Renewable Energy 217 (2023) 119354

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Theoretical estimation of energy potential and environmental emissions mitigation for major livestock manure in Bangladesh☆

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ARTICLE INFO

Keywords:
Livestock manure
Chemical analysis
Mathematical modeling
Energy potential
CO_2 mitigation

ABSTRACT

This study investigates the potential energy resources from livestock manure to evaluate the country's energy potential from domestic animals (e.g., cows, chickens, sheep, and goats). A comparative analysis of four distinct energy routes, such as process I: anaerobic digestion and co-generation, process II: gasification and co-generation, process III: combustion and co-generation, and process IV: direct combustion to heat energy generation is exclusively examined. In addition to that, a simulation using a Biogas calculator was run to get a better idea of how the technical potential of the mathematical models stacks up. Results from this analysis reveal that the gasification process with heat recovery options (process II) has the greatest energy estimation (26,564.64 TJ) among the four energy-producing paths, whereas process IV (combustion) has the lowest energy potential (4419.75 TJ). The maximum electricity generation potential has been found for process II (1630.77 GW h/year), whereas the minimum from process I (27361.45 MW h/year). Moreover, CO_2 reduction potential results show that the maximum potential was obtained for process II (3,78,941.57 ton/year), whereas the minimum reduction potential (63,047.23 ton/year) was obtained from process IV, compared to coal combustion. The annual revenue obtained through process II is the maximum among different techniques, which is 141.87 million dollars.

1. Introduction

This century's scarcity of energy sources drives researchers to explore alternative power sources. Recent years have seen popular investigations in the scientific field of waste recovery and alternate energy sources. A lot of research discusses production from various organic wastes and plant types. Because the world is expected to run out of fossil fuels, renewable energies are becoming increasingly attractive [1–5]. Biogas is composed largely of 60% methane (CH_4), 35–40% carbon dioxide (CO_2), and a few other gases [6], which could be a good substitute for fossil fuels. The key goal of the biogas sector is to reduce the consumption of fossil fuels, with the ultimate goal of minimizing global warming. Several countries, including China, Germany, and Sweden, have focused on the development of bio-energy, while regional authorities in China and India have constructed biogas digesters [7]. The materials pouring into the tanks stimulate anaerobic gas output, while the substrate can be used as fertilizer [8,9]. Similarly, industrial waste as well as wastewater can be handled in biogas digesters\ using anaerobic digestion (AD). This cycle, in addition to producing biogas, helps reduce environmental dangers. Among all the raw materials used for biogas production, manure is the most famous. Manure is a livestock waste product with limited commercial value and is responsible for a variety of environmental consequences across a range of categories [10,11]. The AD process is the most effective method of mitigating manure's negative effects by generating energy from biogas and creating digestate as a bio-fertilizer [12–14]. Biogas is considered a potential replacement for natural gas derived from fossil fuels in the future [15]. Table 1 summarizes previous literature on different approaches for producing biogas from this livestock animal manure with the experiment overview and conclusions. Here, four different animal manures have experimented with four diverse energy generation methods. In recent years, the generation of biogas from organic waste has been increasing due to social, economic, and technological factors [16]. Bangladesh is an over-populated developing country, lacking the availability of energy in

☆ A full research paper submitted for publication in **"Renewable Energy"**.

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https://doi.org/10.1016/j.renene.2023.119354
Received 27 February 2023; Received in revised form 3 August 2023; Accepted 22 September 2023
Available online 28 September 2023

many distant locations. Rural electricity with solar PV technology is a growing trend. Due to the centralization of the industry of solar power systems, both solar power systems are supplying a significant quantity of electricity in rural areas of Bangladesh. Currently, there are a number of enterprises implementing solar energy and biogas program in Bangladesh. Grameen Shakti established a low-cost solar program for the rural poor in 1996 [17,18], and in 1997 [19,20], BRAC initiated a solar energy and small scale biogas program. In Bangladesh, the proven resource of natural gas is 34 TC F, which can serve the country for the next 20 years [21].

Currently, natural gas is utilized in the power sector for power production, accounting for 82% of total natural gas consumption, only 3% of renewable energy sources are responsible for total electricity production [21,35]. Bangladesh is a net importer of petroleum and crude oil [36]. Almost 56% of residential energy demand is supplied by gas [37]. Conversely, the country is suffering from an energy shortage due to its

Table 1
Results and aspects of earlier research for the production of biogas from manure.

Author	Study area	Raw Material	Experimental type	Techniques used	Methodology	Outcomes
Ilbas et al. [22]	Turkey	Animal manure	Experimental	Anaerobic digestion	A portable biogas digester with a 60 L capacity was used in the investigation, which ran for 40 days.	According to the experimental findings, 0.389 m^3/kg of manure was produced as biogas. The basic payback period is only 2.5 years, while the original investment cost was discovered to be $515.
Ammen et al. [23]	Japan	chicken manure, pig manure and cow dung	Experimental	Anaerobic co-digestion	In this investigation, a batch process was run for 90 days at a temperature of 55 °C in an incubator.	A three-stage anaerobic digester was found to have an average methane production of 0.442 m^3/kg.
Khan et al. [24]	Pakistan	cow dung and crop residue	Experimental	Anaerobic co-digestion	This experiment was carried out on a small scale in the biology lab of the University of the Punjab. 30 days of the trial were spent using a 100 L plastic barrel.	The results show that 1 kg of cow manure can generate between 15 and 30 L of biogas each day. It produced 20–60 L of biogas per day by adding wheat straw.
Jeung et al. [25]	Korea	livestock manure, slaughterhouse waste, and agricultural by-products	Experimental	Anaerobic co-digestion	The modified Gompertz model was used to validate the results of our experiment, and it was discovered that the results were nearly identical to those of the experiment.	The three feedstocks were mixed in a ratio that produced the greatest CH_4 production of 0.84 m^3/kg.
Xin et al. [26]	China	Cattle manure	Experimental	Gasification	For the disposal of produced biogas from cow manure, a two-step gasification method was developed. Then, at 750 °C and 850 °C, biochar produced at various pyrolysis-carbonization temperatures was gasified using steam.	The production of syngas was measured at 1.61 m^3/kg at a two-step gasification method.
Dong et al. [27]	China	Cattle manure	Experimental	Gasification	In this study, a large-scale plug flow reactor has been operated at a hydraulic retention time of 25 d under a temperature of 37–40 °C with a working volume of 3.85×10^4 m^3.	The specific biogas and methane yields of substrate was found 0.39 m^3/kg and 0.22 m^3/kg, respectively.
Rahman et al. [28]	Bangladesh	Cow dung, poultry litter and straw	Experimental	Anaerobic digestion	The effectiveness of Cow dung, poultry litter, and straw for biogas production has been studied.	The biogas yields of Cow dung, poultry litter and straw was found 0.034, 0.030 and 0.142 m^3/kg respectively.
Sahu et al. [29]	India	Catle and poultry manure	Experimental	Combustion	The different types of manure was collected and dried carefully and then burned in order to measure calorific value as well as emission characteristics.	Manures had a calorific value that ranged from 2580 to 11,200 kcal per kg, with a mean of 5333 1073 kcal per kg.
Pasolini et al. [30]	Brazil	Poultry manure	Experimental	Combustion	The poultry manure was dried in order to remove its moisture content and then combusted and the heating value was measured.	After drying, poultry manure's calorific value was determined to be 11 MJ/kg, demonstrating that it is a potential biomass for the production of thermal energy.
Abubakar and Ismail [31]	Malaysia	Cow Manure	Experimental	Anaerobic digestion	The effectiveness of cow manure for biogas production has been studied.	The cumulative biogas output and methane concentration were respectively observed by 0.15 m^3/kg and 47%.
Alvarez and Liden [32]	Sweden	Animal waste and domestic fuel	Experimental	Anaerobic co-digestion	Biogas is produced in farm-scale facilities under mesophilic conditions used for domestic fuel. In a mixture of cow-sheep dung fed to the system at low temperatures (291–298 K), the results imply that processing occurs.	This methane output of between 0.07 and 0.14 m^3/kg of gas with a methane concentration of between 47% and 55% has been attained in the mixing studies.
Obiukwu and Nwafor [33]	Nigeria	Animal waste	Experimental	Anaerobic co-digestion	Conducted a small-scale laboratory experiment to examine biogas production, an attractive source of energy using animal wastes, in the laboratory scale.	This system was found to create biogas holding a methane content of 65% at a temperature of 310 K 1 kg of animal waste could be biologically converted to 360 I of biogas in continuous and 1 kg of waste could produce 260 I of biogas in batch process.
Castrillion et al. [34]	Spain	Cattle dung and crude glycerin	Experimental	Anaerobic co-digestion	The study was used to improve biogas production from cattle dung by the addition of crude glycerin.	The CH_4 yield was obtained at 0.056 m^3/kg and a COD removal rate of 90%.

enormous population. However, installed generation capacity was 11, 387 MW as of July 2018, and additional shortfalls are caused by faulty distribution layout and fuel mix instability. Again, increasing numbers of countries are shifting to renewable energy systems as a result of global warming and climate change occurrences now-a-days. That's why biogas energy potential is a huge source of utilization for the country.

