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Biogas Generation from Poultry Manure as an Indicator of Reduction in Environmental Pollution and Biomass Potential Contribution to the Energy Grid in Jordan

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Abstract

This study aims to assess the viability of utilizing poultry manure for biogas production as a means of contributing to the electricity grid and reducing environmental pollution in Jordan. A system consisting of a bioreactor, heating source, biogas collection device, and a subsystem for evaluating the ratio of biomethane to biogas is designed and fabricated. The system operates under mesophilic temperature settings, with a pH of 7, and a carbon-to-nitrogen ratio of 25 to 1. The modified Gompertz system is employed to simulate the experimental results.

The findings demonstrate that poultry manure has the capacity to generate around 2.032×10^3 cubic meters of biogas per year, which is equivalent to 1.32×10^9 kilowatt-hours or 4.75×10^{12} kilojoules. These numbers account for 7.8% of Jordan's energy sector and result in an 18% reduction in biowaste, equivalent to 1.08 million tons. Furthermore, the experimental results coincide completely with the modified Gompertz model. These findings indicate that utilizing poultry manure for biogas production has the potential to contribute to the electricity grid in Jordan and reduce environmental pollution caused by biomass.

Keywords: biogas, poultry manure, bioreactor, modified Gompertz model, bioenergy, Jordan national power grid, biofeuel production, biomass conversion

1. Introduction

The three primary areas of focus, globally and at various levels such as regional and local (in the case of Jordan), are energy, ecology, and economy [1]. Biomass generation has been considered as a potential source of environment pollution at national and global scale [2]. A significant component of biomass production is comprised of animal manure, commonly used in part as organic fertilizers. The rest is either disposed of in landfills or randomly deposited in areas where surface water flows. In order to address this issue of pollution, biomass can be used to generate biomethane, which can make a valuable contribution to Jordan's energy sector [3].

The global energy demand is on the rise due to the steady growth of the world's population, expansion of the economy, and increased energy usage by individuals. The utilization of fossil fuels has increased significantly, leading to an eventual depletion of their limited reserves. In order to ensure the well-being of future generations, it is essential that ongoing research endeavors focus on exploring clean and sustainable alternative energy sources. The primary application of biomass-based renewable energy is the decomposition of biomass or other waste materials, including hazardous compounds, through anaerobic digestion (AD) [4]. Extensive global research has been conducted to ascertain the optimal conditions for biogas production. Research studies have examined several biomass sources according to the abundance of biowaste in the study area. The objective of these studies is to reduce the adverse impacts of biowaste and enhance the role of biomass energy in fulfilling regional overall energy needs. Several studies have also focused on optimizing the production of biogas (specifically biomethane) through anaerobic and co-digestion of biomass and animal manure. These studies have investigated various factors including pH, carbon to nitrogen ratio (C/N), and temperature [5–9]. According to a recent study conducted by Al-Zoubi AS, it was shown that the optimal conditions for the production of biogas are at a mesophilic temperature settings, with a pH level between 6 and 8, and a C/N ratio ranging from 10 to 60 [10].

In recent years, the energy sector has emphasized investments in renewable energy, including solar and wind power. Nevertheless, their contribution did not meet the aims of the energy programs. The idea of utilizing bio-sources to produce methane for electricity generation has received minimal consideration. With increasing energy production efficiency, methane synthesis from bio-sources becomes a more viable and attractive energy option. Biomass-derived methane generation is a highly promising energy source. Animal waste, including manure from cattle, sheep, and poultry, makes up a substantial part of biomass. The enhanced production of methane from these sources augments their capacity to contribute to the global energy system.

In recent years, Jordan's population grew significantly as a result of immigration from neighboring countries and increased birthrate. Consequently, there was a rise in the need for services, particularly electricity, and the utilization of natural resources. The government produces power despite the excessive expenses, recognizing its reliance on imported fossil resources from other countries. Jordan's energy demands are met by imports, accounting for over 96%. Consequently, the country has experienced an annual GDP (Gross Domestic Product) decline of more than 10% for the past decade. In 2011, the interruption of natural gas imports resulted in a sharp rise in the Kingdom's energy expenditure, amounting to $4.8 billion, which constituted 20% of the country's GDP [11]. Hence, it is important for the government to study the possibilities of renewable and environmentally-friendly alternatives to fossil fuels, such as biomass energy.

In the past few decades, the production of biogas in Jordan has significantly increased. A program was initiated by the "Ministry of Energy and Natural Resources" in partnership with the "Jordanian German University," the "Hamburg University of Technology," and the "European Union" to facilitate the production of biogas [12]. The program aims to expedite biogas production and has three main objectives: generating energy from organic waste, suggesting a hybrid biogas design that aligns with Jordan's requirements, and creating an industrial-scale hybrid biogas plant design specifically for municipal agriculture and food waste. It has been shown in a study by Al-Hamamre et al. on the topic of "wastes and biomass as a sustainable renewable energy resource" that Jordan produces around 6 million tons of municipal solid waste, animal manure, and agricultural residues annually [3]. Based on their calculations, over 40% of the total biowastes can be converted into biogas, resulting in an annual energy production of approximately 850 GWh. Furthermore, according to the data provided by Sutaryo in 2012, it was projected that the biogas produced could potentially substitute around 24% of the total energy use for the year. Furthermore, the study asserted that poultry excrement constitutes approximately 18% of solid waste [13].

The 2017 agricultural census of Jordan indicated that there were a total of 2003 organized poultry farms, encompassing various types such as mothers, broilers, and layers. Out of these, 1623 farms specialized in broiler production, 49 farms focused on producing chickens for mothers and grandparents, and 286 farms were dedicated to layer production. Furthermore, the results revealed that 30.3% of these farms are located in Irbid Governorate, whereas Mafraq Governorate trails well behind with only 16.7% [14].

On average, a chicken generates 1 kg of manure with different levels of moisture for every kilogram of grain it consumes. In contrast, a commercially raised laying chicken generates approximately 20 kg of waste each year. Poultry farm waste comprises of litter from broiler and layer birds, hatchery waste, deceased birds, and several other forms of waste. Broiler litter consists of manure, bedding material, residual feed, feathers, and occasionally soil. However, with the exception of bedding and casing material, all the previously stated components can be found in litter from the covered layer [10]. This illustrates that the large quantity of chickens represents a significant amount of organic waste that requires proper treatment for disposal, by converting it into biogas as a renewable fuel source.

