *G. maxima* follows closely. Cow dung's 15.0% volatile stuff is far lower. *G. maxima* and *P. arundinacea* have high volatile matter concentrations, suggesting biogas production potential. Heat generates more gasses from these compounds (Rafiee et al., 2021). These grasses produce a lot of gas, making them suitable biogas producers. *G. maxima* has 5.0% ash, while *Phalaris arundinacea* has 6.0%. More ash is found in cow dung (10.0%). Lower ash levels suggest fewer inorganic residues, which is good. This streamlines post-biogas material management and reduces digester clogs and other issues. *G. maxima* has 19.5% fixed carbon, while *Phalaris arundinacea* has 12.0%. The fixed carbon content affects biomass combustion and energy content. However, its high volatile matter suggests that it could contribute significantly to biogas production if properly dried (Ogwang et al., 2021).

The final analysis explains biomass material elemental makeup and biogas output. *G. maxima* has 47.0% carbon, *P. arundinacea* 46.0%, and cow dung 50.0%. *G. maxima* and cow manure have 6.0% hydrogen, while *P. arundinacea* has 5.8%. The energy content of biomass depends on hydrogen. This hydrogen content increases the biogas calorific value. *G. maxima* has 0.5% nitrogen, while *P. arundinacea* has 0.6%. Cow dung has 1.5% nitrogen, which is much higher. All samples have low sulfur levels: 0.1% for *G. maxima* and *P. arundinacea* and 0.2% for cow dung. These materials have low sulfur concentrations, preventing biogas production equipment corrosion and sulfur compound formation (Nhut & Le, 2020). Thus, biogas production is feasible with all three resources. *G. maxima* and *P. arundinacea* had 41.4% and 41.5% oxygen content, respectively. Contrarily, cow dung has 32.3% oxygen. Cow dung, with its lower oxygen content, can produce biogas with higher energy density (Asiñero et al., 2023).

Table 1 Proximate and ultimate analysis (in %)

Component	<i>G. maxima</i>	<i>P. arundinacea</i>	Cow dung
Moisture	10.5	12.0	75.0
Volatile Matter	65.0	70.0	15.0
Ash	5.0	6.0	10.0
Fixed carbon	19.5	12.0	-
Carbon (C)	47.0	46.0	50.0
Hydrogen (H)	6.0	5.8	6.0
Nitrogen (N)	0.5	0.6	1.5
Sulfur (S)	0.1	0.1	0.2
Oxygen (O)	41.4	41.5	32.3
Ash	5.0	6.0	10.0

G. maxima and *P. arundinacea* have high volatile matter and low moisture and ash content, making them good biogas generators. These materials produce much gas due to their high volatile matter concentration, making them ideal biogas feedstocks. Cow dung has potential due to its high carbon content despite its moisture content. A good pre-treatment strategy to reduce cow dung moisture can boost biogas production. Therefore, using *G. maxima*, *P. arundinacea*, and cow dung in a biogas production system can maximize their benefits, increasing biogas production and process stability. To maximize biogas generation from various biomass

sources, more research should focus on optimal blending ratios and pre-treatment processes. By using each feedstock's distinct properties, an integrated strategy can optimize biogas production.

3.2 Impact of Preprocessing

Applying 2% NaOH and 2% H₂SO₄ solutions as a pretreatment for *G. maxima* and *P. arundinacea* substantially enhanced the availability of organic components for microbial digestion (Table 2). Chuanchai & Ramaraj (2018) study found that pretreatment of biomass reduced lignin and hemicellulose, allowing cellulose accessibility to anaerobic bacteria, leading to increased biogas generation and methane levels, thereby enhancing the breakdown of the matrix. This improvement is particularly significant due to the elevated lignin and hemicellulose content found in *G. maxima* and *P. arundinacea* in comparison to other energy crops. NaOH alkaline pretreatment causes the breakdown of lignin structure and enhances the porosity of biomass, making it easier for enzymes to reach cellulose and hemicellulose (Van Tran et al., 2022).