At this time of energy crisis, Bangladesh needs to utilize its available energy sources, which are regarded as waste. It is also looking to boost the contribution of renewable energy sources to the country's overall energy supply. Especially in the biogas sector, renewable energy utilization has increased in recent years in Bangladesh [38]. As a result, the production of biogas from waste is considered one of the most promising possibilities for meeting the growing worldwide demand for energy consumption. Biogas is the favored alternative renewable energy resource among the numerous forms since it is simple to generate and can be utilized directly in a variety of applications in internal combustion generators, micro-turbines, fuel cells, etc. In Bangladesh, rising energy demands, a lack of natural resources, and a lack of renewable energy alternatives have motivated a strong concern for biogas technology. Among the various sources of producing biogas, livestock manure is one of the finest alternatives. Bangladesh is an agricultural country, and most of its population lives in rural areas, therefore, it has the opportunity to utilize livestock animals to mitigate its energy demand. The high number of cows, chickens, sheep's, goats in the country might be exploited as the primary supply of organic raw materials for biogas generation, as could be seen in other countries. Generally speaking, the amount of animal waste that has been collected from farms is mostly dependent on a variety of criteria, like animal type and size, animal age, food and feeding practices, breeding type, etc.

There are numerous use pathways, including anaerobic digestion (AD), combustion, and gasification, for both raw and improved forms of biogas, and each has its own advantages. According to the findings, the amount of feedstock collected per animal per day for AD may vary mostly depending on their type and age, feeding habits, etc. The data on cattle and poultry came from field experience reported by Grameen Shakti, a large-scale practitioner in Bangladesh.

Sufficient study and energy generation route modeling are not good enough in the previous literature, especially for Bangladesh. We have introduced in this manuscript four mathematical models of energy generation routes as well as simulation results to calculate the approximate biogas energy potential in the country. In this study, the potential of biogas in Bangladesh is estimated based on the availability of four animals (cows, chickens, sheep, and goats), which are the most abundant in the country. Several significant parameters, such as availability, LHV, HHV, volatile matter in manure, and machine efficiency, have been taken into consideration in the development of four mathematical models. In addition, a simulation has been carried out to compare the results from the modeling part of the study. Finally, electricity generation potential as well as CO_2 reduction potential have been determined for various pathways. The information revealed a pattern in likely energy results, which is crucial for researchers, practitioners, and investor's alike.2. Current Energy Scenario in Bangladesh.

Bangladesh is served by a variety of energy sources, like fossil fuels, solar power, hydroelectricity, wind power, geothermal energy, and biofuels. Traditional, commercial, and alternative sources can be classified into three distinct types of renewable energy. The share of traditional energy for heating and cooking in rural areas is over 90% of the total energy, which is 35% of the entire energy of the country [39]. Besides, over 97% and around 3% of the total electricity utilized in Bangladesh are derived from the fossil fuel-based energy and renewable energy, respectively [40]. The rising utilization of renewable energy in Bangladesh has recently occurred. It is especially true in rural regions, where biogas, as well as solar power generation technology are making big inroads. The vast majority of commercial electricity in Bangladesh is derived from natural gas, which accounts for 45.65% of the overall power output in Bangladesh [40]. Table 2 shows Biomass and Biogas energy target of the Bangladesh government along with their prospect and barrier. Power is generated by diesel, furnace, coal, and hydro, with the percentage contribution for each energy source being 4.05%, 26.06%, 10.81%, and 0.92%, respectively [40]. In comparison to other energy sources, most power sources depend on fossil fuels.

The energy requirements are swelling today due to population growth, technological advancement, and economic reasons [43]. Available renewable energy sources will not be able to fulfill our future energy demand, as discovered energy will diminish within a few decades. In our daily lives, energy has been conveyed as a critical component. Bangladesh has secured a good economic growth rate of 8.2% in FY20 [44]. The real GDP of Bangladesh stood 11,637.4 billion, which is the highest in the South Asian region [44]. This was possible due to the growth in the industrial sector. A country with such hasty growth will need access to energy resources. But in comparison with world energy, the situation of Bangladesh's primary energy resource is not good at all. And an increasing population will have a big demand for energy in the future.

According to Table 2, these renewable energy sources have a promising outlook due to support from both the government and private sectors. The government has taken steps to invest in biomass and biogas along with solar, hydropower, nuclear etc. However, these alternative energy sources face certain barriers, particularly related to environmental concerns. Assuming one of them refers to a different energy

Table 2
Biomass and Biogas energy target of Bangladesh government along with their prospect and barrier [21,41,42].

Year	Year wise Bangladesh government target (MW)		Investor in Biomass & Biogas	Prospect of Biomass & Biogas	Barrier of Biomass & Biogas	Total electricity production in the year 2022 (MW)		Share in Renewable energy in 2022 (%)	
	Biomass	Biogas				Biomass	Biogas	Biomass	Biogas
Until 2018	0	1.08	Government and private	Bright	Carbon emission	0.4	0.69	5	8
2019	0	1							
2020	0	2							
2021	15	3							
2022	15	4							
2023	15	4							
2024	15	4							
2025	15	4							
2026	15	4							
2027	15	4							
2028	15	4							
2029	15	5							
2030	15	5							
Total	**150**	**45.08**							

source, we can understand that biomass and biogas energy sources has a positive future outlook due to government and private sector initiatives. The same can be said for other renewable energy sources as well. Although, the government has invested in other energy sources such as biomass and biogas energy sources, there are obstacles associated with these sources, particularly in terms of environmental concerns. It implies that these energy options may face challenges in terms of their impact on the environment, which need to be addressed for their successful implementation.

Bangladesh has a significant opportunity to make use of the bright future prospects offered by renewable energy sources. By harnessing these energy potentials, the country can address its future energy demands effectively. By adopting and investing in these renewable energy sources, Bangladesh can reduce its reliance on conventional, non-renewable energy sources and contribute to mitigating the global energy demand while promoting a sustainable and environmentally friendly energy sector.

The research and development (R&D) activities related to biomass energy in Bangladesh are presented in Table 3. Numerous groups have participated in these activities, and their work is highlighted. In recent years, both government and non-government organizations in Bangladesh have actively participated in promoting biomass energy. These organizations have recognized the potential of biomass as a renewable energy source and have taken steps to advance its development and utilization.

The statement emphasizes that Table 3 provides a summary of the research and development activities conducted by various entities, including both governmental and private organizations. The table likely includes information on the specific initiatives, projects, and advancements made by these entities in the field of biomass energy. By undertaking such research and development efforts, these organizations aim to enhance the understanding, efficiency, and viability of biomass as an energy source in Bangladesh. These activities can include studies on biomass conversion technologies, biomass resource assessment, improving biomass supply chains, exploring new biomass feedstocks, optimizing biomass energy production processes, and assessing the economic and environmental impacts of biomass energy systems.

Overall, the table highlights the active involvement of governmental and non-governmental entities in advancing biomass energy in Bangladesh and provides a comprehensive overview of their research and development activities in this domain.

1.1. Biogas production scenario upto-2040 in Bangladesh

The Bangladesh government has prepared a power system master plan (PSMP-2016) in order to satisfy electricity demand with an installed capacity that would be extended to 21,000 MW by 2021 and 31,000 MW by 2030 [47]. The share of renewable generation capacity is projected to reach 5% by 2015, 10% by 2021, and ultimately 100% by 2050. To achieve this target, the government has implemented various strategies for investment in both the public and private sectors, as mentioned in Table 6. As part of these efforts, the Government of Bangladesh (GoB) has successfully generated 649.95 MW of renewable energy in accordance with the established plan (2023) [47]. The overall objective is to provide funding for 100,000 biogas plants, of which 37,700 have already been built, by the end of March 2015 as part of the initiative [48]. There are three possible scenarios that might occur by the year 2040 with regard to biogas production, as seen in Fig. 1 [48]. A number of solutions were considered and analyzed when deciding on the most cost-effective and efficient production line. Three separate scenario situations, each with a different set of suggestions, were evaluated for comparing the biogas production rate with the number of livestock animals being used. In business-*as*-usual cases, various problems have been found, like inefficient digesters, poor as well as uncontrolled operating parameters, etc. The first scenario (as usual) is based on the current situation in rural Bangladesh, which includes an inefficient digester of dome type having poor maintenance as well as unregulated operating settings. During low-ambitious cases, various factors should be considered, like digester type, appropriate feedstock delivery and mixing with water, operating parameters, etc. That's why it is higher than a low-ambitious case but lower than high-ambitious case. On the other hand, multi-feedstock digesters (plug flow, mesophilic condition, co-digestion of agricultural leftovers and animal wastes, high TS value), with regulated operational parameters and proper maintenance, are required for advanced, i.e., high-ambitious cases. The available feedstock and manures should be utilized appropriately and in a suitable manner for these cases. Moreover, manure collection should be more sensitive in order to improve the overall quantity of the product. Thus, having all of these advantages, the higher value of biogas is obtainable in those cases.

1.2. Environmental and technical evaluation of proposed energy routes from biomass

The use of techniques for unlocking manure's technological potential in some energy conversion routes needs a more thorough analysis of the technical and environmental ramifications of its use. In that research work, four conversion pathways were chosen for calculating technical energy generation potential. These are anaerobic digestion and co-generation, gasification and co-generation, combustion and co-generation, and combustion alone.