Based on the aforementioned arguments that support the rationale for bioenergy investigation, the purpose of this study is to evaluate biomethane (biogas) generation via anaerobic digestion of poultry manure. This evaluation will serve as an indicator of the potential contribution of this process to Jordan's national energy blend and reduction of environmental pollution.

2. Methodology

2.1. Materials

2.1.1. Substrate

A sample of poultry manure was gathered from a poultry farm located roughly 10 kilometers to the west of Mutah University, situated in Karak, a city 120 kilometers south of Amman, Jordan. After collection, the sample was processed to eliminate feathers, chicken residues, and suspended environmental contaminants. The sample underwent a two-phase drying process, starting with natural drying and followed by drying in an electric oven at 105 °C. This drying approach was repeated until the sample was completely dried. The objective of this approach is to eliminate moisture in order to facilitate the storage and handling of the sample's components. Then, the sample is ground using a pin mill and sieved through a 1 mm screen prior to being stored in plastic bags and securely sealed. It is then placed in a desiccator until it is required for laboratory tests.

2.1.2. Inoculum

The inoculum was acquired from the anaerobic digestion unit of Merwid wastewater treatment facility, located in the Karak Governorate of Merwid Municipality, one hundred and twenty kilometers south of Amman in Jordan.

2.1.3. Experimental setup and procedure

Figure 1 shows the complete experimental setup for biogas production and associated subsystems. It includes the bioreactor, controlled heating system, biogas collection system, and biomethane/biogas measurement system. Detailed description of each subsystem has been described elsewhere [10].

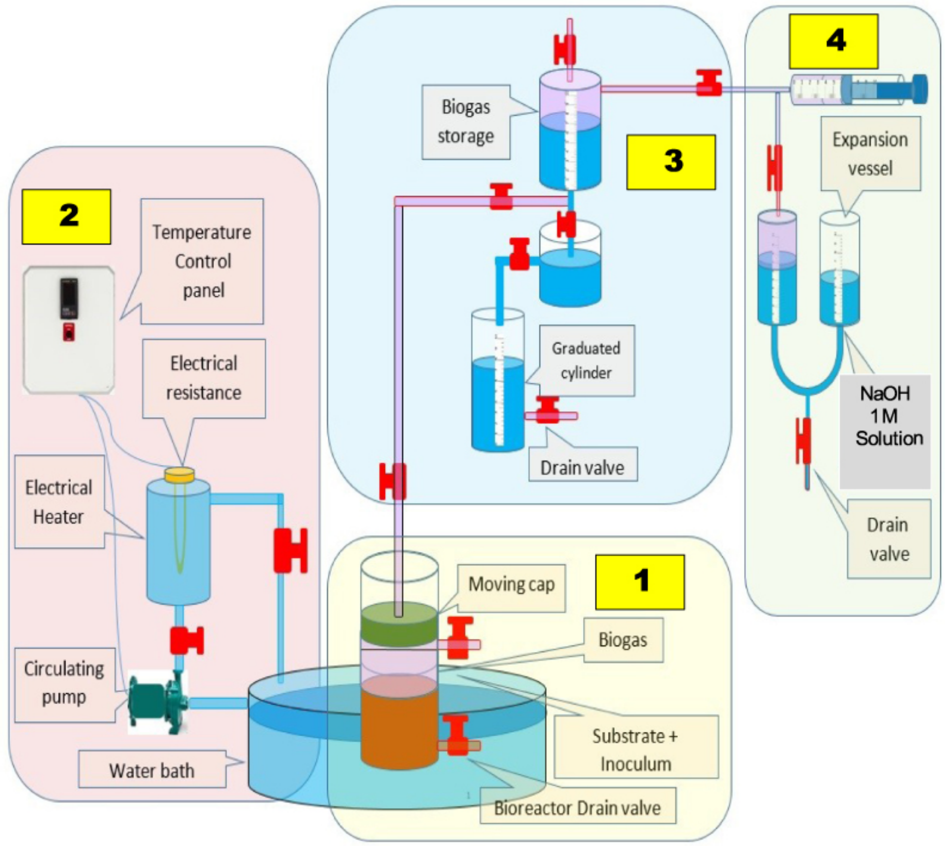

Figure 1. Schematic of the complete experimental system, (1) Bioreactor, (2) Controlled Heating System, (3) Biogas Collection System, (4) Biomethane/Biogas Ratio Measurement System.

2.1.4. Bioreactor

The studies were carried out in mobile confinement batch-bioreactors, with each reactor having a volume of 2 L. The reactors depicted in Figure 1 were constructed using a plastic cylinder with a diameter of 0.111 m, height of 0.25 m, and total capacity of 2 L. The device includes a 20-cm-tall opening that allows the gas to be released when the lid moves up to a little greater height. A valve is fitted to assist the venting and storage of gas. The purpose of utilizing this specific reactor is to solely collect the gas produced by the reaction, thereby preventing any possible contamination with contaminants that could affect the composition of the producing gas. After the sample has been inserted and the reactor has been activated, the movable cover is fitted with a valve coupled to its entrance, which facilitates the evacuation of air from the reactor. The reactor underwent a redesign in order to overcome the complexities associated with conventional reactors employed in assessing biological methane potential.

The earlier reactors included compartments that were 30% smaller than the reactor's total volume and were often filled with air or a purging gas, commonly nitrogen. Consequently, there was contamination and an unequal dispersion of gas concentration within the bioreactor. The isolated reactor system depicted in Figure 2 shows the upward displacement of the gas generated by the reaction within the reactor, leading to the upward movement of the lid. Eventually, the lid reaches a point where it can be released via the valve and caught in a gas trapping apparatus. Moreover, a valve is fitted at the bottom of the bioreactor, allowing access to a sample point. Upon completion of the experiment, the sample is extracted from the bioreactor. At the start of the experiment, a vacuum is generated by extracting air from the reactor via a hole in the movable lid, which is linked to a hose and a valve. Table 1 shows the parameters associated with the bioreactor which include the volume of the inoculum, amount of solid material, volume used for the process, mixing methods, time taken for the material to pass through the system, and the amount of both total and volatile solids in the substance.