Acid pretreatment with H₂SO₄ hydrolyzes hemicellulose, increasing carbohydrate solubility and releasing cellulose fibers (Azeez & Al-Zuhairi, 2020). This breaks down lignocellulosic matrix barriers, allowing anaerobic bacteria to access fermentable sugars (Saetang & Tipnee, 2022). The application of pretreatment on *Glyceria maxima* resulted in a significant increase in biogas production, from 0.30 to 0.45 m³ per kilogram of volatile solids (VS), as well as an improvement in methane concentration, from 50% to 55%. The biogas generation of *Phalaris arundinacea* increased from 0.28 to 0.40 m³ per kilogram of volatile solids (VS), while the methane concentration rose from 48% to 53%. Chemical pretreatment significantly enhances biogas production from lignocellulosic biomass, improving efficiency and reducing methane concentration. (Wannapokin et al., 2017; Chuanchai & Ramaraj, 2018; Wannapokin et al., 2018; Van Tran et al., 2022). This is due to the increased accessibility of cellulose and fermentable carbohydrates to anaerobic bacteria, particularly in *G. maxima* and *P. arundinacea*.

Enhanced conversion efficiency decreases the quantity of feedstock needed, hence reducing the environmental consequences of biomass cultivation and harvesting (Sabarikirishwaran et al., 2023). Pretreatment technologies facilitate the utilization of agricultural and other waste materials as biogas feedstocks (Unpaprom et al., 2021). Converting trash into energy improves the long-term viability and closed-loop nature of the economy. Ultimately, the application of NaOH and H₂SO₄ solutions to *G. maxima* and *P. arundinacea* prior to treatment greatly improves the production of biogas. This technique decreases the amounts of lignin and hemicellulose, which enhances the ability of anaerobic bacteria to access cellulose (Azeez & Al-Zuhairi, 2020). As a result, there is an increase in the production of biogas and methane (Wannapokin et al., 2017; Chuanchai & Ramaraj, 2018; Wannapokin et al., 2018). By including pretreatment techniques, the economic feasibility and environmental sustainability of biogas generation can be enhanced (Van Tran et al., 2022), hence increasing the attractiveness of lignocellulosic biomass as a renewable energy source.

Table 2 Impact of pretreatment on *Glyceria maxima* and *Phalaris arundinacea*

Parameter	<i>G. maxima</i> (Before)	<i>G. maxima</i> (After)	<i>P. arundinacea</i> (Before)	<i>P. arundinacea</i> (After)
Moisture (%)	80	10	75	10
Total solids (%)	20	90	25	90
Volatile solids (%)	80	85	85	87
Cellulose (%)	40	50	35	45
Hemicellulose (%)	30	10	25	10
Lignin (%)	20	5	25	5
Cumulative biogas yield (m ³ /kg VS)	0.30	0.45	0.28	0.40
Average CH ₄ (%)	50	55	48	53

3.3 Biogas production and yield

Biogas co-digestion provides multiple advantages by maximizing the utilization of diverse organic waste materials. It improves the production of biogas by optimizing the balance of nutrients and stabilizing microbial activity, resulting in increased yields (Bhuyar et al., 2021; Pradechboon & Junluthin, 2022). This procedure enables the simultaneous management of several waste streams, resulting in a reduction in overall waste and the redirection of organic materials away from landfills. By amalgamating several feedstocks, the nutrient composition of the digestate is enhanced, rendering it a more beneficial kind of fertilizer (Chuanchai et al., 2019). Co-digesting improves digestion stability, reduces inhibition risk, and increases biogas production. It reduces waste disposal, generates cash through tipping fees, and reduces greenhouse gas emissions (Chuanchai & Ramaraj, 2018). It also reduces reliance on synthetic fertilizers and provides sustainable energy for electricity, warmth, and vehicle fuel (Dussadee et al., 2022; Dussadee et al., 2022).

Table 3 Cumulative biogas yield and methane content for various energy crops

Feedstock	Biogas Yield (m ³ /kg VS)	Methane (%)
<i>G. maxima</i> (100%)	0.45	55%
<i>P. arundinacea</i> (100%)	0.40	53%
<i>G. maxima</i> + Cow dung (70:30)	0.55	60%
<i>P. arundinacea</i> + Cow dung (70:30)	0.50	58%

The adaptability and resilience of co-digestion stem from its ability to utilize a diverse array of organic resources, such as agricultural leftovers and food waste (Saetang & Tipnee, 2022). The biogas production from the different feedstock mixtures was monitored daily over the 30-day digestion period. The cumulative biogas yield for each mixture was as follows: The results showed that the addition of cow dung significantly enhanced biogas production for both *G. maxima* and *P. arundinacea*. The highest biogas yield was obtained from the mixture of *G. maxima* and cow dung, indicating a synergistic effect of co-digestion. To provide a broader context, the biogas yields from *G. maxima* and *P. arundinacea* were compared with other commonly used energy crops (Table 3). The data for the other crops were obtained from the literature. The co-digestion of cow dung with both *G. maxima* and *P. arundinacea* resulted in an increased methane content compared

to the digestion of the grasses alone. The average methane content for each mixture was as follows: The concentration of VFAs and the pH levels in the reactors were monitored to assess the stability of the anaerobic digestion process (Ramaraj & Dussadee, 2015). The VFA concentrations remained within the optimal range (500-2000 mg/L) for all mixtures, indicating stable digestion conditions. The pH levels were maintained between 6.8 and 7.2 throughout the digestion period, which is conducive to efficient biogas production. The reduction in total solids (TS) and volatile solids (VS) during the digestion process was as follows (Table 4):