There are various laboratory-sized studies that have discovered that the AD (**process I**) of manure is feasible during dilution to less than 6% total solid concentration [49]. Still, issues including low pH, ammonia toxicity, and bacterial adaptation to high ammonium levels must be addressed with proper steps. Although anaerobic nutrient disposal is not technically feasible and does not eliminate manure nutrients [50]. Several problems arose during the digestion process, and hence the thermal gasification approach appears to be better. Therefore, the AD process is unlikely to be an economically feasible solution due to hydrogen sulfide (H_2S) in biogas. In order to properly de-sulfurize biogas, sulfur must be decontaminated before thermal processing [51]. In the case of gasification and co-generation (**process II**), animal manure is thermochemically converted to syngas through gasification, which offers syngas with lower calorific values than biogas. But gasification delivers energy outputs that are many times higher than

Table 3
R&D activities regarding renewable energy of various organizations [45].

Technology	Related organizations	Activities
Improved cooking stoves	BCSIR, BRAC, RSF, VERC, GIZ, UNDF etc.	BCSIR develops three fundamental types of stoves (without chimney, with chimney, and with waste heat utilization). VERC, on the other hand, disseminates seven ICS models.
Briquetting machine	KUET, BRRI	KUET has created improved machines with extended screw life under the 'RETs in Asia' program.
Biogas plant	IFRD of BCSIR, LGED, GS, BAU, BRAC, IDCOL, RSF	Fixed-dome type plants are planned, built, and distributed in Bangladesh providing government subsidies of 46.09 USD, with IDCOL donating 82.96 USD for each plant.
Pyrolysis technology	RUET, Radiant Renewable Energy Ltd	Since 2000, research and development for pyrolysis to provide alternative liquid fuel has been performed in RUET. Moreover, Radiant Renewable Energy Ltd. Has begun operations for producing liquid fuel from scrap tire.

1 USD = 108.48 BDT, as on July 3, 2023 [46].

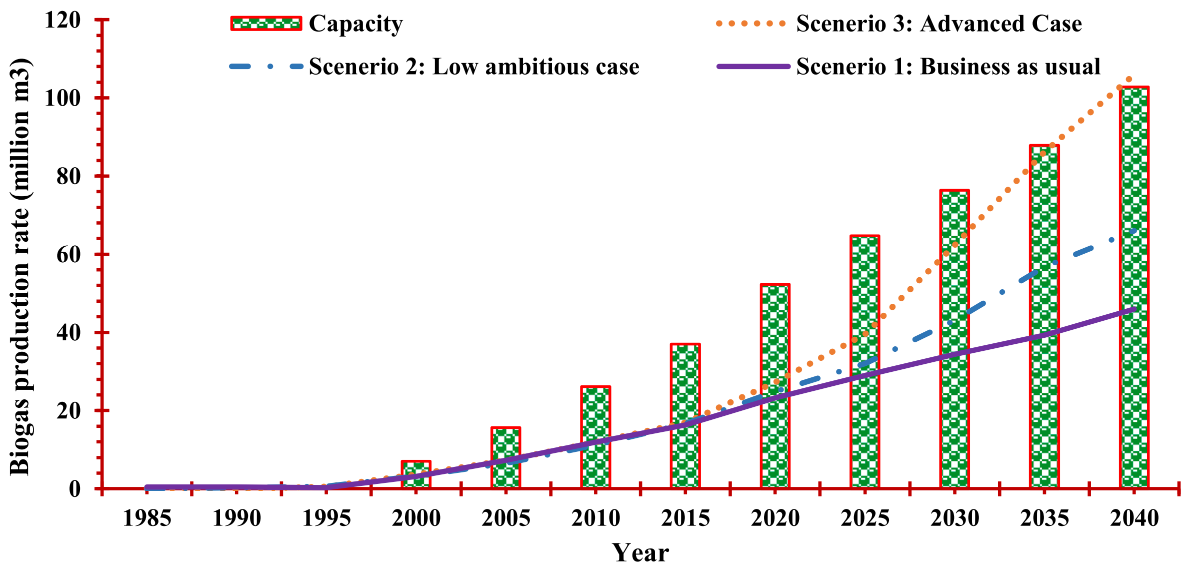

Fig. 1. Biogas production rate till 2040 in million m^3 for three cases in Bangladesh.

digestion. Reactor configuration and operational factors, like temperature and air equivalence ratio, are the key contributors to syngas and residue quality [52]. Chicken manure gasification is used for fixed and fluidized bed reactors. Updraft fixed bed systems are effective at minimizing excessive moisture and ash content [53].

Despite these advantages, there are significant downsides to using this method, which must be taken into consideration before implementation. When syngas is considered for gas turbines and IC engines as a fuel, it must be reformed since it causes undesirable by-products like tar, dust, alkalis, heavy metals, H_2S, HCl, etc. Most manure gasification problems are related to the ash's alkaline composition, which causes it to coagulate in the bed [54]. Decreasing the reactor temperature below the melting point of ash causes excessive char to be generated.

Moreover, a considerable amount of moisture and ash are present in manure; therefore, the combustion pathway (**process III**) might lead to operational issues and lower overall efficiency. As a result, it is required to dry raw manure before further thermal processing, such as burning or gasification. Moisture content can be removed by the use of evaporative dryers [55], incorporated into the ventilation and manure transport systems on the poultry farm, or added to the combustion system. Using the livestock facility's exhaust air for drying greatly reduces the drying costs [56]. Another issue to consider is the creation of NOx, which is the primary air pollutant. To offset these unfavourable trends, extensive research is being conducted [5].

Fluidized bed combustion (FBC) types of combustion can help alleviate this problem [57]. One of the most essential ways to reduce The

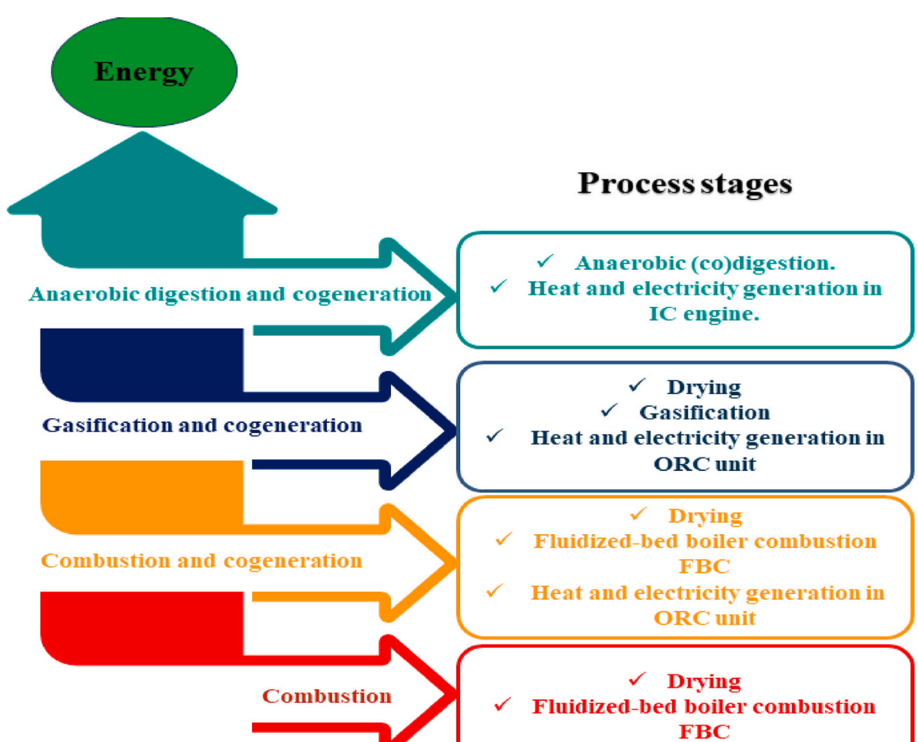

Fig. 2. Description of energy generation processes.

NOx levels can be reduced by lowering the combustion temperature (using excess air). Furthermore, the concentration of high sulfur and volatile matter in the manure provides an air-fuel mixture in the boiler, which indicates high efficiency and low pollutant emissions. The fuel composition necessitates the use of primary reduction technologies as well as extensive gas cleaning systems, like selective catalytic reduction (SCR) for denitrification and sorption for acid gas removal (SO_2, HCl, etc.). These approaches are frequently used in large combustion and cogeneration facilities [53]. Any optimal manure combustion technique is a viable alternative to coal-fired co-generation in Bangladesh, particularly on farms where heat is generated through the use of fossil fuels and can be used to generate heat and energy. When compared to coal burning, it can greatly lower the amount of flue gas components released into the environment [56]. Fig. 2 represents the four energy conversion paths by which energy potential is analyzed. In an anaerobic cogeneration process, the potential is measured by an IC engine. That's why the thermal and electrical efficiency of an IC engine are needed in this process. Electricity and heat generation in the organic ranking cycle (ORC) are needed for measuring combustion and cogeneration. The Organic Rankine Cycle (ORC) is a thermodynamic process that involves the conversion of thermal energy into mechanical work. It is commonly used in power generation systems that utilize low-temperature heat sources, such as waste heat from industrial processes or geothermal energy. In an ORC, a working fluid with a low boiling point is vaporized using the heat source, and the resulting high-pressure vapor is expanded through a turbine to generate electricity. Fluidized bed combustion is a combustion technique that involves suspending solid particles (typically a mixture of fuel and inert materials) in an upward-flowing stream of air or combustion gases. This method offers advantages such as efficient combustion, reduced emissions, and the ability to handle a variety of fuels. Yet again, in the combustion process, a fluidized bed boiler is used for combustion.