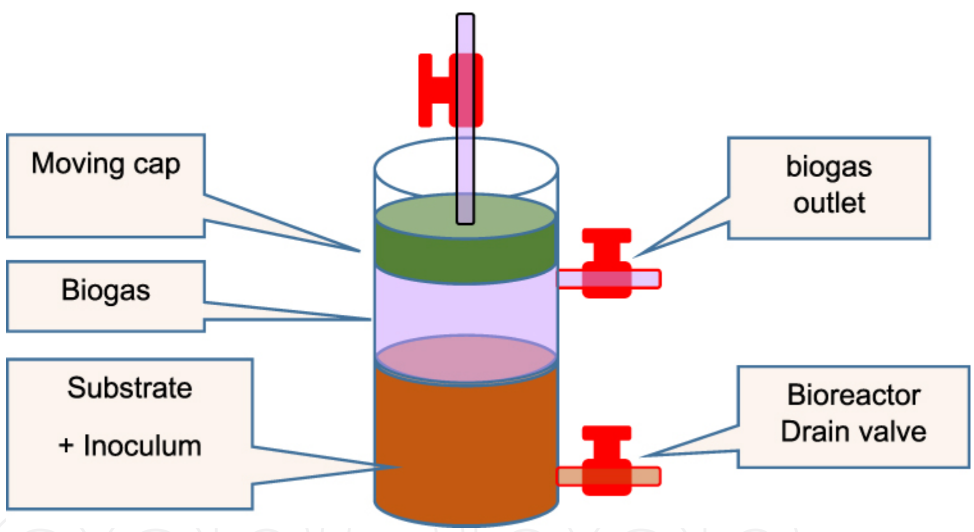

Figure 2. A schematic representation of the bioreactor, illustrating the main components and their corresponding valves.

The experimental setup for the bioreactor consists of a reactor volume of 2 L, with a working volume of 1 L. The samples used in the experiment include substrate and inoculum, each weighing 100 g. The experiments were conducted at three distinct temperatures: 37 °C, 52 °C, and 22 °C. The pH level was kept neutral at 7, while the C/N ratio was maintained at 25. The optimum temperature for the generation of biogas from poultry manure has been reported as 37 °C [10]. The mixing process was conducted manually once a day. Total solids (TS) and volatile

Table 1. Proximate analysis of poultry manure and inoculum used in the study.

Variable	Poultry manure	%	Inoculum	%
Wet sample (g)	40 (g)		100 (g)	
Total solid (TS) (g) after drying at 105 °C for 24 h	10.54	26.34	4.32	4.32
Moisture content (g)	29.46	73.66	95.69	95.69
Total solid analysis				
Total fixed solid (TFS) (g) after ash collection at 550 °C for 2 h	1.46	13.83	0.55	12.75
Total volatile solid (VS) (g) after ash collection at 550 °C for 2 h	9.08	86.17	3.76	87.08

solids (VS) measurements were made using the American Public Health Association (APHA) standard procedures [15].

Figure 3 depicts the method used to measure the amount of biogas produced in the bioreactor using a liquid replacement system. The system for replenishing liquid consists of a container that holds liquid and employs two valves located at the upper and lower ends. The apparatus is connected to the bioreactor via a rubber tube and is fitted with a valve that may be employed to extract gas samples from the reactor as needed. The volume of the resulting gas is determined using a graduated cylinder scale.

2.1.5. Measurement of biomethane to biogas ratio

Figure 4 depicts a schematic of the apparatus used to determine the ratio of biomethane produced to biogas generated. Alkaline solutions, specifically NaOH and KOH solutions, can be utilized for quantifying the methane concentration in biogas due to their capacity to absorb carbon dioxide while excluding methane. A specified quantity of biogas is extracted from the bioreactor using a syringe and thereafter introduced into a graduated glass container prefilled with NaOH solution at a concentration of 1 M. A vacant container is linked to this one (Figure 1). Upon injection of gas into the initial vessel, the solution is transferred to the subsequent vessel, where the alkaline solution assimilates carbon dioxide, leaving behind methane. The ratio between biomethane and biogas is subsequently determined [16].

2.1.6. Heating the bioreactor

A water bath heated by electrical resistance and a temperature controller simulating a temperature-controlled solar heating system was designed to heat the bioreactors. Figure 5 illustrates the heating system used with three temperature settings for thermophilic, mesophilic, and psychrophilic environments. The intended temperature ranges for the trials were 52 °C, 37 °C, and 22 °C. The heating system

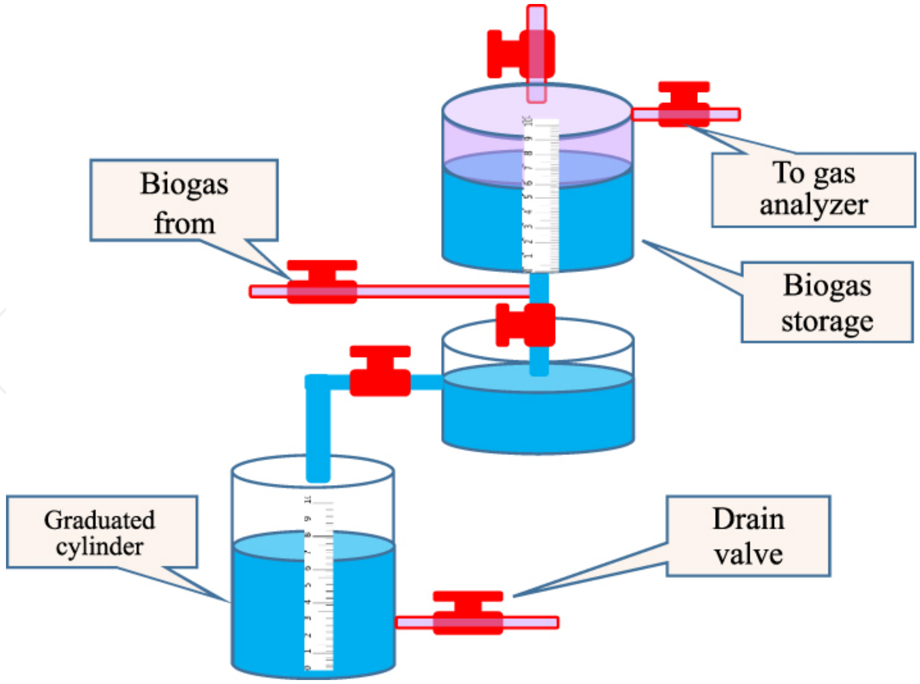

Figure 3. A schematic representation of the device employed for the measurement of biogas volume.