Table 4 Reduction in total and volatile solids (%)

Mixture	TS	VS
	Reduction	Reduction
Mixture 1 (100% <i>G. maxima</i>)	35%	40%
Mixture 2 (100% <i>P. arundinacea</i>)	33%	38%
Mixture 3 (70% <i>G. maxima</i> + 30% cow dung)	45%	50%
Mixture 4 (70% <i>P. arundinacea</i> + 30% cow dung)	42%	48%

The co-digestion mixtures exhibited greater reductions in both TS and VS, indicating a more effective breakdown of organic waste. The findings unequivocally indicate that the simultaneous digestion of *G. maxima* and *P. arundinacea* with cow manure substantially increases both the production of biogas and the concentration of methane. The balanced nutritional composition of cow dung helps the anaerobic digestion process by fostering the growth of microbial populations. The presence of cow dung likely provided crucial nutrients, such as nitrogen, which enhanced the decomposition of complex organic matter in the grasses, leading to a more efficient breakdown process. *G. maxima* exhibited marginally superior biogas and methane production in comparison to *P. arundinacea* in single feedstock digestions, potentially attributable to its elevated cellulose content, which is more easily decomposed by anaerobic microorganisms.

Co-digestion of *G. maxima* and *P. arundinacea* with cow manure can enhance biogas production by increasing biogas yields and methane content. This approach has the potential to improve the efficiency and economic viability of biogas production. This methodology not only enhances energy generation but also provides a sustainable means of controlling wetland grasses and cow dung. Utilizing these feedstocks can decrease dependence on conventional

energy crops, thereby addressing concerns such as the decline in biodiversity and competition for cultivable land (Ramaraj et al., 2016; Junluthin et al., 2021; Nong et al., 2022a). The environmental advantages encompass decreased greenhouse gas emissions, enhanced nutrient recycling, and heightened biodiversity in wetland regions. Although the results show promise, there are difficulties in both harvesting and processing marsh grasses. The topography might present challenges for navigation, necessitating the use of specialist equipment (Nong et al., 2022b). Moreover, the biogas generation might be influenced by the fluctuation in the chemical composition of the grasses, which is caused by seasonal and environmental conditions (Van Tran et al., 2022; Muronda & Gotore, 2023).

Future studies should prioritize the optimization of harvesting and processing procedures, as well as the exploration of alternative co-digestion substrates, to further boost biogas outputs. Furthermore, it is imperative to conduct long-term studies to evaluate the sustainability and economic viability of utilizing these feedstocks on a wider magnitude. To summarize, the research emphasizes the capacity of *G. maxima* and *P. arundinacea*, particularly when combined with cow manure, as viable and environmentally friendly sources for generating biogas. This strategy has the potential to make a substantial contribution to the generation of renewable energy and the management of wetlands in a sustainable manner (Wannapokin et al., 2018; Azeez & Al-Zuhairi, 2020; Unpaprom et al., 2021). By incorporating wetland grasses and cow dung into biogas production systems, we may effectively increase renewable energy outputs and simultaneously support environmental sustainability and biodiversity protection.

4. Conclusion

The study investigates the biogas production potential of *G. maxima* and *P. arundinacea*, two wetland grasses, with and without co-digestion of cow dung. The results show that co-digestion significantly enhances biogas yield and methane content for both grasses. The highest biogas yield was observed in the mixture of *G. maxima* and cow dung (0.55 m³/kg VS), followed closely by the mixture of *P. arundinacea* and cow dung (0.50 m³/kg VS). The methane content was also higher in the co-digestion mixtures, with 60% for *G. maxima* and cow dung and 58% for *P. arundinacea* and cow dung. The study suggests that the co-digestion of cow dung with these wetland grasses can provide a balanced nutrient profile, supporting the microbial communities responsible for anaerobic digestion. This approach not only improves energy production but also offers a sustainable method for managing wetland grasses and cow dung, mitigating environmental issues associated with their cultivation. Future research should focus on optimizing harvesting and processing techniques for wetland grasses and exploring other co-digestion substrates to enhance biogas yields further.