2. Materials and methods

Bangladesh is a country in which more than half of the population is based on agriculture and livestock farming. Livestock animals are specially kept on farms for economic benefits. In Bangladesh, these are generally chickens, cows, goats, sheep's, etc. These livestock animals are an important part of the country's wealth. These animals provide us with milk, meat, and manure from which a large amount of biogas could be produced, which can mitigate the future energy demand. The amount of livestock animal statistics is presented in Table 4. It has been found that for the year 2014–15, the chicken and cow was 261.770 and 23.636 million, respectively. However, in the years 2020–21, the number of chickens and cows will have increased by approximately 16% and 4%, respectively. Therefore, these increased numbers of livestock are responsible for generating a huge amount of manure waste. The more or less same increasing trend can be seen for goats and sheep. The total quantitative potential of this animal manure can be determined from the sum of the potential manure produced by all the animals. Table 5 illustrates the data on daily manure generation from major livestock animals in Bangladesh. The amount of these animal manures indicates the availability of biogas energy potential. It can be seen that; cows produce on average 29.5 kg of manure daily. In terms of droppings (kg/day/animal), the chickens are divided into layer and boiler categories. Layer chickens produce 136 g of droppings per day, whereas boilers produce 40 g of droppings. Moreover, 70 g of average droppings per chicken per day were used for calculation due to a lack of precise data. The calculations have been adopted by taking the mean values of the manure produced by these animals. Generally, it depends on the feeding systems of these animals, which vary from region to region. Therefore, a mean value is taken for general calculation. The proximate and ultimate analysis of these four animal manures mean values is collected from several papers and internet sources, which will be useful to find the biomass potential in Bangladesh. The annual manure production in different years is calculated from the average droppings in a day of these animals from Table 5 is multiplied by the total livestock animals available (Table 4) in Bangladesh. Afterwards, it is multiplied by 365 to find the net annual droppings of each animal presented in the results and discussion section.

Table 5
Daily manure generation from different animal manure taken from calculation.

Name of species		Animal manure (kg/day/animal)	Animal manure taken for calculation (kg/day/animal)
Chicken	Layer [59]	0.136 kg at 75% moisture	0.070
	Boiler [59]	0.040 kg at 25% moisture	
Cow [5,60]		29.5	29.5
Goat [61,62]		0.38	0.38
Sheep [11,63]		1.81	1.81

With the increase in livestock, the amount of animal manure has increased concurrently. Disposing of these huge amounts of animal manure causes difficulties like air pollution. Moreover, it is necessary to find a cost-effective solution through which our environment will remain harmless and manure can be converted into sustainable energy. The maximum contributions in total biogas come from animal manure, which accounts for 36% of total biogas [68]. This percentage can be increased by utilizing the manure through a good disposal chain. Fig. 3 shows the flowchart of the animal manure waste disposal chain in Bangladesh.

This process started with collecting the animal droppings. Dropping depends on the animal. In the case of some animals, some droppings were collected on a daily basis, and some were collected on a weekly basis. Like normal, the droppings of layer birds are cleaned daily, and some traditional chicken manures are collected on a weekly basis. Proper disposal of these droppings is a big challenge for the environment. Some little amount was disposed of along the roadside and drain side. The majority of the farmers disposed of the fresh manure in the fishpond directly, where some farmers used the manure on agricultural farms. But raw manure is not suitable for fishpond as they contain many toxic elements. Some farmers disposed of the droppings in a pit near the farm. A very small percentage of these droppings are used for biogas plant composting and fuel cooking. But if these manures can be utilized properly, they can be a big source of energy production.

2.1. *Ultimate, proximate and heating value analyses of different types of manure in Bangladesh*

Ultimate analysis delivers into a method for reporting the major organic element composition of manure samples, where proximate analysis reports volatile matter, moisture content, fixed carbon, etc. Due

Table 4
Amount of livestock animal's in Bangladesh (in million number) [58].

Name of species	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20	2020–21
Chicken	261.77	268.39	275.18	282.15	289.28	296.60	304.11
Cow	23.64	23.79	23.94	24.09	24.24	24.39	24.55
Goat	25.60	25.77	25.93	26.10	26.27	26.44	26.61
Sheep	3.27	3.34	3.41	3.45	3.54	3.61	3.68

Table 6
Proximate and ultimate analysis of major livestock animal manure in Bangladesh.

Manure types	Proximate analysis (wt. %)			Ultimate analysis (wt. %)							Ref.
	M	VM	FC	C	H	O	N	S	LHV (kJ/kg)	HHV(kJ/kg)	
Chicken manure	74.53	-	-	36.2	4.6	–	5.9	0.11	2664	13,084	[64]
Cow manure	75.56 ± 3.07	80.42 ± 2.85	19.58 ± 2.85	37.64 ± 1.87	5.06 ± 0.25	28.64 ± 2.36	1.87 ± 0.40	0.18 ± 0.05	10,950 ± 0.44	16,090 ± 0.44	[65]
Goat manure	8.7 ± 0.08	69.5 ± 0.44	4.5	17.3 ± 0.20	40.09 ± 0.04	5.85 ± 0.05	24.16 ± 0.06	1.95 ± 0.04	ND	12,980 ± 0.14	[66]
Sheep manure	47.80	34.03	7.26	10.91	21.19	2.66	16.03	1.10	6610	8360	[67]

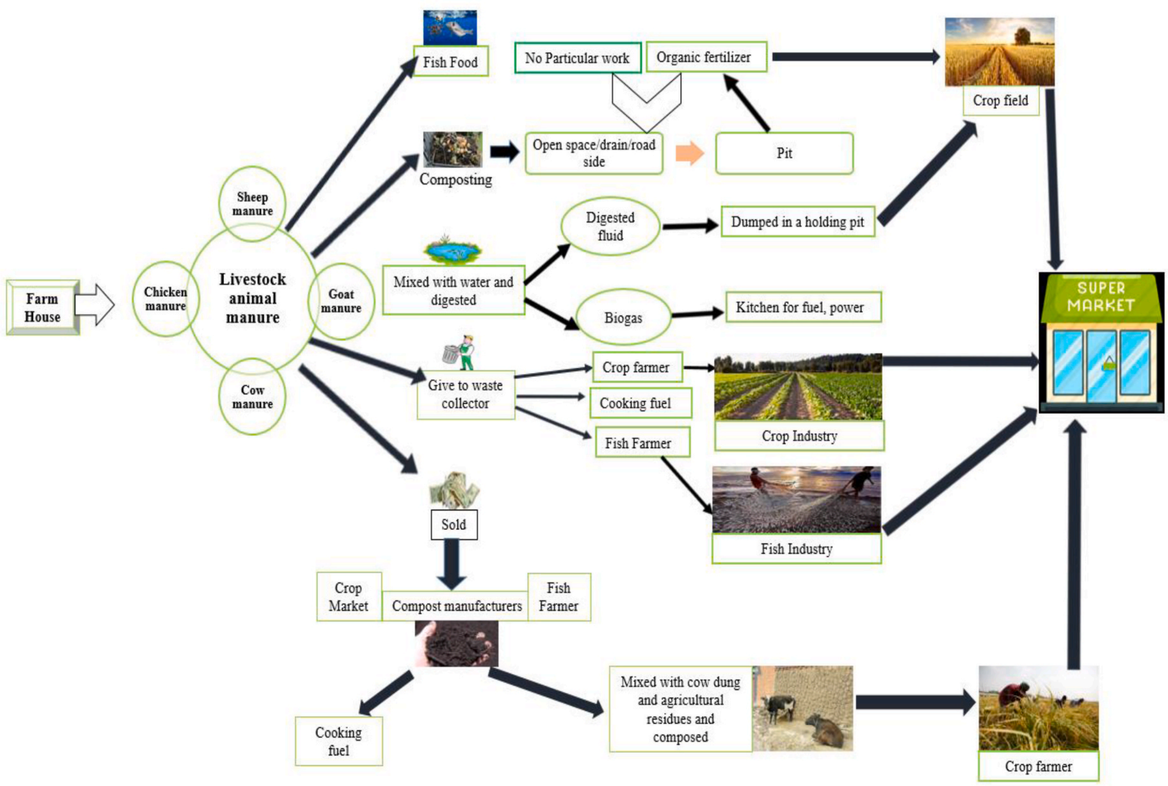

Fig. 3. Flowchart of animal manure waste disposal chain in Bangladesh.

to a lack of available data and technology, it is not possible to experiment in each region of Bangladesh with animals (chicken, cow, sheep, and goat) manure for testing to determine ultimate and proximate analysis. That's why the mean value of each animal is considered for calculation. The concentration of carbon, nitrogen, sulfur, and hydrogen is determined in the ultimate analysis. It can be seen from Table 6 that the carbon percentage is greater in cow manure, which is 37.64 ± 1.87, whereas in chicken, it is 36.2% by average. The lowest carbon percentage is seen in sheep manure (10.91%) among the enlisted animal manures. In terms of hydrogen percentage, the lowest percentage of hydrogen is in chicken manure and the highest is in goat manure which is 40.09 ± 0.04. The total organic matter (VS) is the sum of these organic matter found in ultimate analysis. The highest amount of VS is found in goat manure, which is almost 89.39% and the lowest is found in chicken manure, which is 46.81%. The total organic matter in sheep manure is 52.2 on average, while it is 73.39 in cow manure.