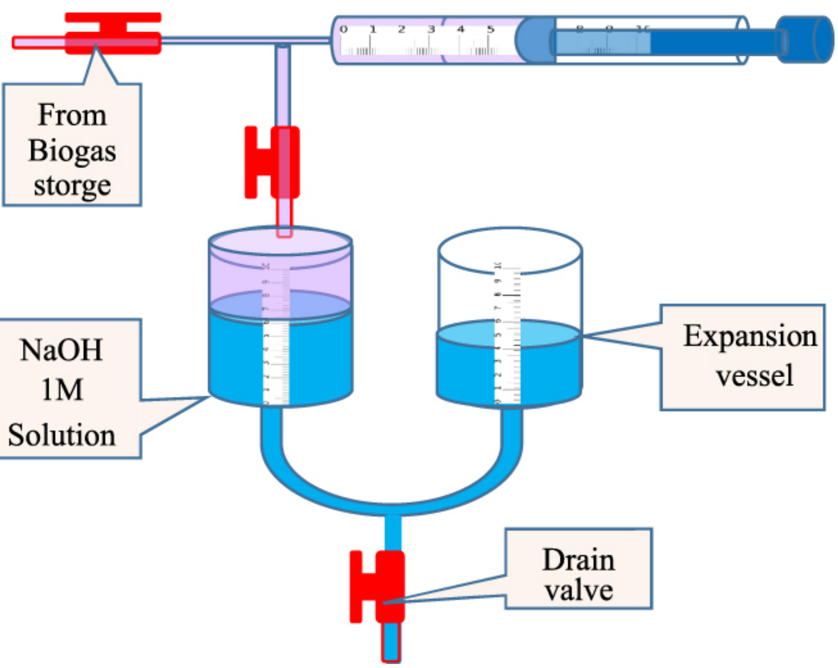

Figure 4. Schematic of the apparatus used to determine the ratio between biomethane and biogas produced.

utilized can be replaced in future studies with a solar heating-controlled system, reducing the cost of establishing a large-scale biogas generation facility.

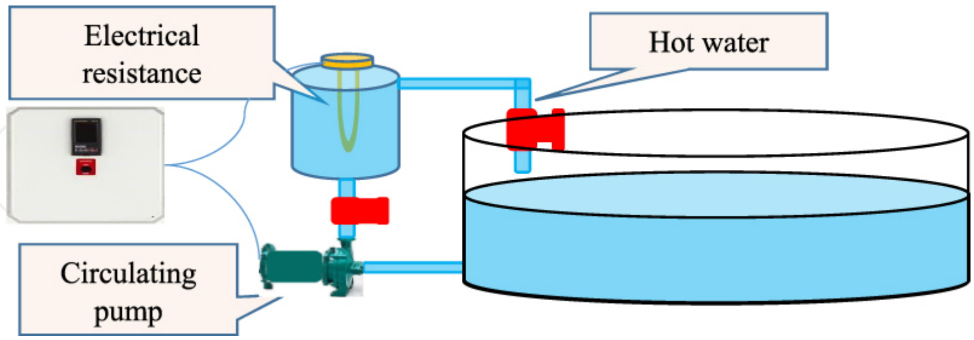

Figure 5. A schematic of the simulated water bath temperature control system used in the study.

2.2. Mathematical method

2.2.1. Modified Gompertz model

A study by Gomes et al. indicated that batch studies have utilized the modified Gompertz model to accurately estimate the cumulative biogas or methane production curves of anaerobic digestion for various substrates. A satisfactory level of compatibility was confirmed for various types of waste materials, including gelatin and leather waste, plants, municipal solid wastes, food and kitchen waste, agricultural waste, industrial waste, biochar (a by-product of the pyrolysis of plant material), and manure, either in isolation or in combination with other substrates [17]. The anaerobic breakdown of gelatin was subjected to further analysis, resulting in the development of a two-phase cumulative biogas production curve. The modified Gompertz model has been extensively utilized in the modeling methane production due to its ability to effectively describe and forecast the cumulative methane yield during the whole anaerobic digestion process [18].

Therefore, the modified Gompertz model is employed to fit the experimental data of biogas production resulting from anaerobic digestion of poultry manure. Anaerobic digestion's efficacy has been evaluated using this approach [19]. The following equation illustrates the model:

$$P = P_m * \exp\left\{-\exp\left[\frac{R_m * e}{P_m}(\lambda - t) + 1\right]\right\} \tag{1}$$

where:

P: the maximum cumulative biogas production rate (L/day)

P_m: the maximum methane production volume (L)

U: the maximum methane production rate (L/day)

λ: lag time

R_m: the production rate at the deflection point of the S-shape growth rate

e: mathematical constant (2.718)

The value of R_m is found by finding the tangent through the inflection point of the sigmoid growth curve and then finding λ as the time-axis intercept of the tangent at that moment. In order to determine the parameters of the modified Gompertz model, nonlinear regression and the reduction of the sum of squared error are utilized [19].

3. Results and discussion

3.1. Characterization of poultry manure samples

The proximate analysis results for the inoculum and poultry manure samples used in this experiment are presented in Table 1. The manure contains 26.34% TS, while the inoculum samples possess 4.32% TS. Furthermore, the findings indicate that 86.17% of the overall solids consist of volatile solids (VS). The elemental composition of the poultry manure was examined in the ultimate analysis, as depicted in Table 2. According to the findings, the C/N ratio is approximately 10, indicating a high concentration of carbon (62%) and a low quantity of nitrogen (6%). Oxygen makes up approximately 24% of the total, but hydrogen and sulfur account for approximately 8% and 1% respectively, which are relatively smaller proportions. Previous studies on poultry manure have demonstrated significant variation in the composition of different samples [20]. This could be attributed to variations in poultry feeding habits across different regions.

Table 2. Ultimate analysis of elemental composition and C/N of poultry manure (Mutah-Al Karak Area).