References

- Alfa, M. I., Adie, D. B., Iorhemen, O. T., Okafor, C. C., Ajayi, S. A., Danhuni, S. O., & Akali, D. M. (2013). Assessment of mesophilic co-digestion of cow dung with lemon grass for biogas production. *Nigerian Journal of Technology*, 32(3), 478-484.
- Angalika, M. W., Suzuki, S., Le-Huynh, T. L., Itayama, T., & Tanaka, W. (2022). Assessing nutrient budget of ungauged catchment using intermittent water quality markers. *Maejo International Journal of Energy and Environmental Communication*, 4(3), 1-10.
- Asiñero, D. M. M., Magomngang, A. A. S. M., & Pabilona, L. L. (2023). Performance of various fuels: gasoline, liquefied petroleum gas and biogas from agricultural biomass waste in a two-stroke internal combustion engine. *Mindanao Journal of Science and Technology*, 21(1).
- APHA-AWWA-WPCE, (2005). Standards methods for the examination of water and wastewater, 21st edn. APHA-AWWA-WPCF, Washington, DC
- Azeez, R. A., & Al-Zuhairi, F. K. (2020). Biofuels (Bioethanol, Biodiesel, and Biogas) from Lignocellulosic Biomass: A Review. *Journal of University of Babylon for Engineering Sciences*, 202-215.
- Banaszuk, P., Kamocki, A. K., Wysocka-Czubaszek, A., Czubaszek, R., & Roj-Rojewski, S. (2020). Closing the loop-Recovery of nutrients and energy from wetland biomass. *Ecological engineering*, 143, 105643.
- Bhuyar, P., Trejo, M., Dussadee, N., Unpaprom, Y., Ramaraj, R., & Whangchai, K. (2021). Microalgae cultivation in wastewater effluent from tilapia culture pond for enhanced bioethanol production. *Water Science and Technology*, 84(10-11), 2686-2694.
- Chuanchai, A., Tipnee, S., Unpaprom, Y., & Wu, K. T. (2019). Green biomass to biogas—A study on anaerobic monodigestion of para grass. *Maejo International Journal of Energy and Environmental Communication*, 1(3), 32-38.
- Chuanchai, A., & Ramaraj, R. (2018). Sustainability assessment of biogas production from buffalo grass and dung: biogas purification and bio-fertilizer. *3 Biotech*, 8(3), 151.
- Czubaszek, R., Wysocka-Czubaszek, A., & Banaszuk, P. (2020). GHG emissions and efficiency of energy generation through anaerobic fermentation of wetland biomass. *Energies*, 13(24), 6497.
- Dussadee, N., Ramaraj, R., & Cheunbarn, T. (2017). Biotechnological application of sustainable biogas production through dry anaerobic digestion of Napier grass. *3 Biotech*, 7, 1-9.
- Dussadee, N., Reansuwan, K., Ramaraj, R., & Unpaprom, Y. (2022). Removal of CO₂ and H₂S from biogas and enhanced compressed bio-methane gas production from swine manure and elephant grass. *Maejo International Journal of Energy and Environmental Communication*, 4(3), 39-46.
- Gotore, O., Mushayi, V., & Tipnee, S. (2021). Evaluation of cattail characteristics as an invasive wetland plant and biomass usage management for biogas generation. *Maejo International Journal of Energy and Environmental Communication*, 3(2), 1-6.
- Gotore, O., Rameshprabu, R., & Itayama, T. (2022). Adsorption performances of corn cob-derived biochar in saturated and semi-saturated vertical-flow constructed wetlands for