2.2. Energy generation potential

The energy potential of animal manure depends upon its characteristics such as weight, chemical composition, volatile matter, etc. The energy generation potential can be classified into theoretical potential, technical potential, economic potential, and applicable potential.

In the theoretical potential process, availability of equipment and efficiency are considered 100%, as are losses in the process. The total potential using this full efficiency without any losses is calculated. Moreover, technical potential can be practically utilized as technical restrictions like available equipment efficiency, internal losses, geographical location, transmission losses, etc. Are accounted for in the calculation. The availability factor is taken as 0.7 in all cases of calculation for this. The efficacy with which chemical energy in raw manure (representing energy potential) is converted to a useable type of energy is dependent on the specific transition path. It can be accounted for the criteria of economic tools after detailed analysis of economic tools with profitability, market fuel prices, tax rates, etc. Again, the ultimate and applicable energy potential could be used in energy production after minimizing all the losses. The ultimate and proximate analysis values of the collected animal manure (From Table 6) are applied in the procedure for finding the energy potential of this animal manure in Bangladesh. It is possible to find the approximate values of energy potential in Bangladesh, as most of the animals here are cows, goats, sheep's, chickens etc. The further calculations are limited to three parts: such as

Table 7
Input data for calculating technical level energy potential.

Parameters	Unit	Value			
		Chicken	Cow	Goat	Sheep
Process I					
VS	% by weight	48.099	73.39	89.05	41.29
b	m^3/ mg of VS	300	270	150	250
LHV	MJ/m^3	11.18	10.95	13.06	6.61
η_{el}	%	20	20	20	20
η_{th}	%	15	15	15	15
Process II					
M_{tw}	% by weight	74.53	75.56	8.7	47.80
$M_{tw,ad}$	% by weight	15.0	14.0	5.3	12.0
q	kWh/kg of evaporated water	0.80	0.80	0.80	0.80
e	kWh/kg of evaporated water	0.06	0.06	0.06	0.06
s	m^3/kg of dried mass input	2.5	2.5	2.5	2.5
LHV	MJ/m^3	11.18	10.95	13.06	6.61
η_{el}	%	20	20	20	20
η_{th}	%	15	15	15	15
Process III					
M_{tw}	% by weight	74.53	75.56	8.7	47.80
$M_{tw,ad}$	% by weight	15.0	14.0	5.3	12.0
q	kWh/kg of evaporated water	0.80	0.80	0.80	0.80
e	kWh/kg of evaporated water	0.06	0.06	0.06	0.06
LHV	MJ/m^3	11.18	10.95	13.06	6.61
η_{el}	%	20	20	20	20
η_{th}	%	15	15	15	15
Process IV					
M_{tw}	% by weight	74.53	75.56	8.7	47.80
$M_{tw,ad}$	% by weight	15.0	14.0	5.3	12.0
q	kWh/kg of evaporated water	0.80	0.80	0.80	0.80
e	kWh/kg of evaporated water	0.06	0.06	0.06	0.06
LHV	MJ/m^3	11.18	10.95	13.06	6.61
η_{th}	%	15	15	15	15

theoretical level energy potential, technical level energy potential, and simulation result.

The theoretical potential is calculated by using Equation (1) for four different potential animal manures. The overall theoretical potential can be found by summing the four potentials listed (Equation (2)).

$$E_{th} = B_i \times LHV_{ar} \tag{1}$$

$$E_{th} = \sum_{n=i} (E_{th,i})$$

$$\text{or, } E_{th} = E_{th,chicken} + E_{th,cow} + E_{th,goat} + E_{th,sheep} \tag{2}$$

The mathematical model has been developed, and technical-level energy potential is calculated using Equations (3)–(8) for four different pathways. These are anaerobic digestion and cogeneration (process I), gasification and cogeneration (process II), combustion and cogeneration (process III), and combustion alone (process IV). The explanation of the symbols is presented in the nomenclature table.

Process I: For anaerobic digestion and cogeneration processes, the energy potential is calculated for all four animals by following Equation (3).

$$E_{Technical}^{Process\ 1} = \left(B_{a,n} \times (VS)_n \times a_f \times b_n \times LHV_n \times \eta_{th,IC}\right) + \left((B_a)n \times (VS)_n \times a_f \times b_n \times LHV_n \times \eta_{el,IC}\right) - E_{d,n} \tag{3}$$

Process II: The second process gasification and cogeneration by ORC technology, energy potential is designed by Equation (4).

$$E_{Technical}^{Process\ 2} = \left(B_{dried,n} \times (s)_n \times LHV_n \times \eta_{th,ORC}\right) + \left(B_{dried,n} \times (s)_n \times LHV_n \times \eta_{el,ORC}\right) - E_{d,n} \tag{4}$$

Process III: The technical potential by combustion and cogeneration is done by ORC energy generation with fluidized bed boiler which is calculated by Equation (5).

$$E_{Technical}^{Process\ 3} = \left(B_{dried,n} \times LHV_n \times \eta_{th,ORC}\right) + \left(B_{dried,n} \times LHV_n \times \eta_{el,ORC}\right) - E_{d,n} \tag{5}$$

Process IV: The fourth process is designed by the analysis of direct heat production in boiler which can be estimated by Equation (6).

$$E_{Technical}^{Process\ 4} = \left(B_{dried,n} \times LHV_n \times \eta_{th}\right) - E_{d,n} \tag{6}$$

In the case of processes I, II and III, the animal manures required drying before further processing. The amount of energy E_d used calculation depends on the manure. Again, it depends on electricity demand and specific heat for the drying process.

$$E_{d,n} = \left(B_{w,n} \times q\right) + \left(B_{w,n} \times q\right) \tag{7}$$

The specific heat and electricity demand for drying evaporated water are represented by q and e, respectively. The amount of water evaporated, available raw manure, moisture content before drying, and moisture content after drying are represented by B_w, B_a, M_{tw} and $M_{tw,ad}$, respectively. The amount of water evaporated was calculated according to Equation (8).

$$B_{w,n} = \left(M_{tw} \times B_{a,n} \times a_f\right) - \left(M_{tw,ad} \times B_{dried,n} \times a_f\right) \tag{8}$$

When the material had fully dried, the total volume of B was measured using the mass balance of the procedure. The input data for technical energy generation calculations are tabulated in Table 7. These data came from Tables 5 and 6, using the mean values of the proximate and ultimate analyses of manure available in South Asia. As Bangladesh is in the South Asian region, these mean values are taken into consideration for calculation. As the values change from region to region, mean values are taken for general calculations, including the availability factor. A simulation (by a biogas calculator [69]) has been conducted to determine the amount of energy that can be extracted from these manure.

2.3. Electricity generation potential and plant capacity of various processes

Methane, as well as electricity generation potential, are two important parameters for investigating the effectiveness of any process. The electricity generation (kWh/y) as well as the size of the specific plant (kW) for four energy generation processes (process I-IV) were determined using Eqs. (9) and (10) [70].

$$E_{el} = \frac{E_{th} \times GEN_{eff} \times CAP_{fact}}{3.6} \tag{9}$$

$$E_{el,plant} = \frac{E_{el}}{D_{hour} \times N} \tag{10}$$

where, E_{th} is the technical energy generation potential, GEN_{eff} is the generation efficiency of the biogas generator and taken as 26% [71], CAP_{fact} is the capacity factor of the plant and considered as 85% [72], and 3.6 is used for conversion from MJ to kWh. Besides, the plant size for various processes was determined in kW, assuming that the projects operate throughout the year. Here, D_{hour} is the number of hours in a day (24 h), and N is the operating days in a year (365 d). The price of electricity sold is considered to be 0.087 $/kWh [73], and annual revenue was also calculated for the year 2020–21 in Bangladesh.