Elemental composition	C	H	O	N	S	Total	C/N
% of VS	61.5	7.5	23.76	6.24	1.0	100%	9.86

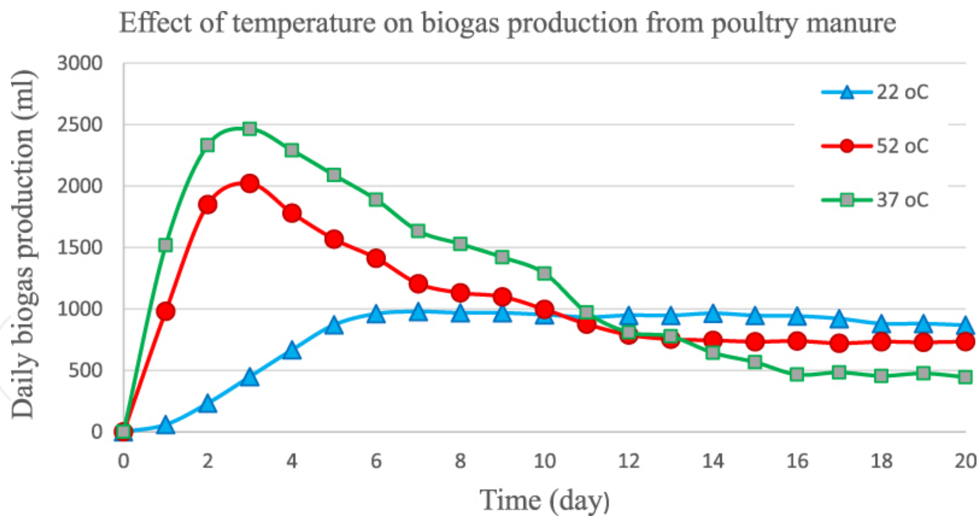

Figure 6. Average daily bigas production from poultry manure at psychrophilic, mesophilic, and thermophilic conditions.

3.2. Daily biogas production

Figure 6 illustrates that the maximum cumulative production is observed in mesophilic circumstances (37 °C), followed by thermophilic conditions (52 °C), while psychrophilic conditions (22 °C) are associated with the lowest cumulative production. Furthermore, for the temperature of 37 °C, the initial rate of production is at its maximum, reaching a peak in approximately 3 days. Psychrophilic conditions do not show any peaks, although they do reach a plateau and extend beyond it. In contrast, both mesophilic and thermophilic conditions reach their maximum at approximately three days. Following a period of three days, the rates of production in both mesophilic and thermophilic conditions start to decrease, eventually stabilizing at a constant level. This stabilization occurs after 12 days in thermophilic conditions and 16 days in mesophilic ones. Furthermore, after a duration of 11 days, the daily production of biogas in both thermophilic and mesophilic settings starts to decrease compared to the production in psychrophilic conditions. Additionally, when comparing mesophilic and thermophilic conditions, the daily production in mesophilic settings begins to decline after 13 days.

Figure 7 indicates that the total accumulative biogas produced during a 20-day retention period is around 25 L under mesophilic conditions, 22 L under thermophilic conditions, and approximately 16 L under psychrophilic conditions.

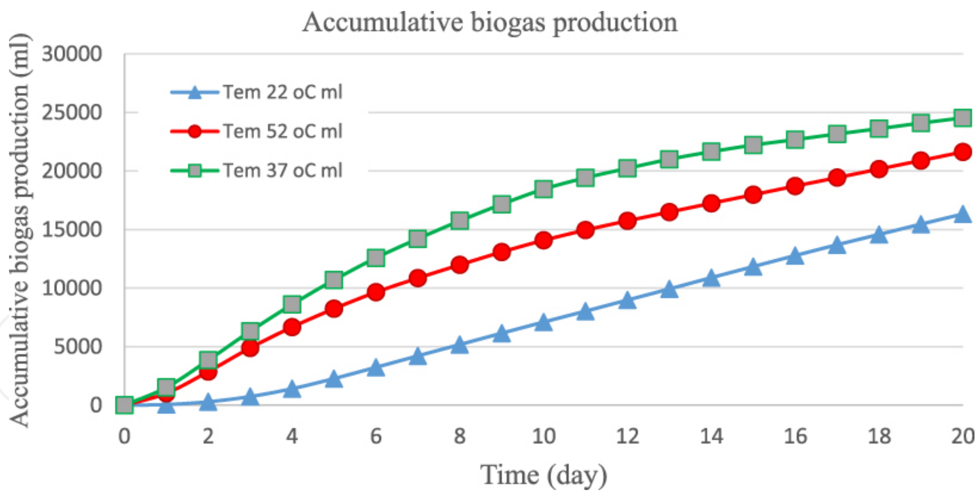

Figure 7. Accumulative biogas production at 22 °C, 52 °C, and 37 °C conditions (ml).

Figure 8 demonstrate a specific accumulative biogas generation of around 285 ml/g VS, about 252 ml/g VS, and around 195 ml/g VS. Both mesophilic and thermophilic settings exhibit a lazy-S profile in terms of the rate of biogas production, with a sluggish rate on the first day and then a surge in the rate until a retention period of 10 to 11 days, at which point the rate begins to slow down. Psychrophilic circumstances, on the other hand, display a distinct pattern characterized by a slow production for approximately 4 days, followed by an extended period of over 20 days. Consequently, increasing the temperature reduces the duration required for biogas production. Nevertheless, the expense associated with energy use becomes increasingly significant. The cost of the energy source poses a limitation on the establishment of a continuous process for biogas generation.

The reported literature values for biogas production from poultry manure at mesophilic and thermophilic settings are around 555 ml/g VS (Rahman et al, 2018), compared to 285 ml/g VS for mesophilic circumstances and 252 ml/g VS for thermophilic conditions obtained in our study [21]. This discrepancy is most likely attributable to the fact that the tests were halted after 20 days. Furthermore, it is well known that the high nitrogen concentration in poultry manure makes microorganisms in a biogas plant difficult to consume. Kjeldahl tests under psychrophilic conditions show that nitrogen percent is reduced by roughly 50% after 20 days, whereas original manure samples and those after 20 days after ashing contain no nitrogen. Other researchers reported values of around 262 NL/kg VS for mesophilic and thermophilic settings (Rahman et al, 2018), whereas reference (Rahman et al, 2019) showed a value of 252 NL/kg VS for mesophilic conditions. All results were obtained after 90 days of incubation [21].