- nutrient removal under erratic oxygen supply. *Environmental Chemistry and Ecotoxicology*, 4, 155-163.
- Hartung, C., Andrade, D., Dandikas, V., Eickenscheidt, T., Drösler, M., Zollfrank, C., & Heuwinkel, H. (2020). Suitability of paludiculture biomass as biogas substrate—biogas yield and long-term effects on anaerobic digestion. *Renewable energy*, 159, 64-71.
- Junluthin, P., Pimpimol, T., & Whangchai, N. (2021). Efficient conversion of night-blooming giant water lily into bioethanol and biogas. *Maejo International Journal of Energy and Environmental Communication*, 3(2), 38-44.
- Lupascu, M., & Wijedasa, L. S. (2021). Paludiculture as a sustainable land use alternative for tropical peatlands: A review. *Science of the Total Environment*, 753, 142111.
- Muronda, M. T., & Gotore, O. (2023). Revealing sustainable energy opportunities through the integrated use of *Canna indica* biomass and buffalo manure for biogas generation. *Maejo International Journal of Energy and Environmental Communication*, 5(2), 41-46.
- Nurzakiah, S., Wakhid, N., & Hairani, A. (2020). Carbon dioxide emission and peat hydrophobicity in tidal peatlands. *SAINS TANAH-Journal of Soil Science and Agroclimatology*, 17(1), 71-77.
- Nhut, H. H., & Le, L. T. (2020). Removal of H₂S in biogas using biotrickling filter: Recent development. *Process Safety and Environmental Protection*, 144, 297-309.
- Nong, H. T. T., Whangchai, K., Unpaprom, Y., Thararux, C., & Ramaraj, R. (2022a). Development of sustainable approaches for converting the agro-weeds *Ludwigia hyssopifolia* to biogas production. *Biomass Conversion and Biorefinery*, 12, 793-801.
- Nong, H. T. T., Unpaprom, Y., Whangchai, K., & Ramaraj, R. (2022b). Sustainable valorization of water primrose with cow dung for enhanced biogas production. *Biomass Conversion and Biorefinery*, 12, 1647-1655
- Pinho, H. J., & Mateus, D. M. (2023). Bioenergy routes for valorizing constructed wetland vegetation: an overview. *Ecological Engineering*, 187, 106867.
- Pradechboon, T., & Junluthin, P. (2022). Alkali pretreatment and enzymatic saccharification of blue-green alga *Nostochopsis lobatus* for bioethanol production. *Maejo International Journal of Energy and Environmental Communication*, 4(1), 23-28.
- Rafiee, A., Khalilpour, K. R., Prest, J., & Skryabin, I. (2021). Biogas as an energy vector. *Biomass and Bioenergy*, 144, 105935.
- Ramaraj, R., & Unpaprom, Y. (2016). Effect of temperature on the performance of biogas production from Duckweed. *Chemistry research journal*, 1(1), 58-66.
- Ramaraj, R., Unpaprom, Y., & Dussadee, N. (2016). Potential evaluation of biogas production and upgrading through algae. *International Journal of New Technology and Research*, 2(3), 263567.
- Ramaraj, R., & Dussadee, N. (2015). Biological purification processes for biogas using algae cultures: a review. *International Journal of Sustainable and Green Energy*, 4(1), 20-32.
- Ogwang, I., Kasedde, H., Nabuuma, B., Kirabira, J. B., & Lwanyaga, J. D. (2021). Characterization of biogas digestate for solid biofuel production in Uganda. *Scientific African*, 12, e00735.
- Sabarikirishwaran, P., Shen, M. Y., Ramaraj, R., Unpaprom, Y., Wu, H. C., & Chu, C. Y. (2023). Feasibility and optimizing assessments on biogas and biomethane productions from *E. coli* fermenter effluent. *Biomass and Bioenergy*, 173, 106783.
- Saetang, N., & Tipnee, S. (2022). Anaerobic digestion of food waste from fruits and vegetables to improve stability and effectiveness. *Maejo International Journal of Energy and Environmental Communication*, 4(1), 55-60.
- Tanneberger, F., Birr, F., Couwenberg, J., Kaiser, M., Luthardt, V., Nerger, M., Pfister, S., Oppermann, R., Zeitz, J., Beyer, C., & Närmann, F. (2022). Saving soil carbon, greenhouse gas emissions, biodiversity and the economy: paludiculture as sustainable land use option in German fen peatlands. *Regional Environmental Change*, 22(2), 69.
- Unpaprom, Y., Pimpimol, T., Whangchai, K., & Ramaraj, R. (2021). Sustainability assessment of water hyacinth with swine dung for biogas production, methane enhancement, and biofertilizer. *Biomass Conversion and Biorefinery*, 11, 849-860.
- Van Tran, G., Ramaraj, R., Balakrishnan, D., Nadda, A. K., & Unpaprom, Y. (2022). Simultaneous carbon dioxide reduction and methane generation in biogas for rural household use via anaerobic digestion of wetland grass with cow dung. *Fuel*, 317, 123487.
- Wannapokin, A., Ramaraj, R., & Unpaprom, Y. (2017). An investigation of biogas production potential from fallen teak leaves (*Tectona grandis*). *Emergent Life Sciences Research*, 3, 1-10.
- Wannapokin, A., Ramaraj, R., Whangchai, K., & Unpaprom, Y. (2018). Potential improvement of biogas production from fallen teak leaves with co-digestion of microalgae. *3 Biotech*, 8, 1-18.