2.4. Greenhouse gas (GHG) emission reduction potential for various processes

The amount of biogas as well as electricity generation from various processes could reduce carbon dioxide (CO_2) emissions by replacing fossil fuels such as coal. Biogas consists of 65% CH_4, 25% CO_2, and 10% other gases; therefore, CO_2 from biogas combustion is mainly from CH_4 and its CO_2 component. Moreover, methane combustion with oxygen can produce an equal volume of CO_2. Therefore, the CO_2 emissions from biogas combustion are the sum of the methane volumes and CO_2 in the biogas. As we know, 16 g of methane produces 44 g of CO_2, i.e., the complete combustion of 1 kg of methane generates 2.75 kg of CO_2. The CO_2 emissions reduction is calculated by subtracting CO_2 emissions from biogas combustion from CO_2 emissions from standard coal combustion. The CO_2 emission from biogas combustion from gasification and anaerobic digestion processes was calculated using **Equation (11)** [74] Moreover, the CO_2 emissions from combustion as well as the combustion and co-generation processes were calculated using **Equations 12 and 13** [75].

$$M_{CO_2,biogas} = CH_{4(act)} \times \left[\left(x\,\%\,CH_4 \times \rho_{CH_4} \times 2.75 \right) + \left(\rho_{CO_2} \times (1 - x\,\%\,CH_4) \right) \right] \tag{11}$$

$$M_{CO_2,comb} = EL_{comb} \times EF_{el} \tag{12}$$

$$M_{CO_2,cogn} = \left(EL_{cogn} \times EF_{el} \right) + \left(TH_{cogn} \times EF_{th} \right) \tag{13}$$

Where, $M_{CO_2,biogas}$ is the CO_2 emission from the combustion of biogas through various processes. Besides, the density of methane is represented by ρ_{CH_4} and taken as 0.65 kg/m^3, ρ_{CO_2} is the density of CO_2 is given as 1.80 kg/m^3, and x% CH_4 is the percent content of methane in the biogas by volume. The total carbon dioxide emissions from the combustion of a 1-m cube of biogas are the sum of the carbon dioxide content in the biogas and the amount of CO_2 resulting from the combustion of methane. Notably, 1 m^3 of biogas can produce 1.8 kg of CO_2 after combustion, no matter what the composition of methane is [76]. $M_{CO_2,comb}$ and $M_{CO_2,cogn}$ represent CO_2 emission from combustion as well as combustion and cogeneration process. Besides, EL_{comb} and EF_{el} is the electrical energy generation, and emission factor through the combustion processes, respectively. Moreover, EL_{cogn}, EF_{el}, TH_{cogn} and EF_{th} are the electrical energy generation, emission factor for electrical energy generation, thermal energy generation and conversion factors for thermal energy generation for combustion and co-generation process respectively. The conversion factor for thermal and electrical energy generation were 33.5 kg CO_2/GJ and 0.44 ton CO_2/MWh, respectively [75,77]. The CO_2 emission from standard coal, and the CO_2 emission reduction potential of various processes were calculated using **Equations 14 and 15** [76].

$$M_{CO_2,coal} = [(3600 \times E_{el}) / (\eta_c \times Q_{coal})] \times F_{coal} \tag{14}$$

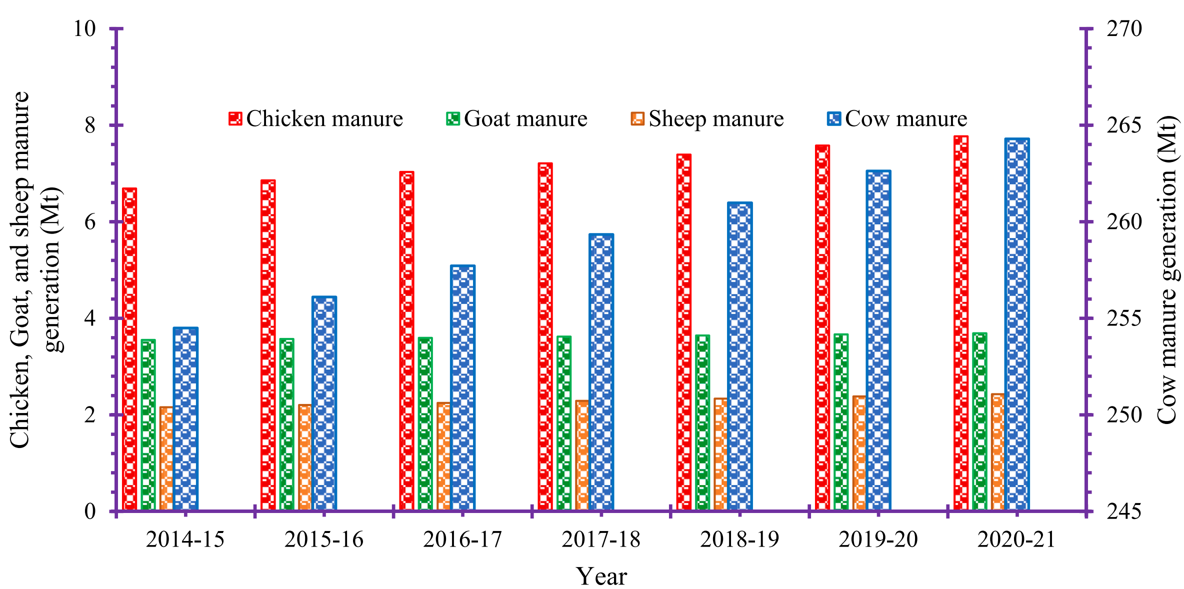

Fig. 4. The various type of animal manure generation trend in Bangladesh for different year.

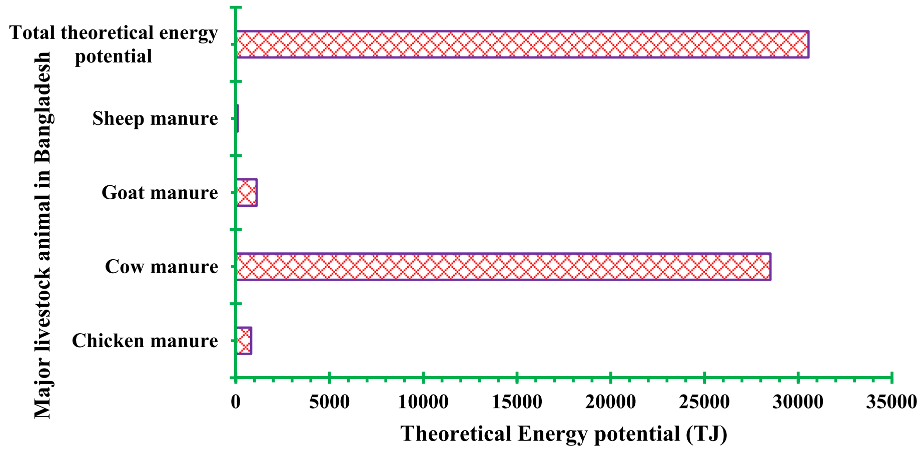

Fig. 5. Theoretical energy generation potential from major livestock animal manure for the year 2020–21 in Bangladesh.

$$\Delta M_{CO_2} = M_{coal} - M_{process} \tag{15}$$

$M_{CO_2,coal}$ is the CO_2 emission from the combustion of standard coal, and ΔM_{CO_2} is the CO_2 emission reduction potential of various processes. Moreover, W_{coal} represents the standard coal consumption for generating an equivalent amount of electricity, F_{coal} is the CO_2 emission coefficient of standard coal and taken as 2.4925 t CO_2/t standard coal, E_{el} is the electrical energy potential, η_c is the engine-generator efficiency of coal and given as 30%, the calorific value of standard coal is represented by Q_{coal} and taken as 29,307 MJ/t.

3. Results and discussion

3.1. Animal manure generation potential

The trend in livestock manure generation trend in Bangladesh is presented in Fig. 4. It has been found that the generation of animal population increases as the animal number increasing with economic as well as population growth in Bangladesh. Results indicate that the amount of cow manure was 254.5 Mt for the year 2014–15, but for the year 2020–21, it has reached 264.28 Mt. A similar trend in nature is observed for other animal manures as well.

3.2. Theoretical energy potential

The values of the theoretical energy potential are computed using the data that has been gathered, input using methods described, and proximate, ultimate, and heating potentials in conjunction with data on Bangladeshi animal manure. Using Equations (1) and (2), the computation results are shown in Fig. 5. It has been found that the maximum energy potential comes from cow manure, and the lowest energy potential lies in sheep manure. Cow manure weight is the big factor here. Though all the manures cannot be properly utilized because disturbance and the harmfulness of the environment. But here calculations are made by ensuring that all manures are being utilized properly. Again, the availability factor a_f is not used here. The maximum energy potential from cow manure is 28,517.47 TJ, and from sheep manure it is 101.84 TJ. The total energy potential from only these four animals is 30,545.76 TJ, which is a very gigantic source if properly utilized.

3.3. Technical energy potential

According to a commonly used classification of energy potential, the following step in analyzing it should be related to the technical challenge of measuring the efficiency with which the chemical energy in the manure is converted to useable energy forms. Technical energy potential is calculated using the collected data and according to the mathematical model developed at Equations (3)–(8). As reported earlier, it is not always possible to utilize the full amount of potential because of some technical issues. That's why technical energy potential is used here, including those factors in the model. The estimation of technical energy potential is presented in Fig. 6. It has been found that the biggest quantity of technical energy potential came from cow manure because they produce roughly 29.5 kg [78] of dung per day, while the lowest amount of technical energy potential came from sheep due to their relative scarcity in Bangladesh. On the basis of the findings, it can be asserted that the greatest technical energy potential of manure was realized through the process I and process II conversion approaches, while a lower energy potential was found by process III and process IV,

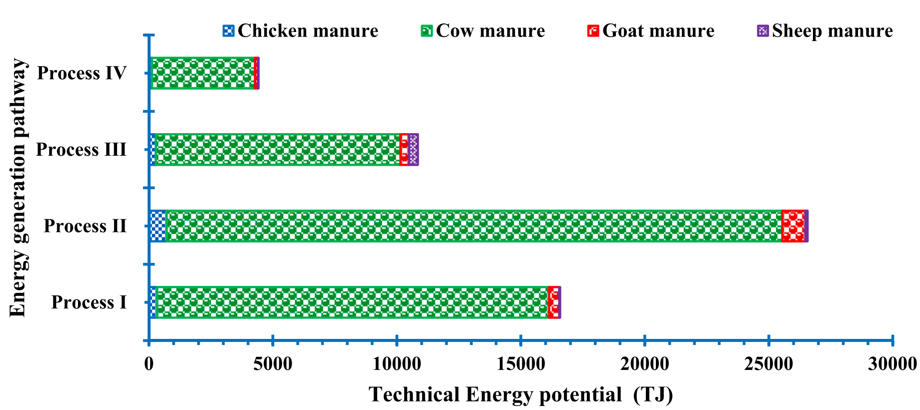

Fig. 6. Comparison of calculated technical energy potentials for different paths for the year 2020–21 in Bangladesh.