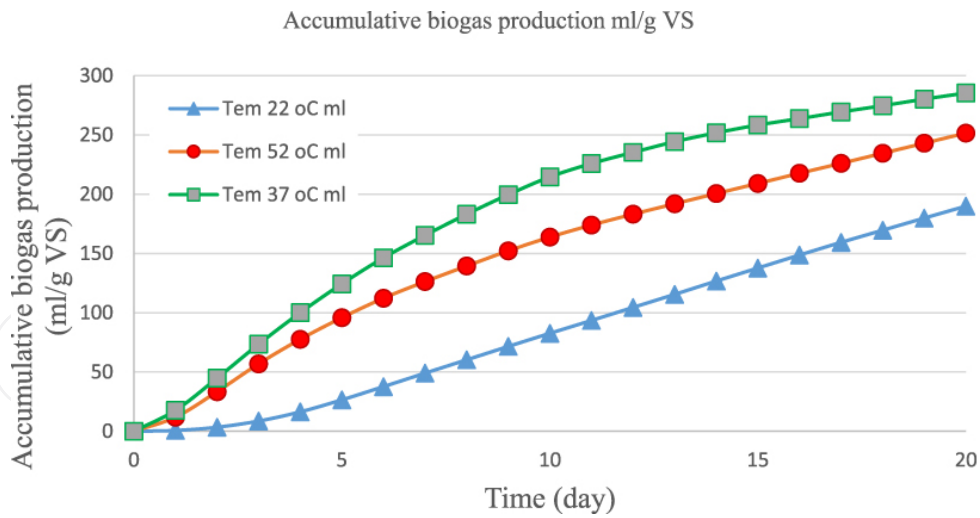

Figure 8. Specific accumulative biogas production (ml/g VS).

3.3. Modified Gomertz model

The modified Gompertz model is utilized with average experimental data on the production of biogas from poultry manure in psychrophilic, mesophilic, and thermophilic conditions. The model parameters are obtained using nonlinear regression and the minimization of the sum of squared errors, as presented in Table 3. Figure 9 displays the final findings of the analysis. This figure illustrates the strong correlation between the experimental results and the modified Gompertz model, suggesting that the model accurately represents the biogas production data across a wide range of temperatures, from psychrophilic to thermophilic conditions.

Table 3. Parameters of modified Gompertz model.

Parameter	Psychrophilic conditions	Thermophilic conditions	Mesophilic conditions	Average of original data
P_m	246.06	255.88	282.88	259.67
R_m	12.50	17.39	25.03	17.70
λ	18.00	10.89	8.62	12.86
e	2.72	2.72	2.72	2.72

The predicted results of the modified Gompertz model under various temperature conditions are illustrated in Figure 10. The experimental data demonstrate that optimal yields are achieved under mesophilic conditions, followed by thermophilic and psychrophilic conditions, confirming the anticipated outcomes.

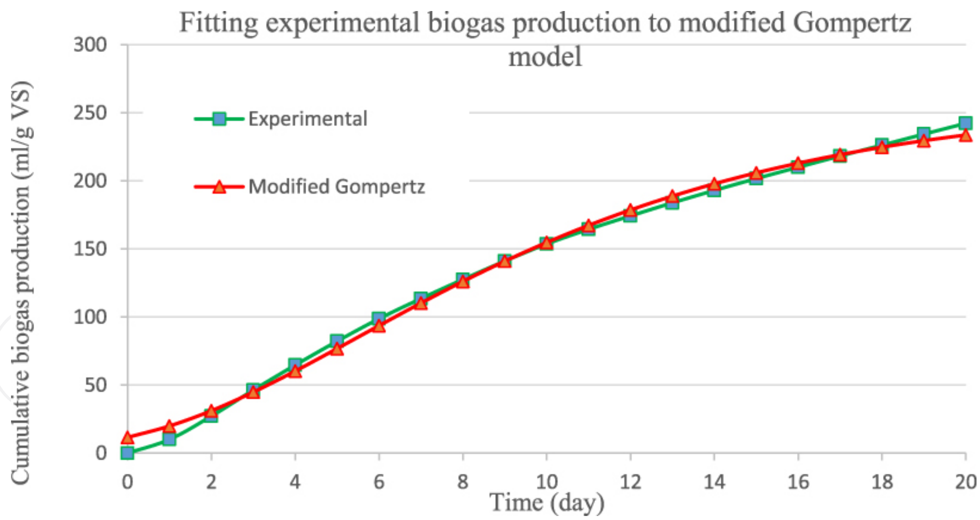

Figure 9. Fitting average experimental biogas production data to a modified Gompertz model for the entire range of trials 22 °C–52 °C.

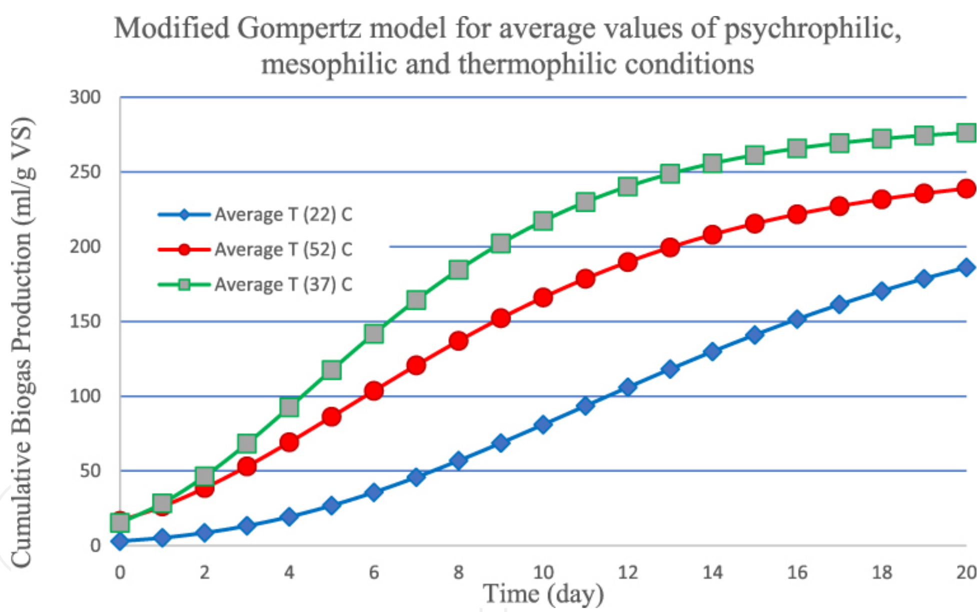

Figure 10. Results on modified Gompertz model for average values of psychrophilic (22 °C), mesophilic (37 °C), and thermophilic (52 °C) conditions.