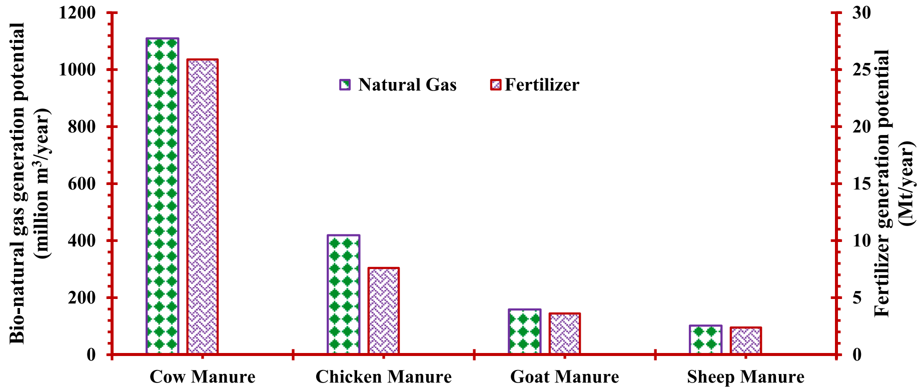

Fig. 7. Simulation results for extractable natural gas and by-product fertilizer from major livestock animal manure.

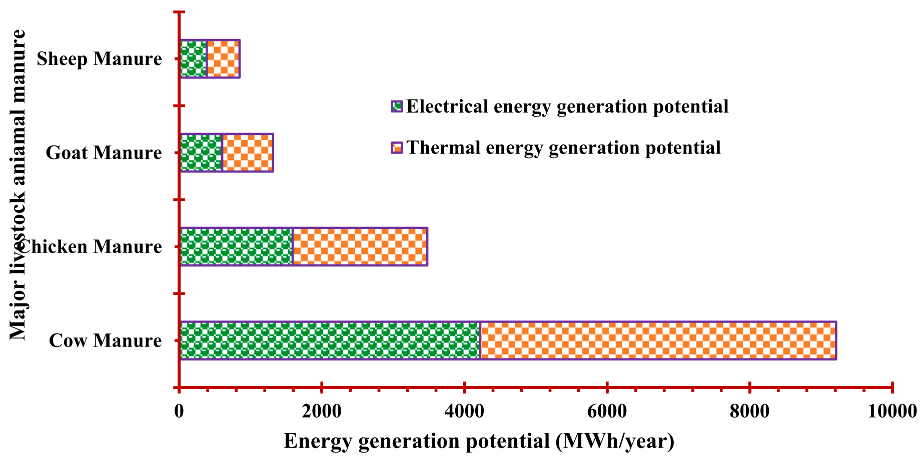

Fig. 8. Simulation results for extractable heat and electricity energy from major livestock animal manure.

which represent combustion. It can be demonstrated that, for all four animal manures, the energy potential that emerges through anaerobic digestion is smaller than what can be derived by gasification. The increase in energy production was also noted by Chang [51], who claimed that syngas yielded 44.5% more energy than biogas. The maximum technical energy potential was obtained through process II, which is 26, 564.64 TJ, whereas the maximum potential was obtained from cow manure.

3.4. Simulation results

In this study, the simulation is carried out using the Biogas Simulator software to examine the energy and bio fertilizer potential. The simulation results of biogas and fertilizer as well as electrical and thermal energy generation potential from different animal manures in Bangladesh for the years 2020–21are presented in Figs. 6 and 7. It has been found from the numbers that the most bio-natural gas was produced by cow manure, with 1109.64 million m^3 produced each year being the highest. If correctly utilized, these biogases have the potential to supply a significant number of households. Using a cow manure biogas simulation, it can be observed that bio natural gas can be transformed into electrical and thermal energy as well. Goat manure produced the most biogas, followed by cow manure. Fig. 6 shows that the goat dung accessible in Bangladesh has the potential to yield around

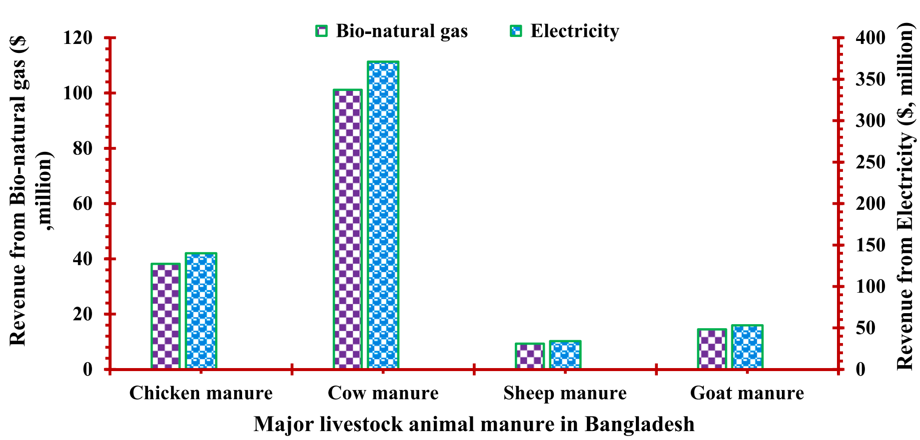

Fig. 9. Annual revenues calculating from the gas and electricity price in Bangladesh.

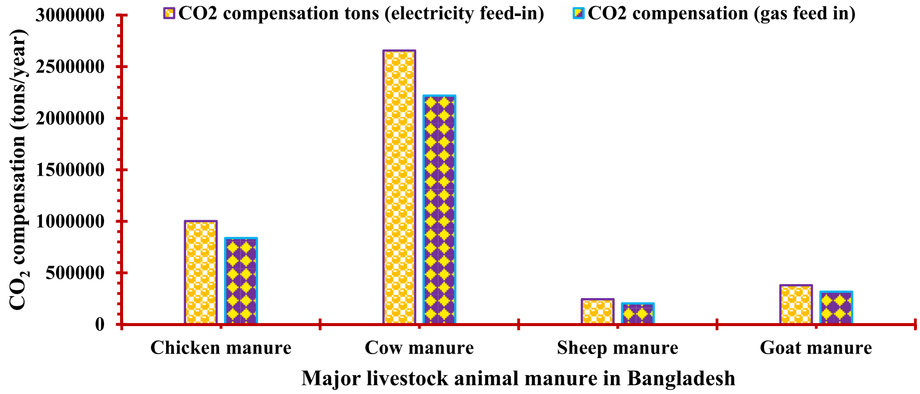

Fig. 10. CO_2 compensation for gas and electricity feed in.

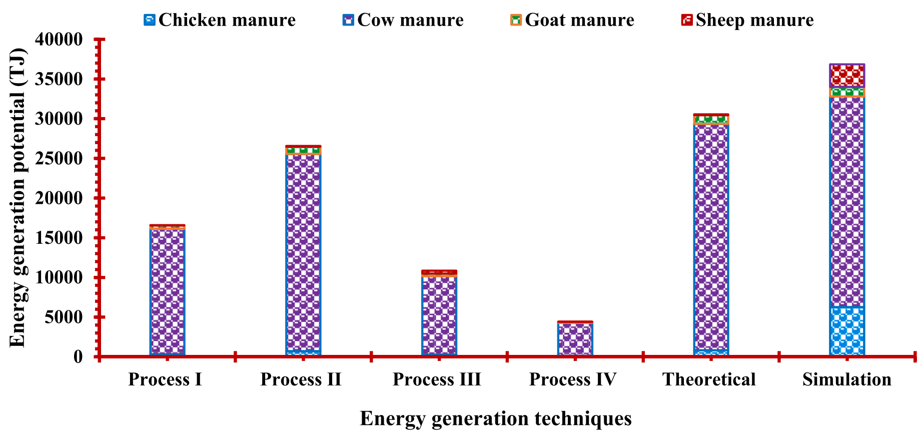

Fig. 11. Comparison of different processes for investigating the total energy generation potential.