The experimental data on biogas production is fitted to a modified Gompertz model for three different temperature conditions, as shown in Figures 11–13.

A strong correlation between thermophilic to psychrophilic conditions can be inferred from the data. Nevertheless, both mesophilic and thermophilic conditions

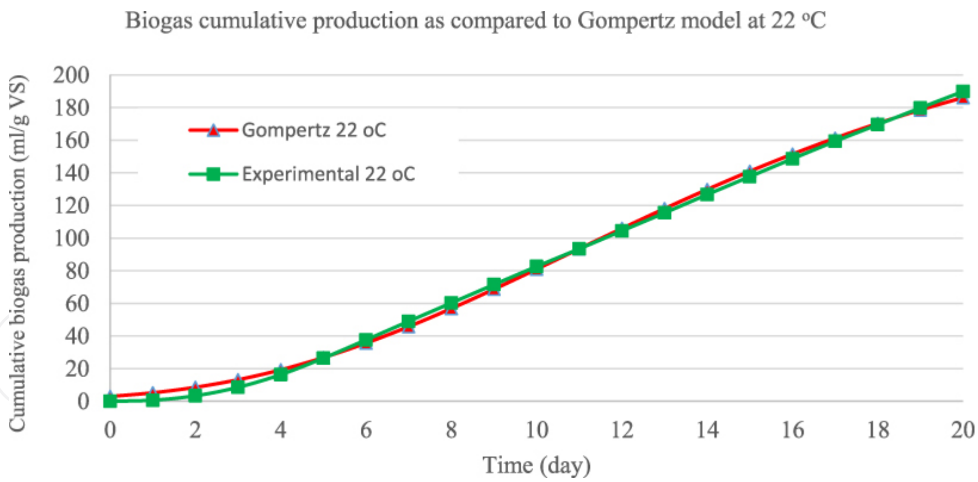

Figure 11. Biogas cumulative production as compared to modified Gompertz model at psychrophilic conditions (22 °C).

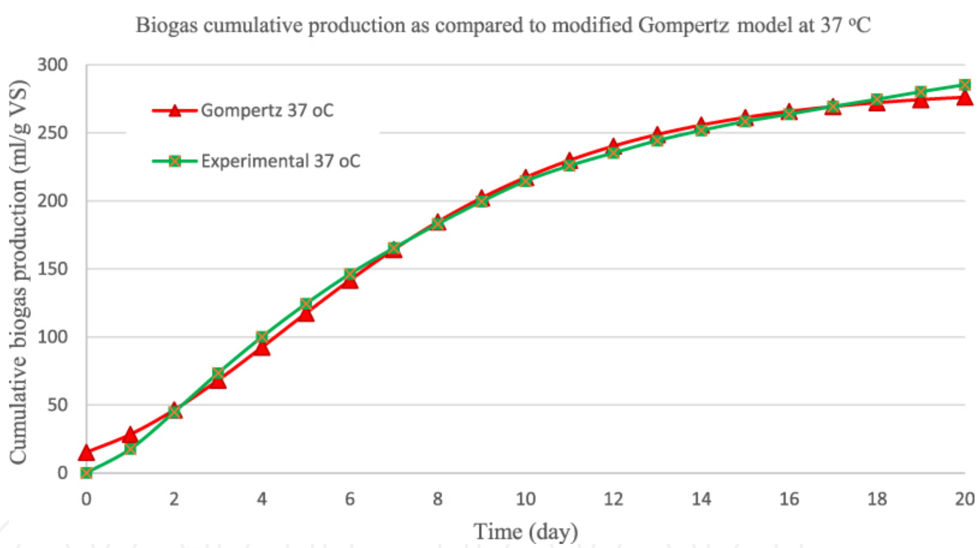

Figure 12. Biogas cumulative production as compared to modified Gompertz model at mesophilic conditions (37 °C).

display a lazy S-shaped curve for the 20-day retention time in all experiments, suggesting that this duration might serve as the retention period.

The psychrophilic conditions curve, however, does not display a comparable pattern, indicating that the duration of these conditions is longer than the 20-day interval. This behavior aligns with the results documented in previous studies [20–22].

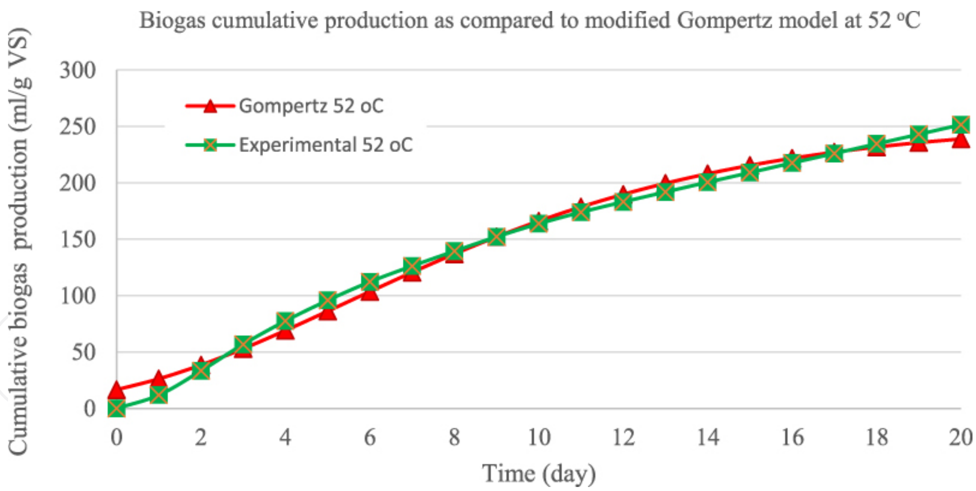

Figure 13. Biogas cumulative production as compared to modified Gompertz model at thermophilic conditions (52 °C).

3.4. The potential of poultry manure biogas as an energy source and an environmental pollution reduction strategy in Jordan

The biogas composition analysis results obtained by employing the Kjeldahl test are depicted in Table 4. The results presented here are obtained from samples that were collected following a retention period of 20 days. The data corresponds to the average values recorded at thermophilic, mesophilic, and psychrophilic temperatures.

Table 4. Biogas composition at different temperature conditions.

Component	**Conditions**		
	Psychrophilic 22 °C	**Thermophilic** 52 °C	**Mesophilic** 37 °C
CH_4 (%)	38.14	45.585	57.94
H_2S (%)	0	0	0
CO_2 (%)	0.02	0	0.015
O_2 (%)	12.6	12.75	7.85

The findings indicate that mesophilic conditions exhibit the highest concentration of biomethane, followed by thermophilic conditions, whilst psychrophilic conditions demonstrate the lowest levels. Nevertheless, due to the utilization of a 20-day retention time, the findings suggest that the duration of retention is extended when subjected to low temperature conditions, aligning with previously documented results based on around 90 days of retention time [20–22]. The mean CH4 concentration under mesophilic conditions is approximately 58%, with a concentration range of 56% to 64%, which indicates a reasonable biomethane concentration resulting from the anaerobic digestion process.

A previous study [3] stated that the estimated amount of dry manure in Jordan is 3.313×10^3 tons, with 25% of it originating from poultry. The calorific contents of the entire animal manure were estimated to range from 13.5 to 17.8 MJ/kg. Another study [2] reported a value of 6.5 kWh/m^3 or 23,400 kJ/m^3 of biogas at standard temperature and pressure (STP). The aforementioned analysis reveals that 24.541 L of biogas (STP) can be generated from 100 g of total solids. Based on the data provided, the annual biogas production from poultry manure is projected to be 203,275,836.4 m^3. This corresponds to an estimated annual power output of 1,321,292,937 kWh or an estimated annual energy of 4.75×10^{12} kJ. These estimates are equivalent to a daily power output of 150,832.527 kW and a daily energy output of 542.8 kJ.

The energy consumption of Jordan in 2019 [23], amounted to 16.82×10^9 kilowatt-hours. Besides, our study revealed that the annual electricity produced from poultry waste amounts to 1.32×10^9 kWh, or roughly 7.8% of the total energy usage. Renewable energy and other sources account for 13% of the overall energy supply, suggesting that poultry manure could be a viable choice for generating electricity. Projections suggest that by combining poultry dung energy generation with other types of manure, it is possible to contribute up to 20% of Jordan's energy grid.

The study findings demonstrate the viability of utilizing poultry manure for biogas production, which can subsequently contribute to the generation of electricity for the national grid. The aforementioned procedure can be scaled-up to accommodate both municipal waste and waste from scattered animal farms nationwide. Over half of Jordan's country, in the southern and eastern regions, residents engage in extensive animal farming, including the raising of sheep, cows, and camels. This results in the generation of a substantial amount of waste annually, alongside the presence of numerous large-scale poultry farms. Investing in these areas can yield significant benefits, as the pilot system mentioned above costed less than 400 JD and had satisfactory results. These outcomes can serve as a benchmark for scaling-up the process. The utilization of huge quantities of biomass for biogas energy production not only demonstrates its potential, but also contributes to the reduction of environmental pollutants. Furthermore, the utilization of bioreactor residue will be advantageous for the organic fertilizers industry.

For future development, the suggested system can be modified as depicted in Figure 14. The suggested bioreactor can be heated by utilizing solar energy through hot water and employs a cascade control system to regulate temperature (i.e.) the bioreactor will be thermally regulated by a water jacket supplied by a solar-powered

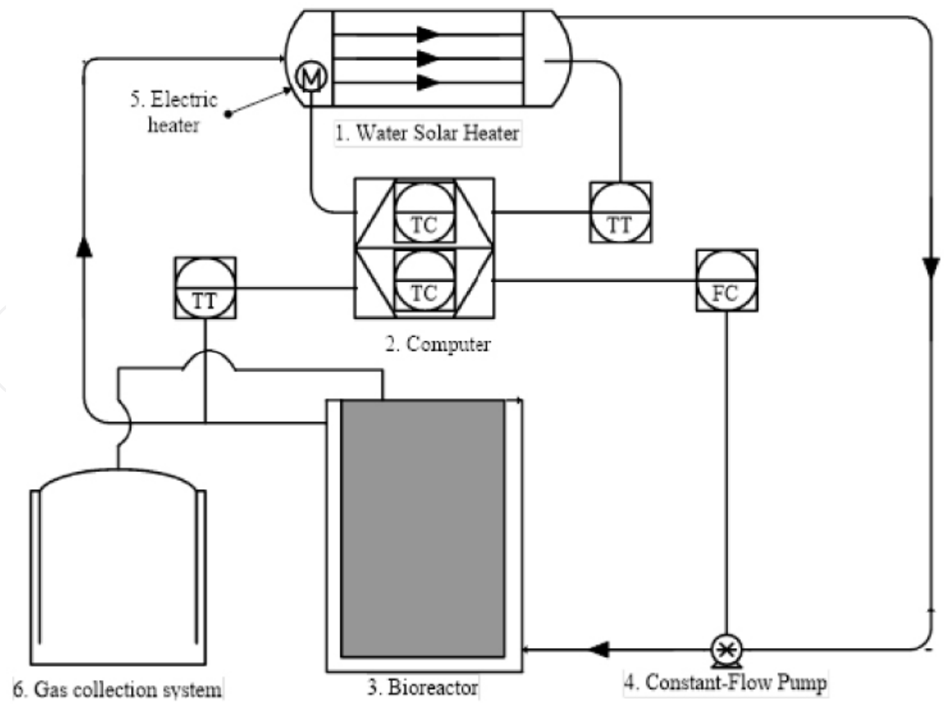

Figure 14. A schematic of the solar water heated bioreactor system as a projection for future work.

water heating system. Moreover, continuous monitoring of the temperature and pH of the bioreactor is possible. The biogas volume of each tested sample can be collected, tested for methane content, and reported in relation to the hydraulic retention time (HRT). The bioreactor can be equipped with a gas collection and storage system or linked to a power generation system. Residues may be transferred to a different process in order to generate organic fertilizers.

The proposed system has the potential to be easily scaled-up to accommodate chicken manure and various other forms of waste. The suggested temperature-controlled system enables the utilization of various renewable energy sources for heating purposes. The country can use solar and wind energy sources to utilize variations in weather conditions. The weather conditions in Jordan exhibit a significant duration of sunshine, leading to a yearly accumulation of 1400–2300 kWh/m^2. The average duration of sunshine is more than 300 days per year [24]. This suggests that utilizing solar energy as a heating source for a scaled-up biogas production process confirms the viability of producing biogas from biowastes, contributing to energy generation within the electrical grid in Jordan and subsequently reducing biowaste pollution.

Conflict of interest

The author declares no conflict of interest.

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