158.67 million m^3 per year, which is significant. From the 7.76 million tons of chicken manure that are now available in the country (2020–21), approximately 419.04 million m^3 of biogas can be produced per year. The least amount of biogas, with only 102.06 million m^3 produced each year from sheep manure. Thus, there is a possibility to produce a significant amount of biogas from major livestock animal manures (sheep, chicken, goat, and cow manures). The annual bio natural gas produced by these manures is turned into electrical energy and thermal energy, with the remainder going to waste. The bio-natural gas produced from cow manure may be transformed into 1109.64 million m^3 of energy for the years 2020–21. It is found that cow manure can produce the highest amount of fertilizer, while the lowest amount can be made from sheep manure, as it is less. The Simulation results for extractable heat and electricity energy from major livestock animal manur**e is presented in** Fig. 8**.** It is possible to generate 4216.63 MWh/year of thermal energy. The amount of electrical and thermal energy produced by chicken manure is 1592.35 MWh/year and 1885.68 MWh/year, respectively. The electrical energy generated by the available biogas created by goat manure is 602.95 MWh per year, while the thermal energy produced is 714.01 MWh per year. Electrical and thermal energy produced by sheep

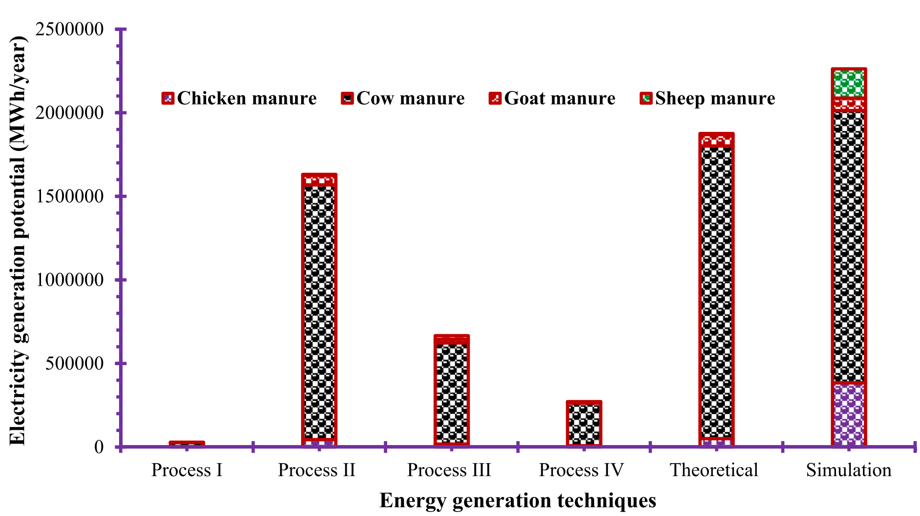

Fig. 12. Comparison of various techniques for electricity generation potential per year.

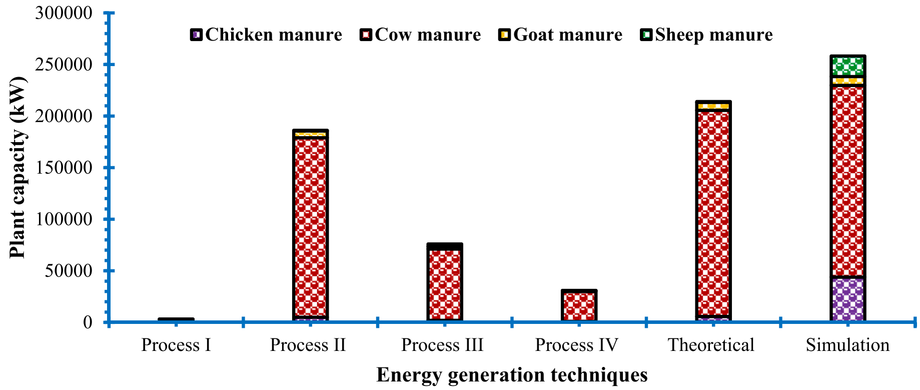

Fig. 13. Comparison of various techniques for plant size (kW/year).

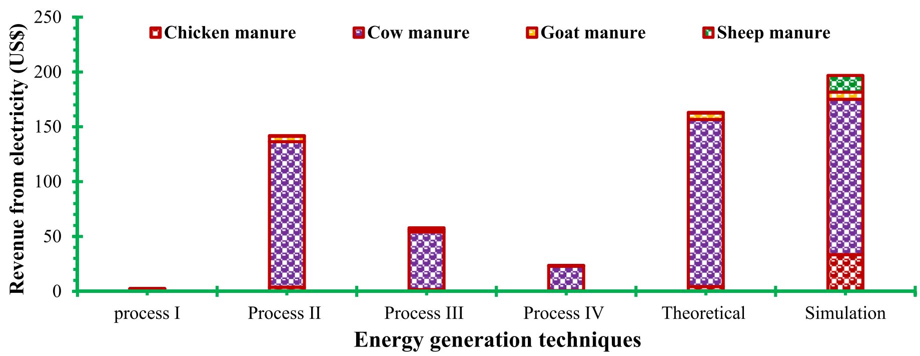

Fig. 14. Comparison of various techniques for revenue earned in a single year.

manure are 387.83 MWh and 459.27 MWh each year, respectively. Based on the data, it can be concluded that the amount of thermal energy that can be created is always greater than the amount of electrical energy.

The carbon dioxide compensation can also be calculated from simulations. With 0.09 $/kWh for the bio-natural gas charge and 0.088 $/kWh for the electricity charge, the annual revenue was calculated, which is presented in Fig. 9. It has been found that the highest revenue is obtained from cow manure, whereas the lowest is from sheep manure. The annual revenue from cow manure is about $101.18 and $371.06 million from bio-natural gas and electricity, respectively. The lowest income from these 4 types of manure is from sheep manure, since the amount of manure is less than three other animals' manure. Natural gas and electricity generated from sheep manure amount to $9.30 million and $34.12 million, respectively, in a year. The CO_2 compensation from electricity and gas feed-in is presented in Fig. 10. It has been found that the maximum CO_2 compensation is obtained from cow manure, whereas the least compensation is obtained from sheep manure. The CO_2 compensation from four types of animal manure is 4.28 million tons in the case of electricity feed-in, whereas from gas feed-in the value is 3.58 million tons.

3.5. Comparison of various energy generation routes

3.5.1. Energy potential

A summary of the various energy generation techniques is presented in Fig. 11. It has been found that, with regard to the technical energy potential, one can clearly see that it is significantly smaller than the theoretical energy potential. Process II (gasification and cogeneration) can generate the maximum amount of energy of all the possible processes, which is 26,564.64 TJ. Process IV (combustion) produced the lowest overall energy output with a total of 4419.75 TJ. Thus, the calculations show that the maximum outcome came from the gasification and cogeneration (Process II) of all the four kinds of animal manure.

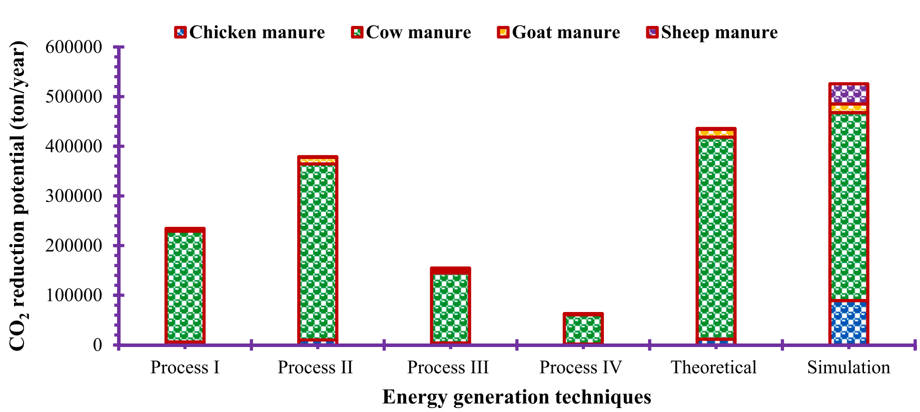

Fig. 15. CO_2 reduction potential for various techniques in a year.

Table 8
Overall comparison of biomass to energy conversion technology by means of economic-environmental benefit [83].

Conversion techniques	Operating parameters	Output products	Byproducts	Environmental impact			Energy, economic and health impact			
				Greenhouse effect	Odor problem	Air/water pollution	Human health	Process speed	Energy production yield	Relative cost
Anaerobic digestion	Temperature: 35–55 °C; Reactor size: 10-10,000 m^3; Environment: anaerobic.	Gas (main components CH_4 and CO_2)	Sludge (use as fertilizer after proper treatment)	4	1	4	2	1	1	2
Ethanol fermentation	Temperature: 30–35 °C; pH: 6.0; Environment: anaerobic.	Ethanol, CO_2	Animal feed	4	2	5	4	3	3	2
Incineration	Temperature: 400–540 °C.	Heat, Electricity	Ash	1	5	1	1	4	3	2
Pyrolysis	Temperature: 250–750 °C; Environment: absence of oxygen	Char, Oil or tar, gas (CH_4, CO, CO_2, hydrocarbons, H2, etc. (content dependent on process conditions)	Char (use as oil amendment, activated coal, or solvent.	3	5	3	1	4	3	3
Gasification	Temperature: 350–1800 °C; Environment: air, oxygen, or steam; Pressure: 1–30 bar.	Gas (CH_4, CO, CO_2, N_2, H2, etc. (content dependent on process conditions)	Ash	3	5	3	3	4	3	3

Additionally, each of the four processes is compared for each animal manure, and the results are also obtained in Fig. 11. It has been found that the maximum energy potential found among all four processes comes from cow manure. In order to compare the simulation results, different theoretical and technical paths yield different results, as shown in Fig. 11. The theoretical potential is greater than the technical one because there is not any consideration of losses for conversion as well as availability factor. Moreover, the simulation result is higher than technical as well as theoretical ones. The reasons behind that in practical application, various losses should be considered, but in the case of simulation, all losses could not be considered because various unexpected things happened in practical application. The electricity generation potential through different energy generation pathways is presented in Fig. 12. The procedure for calculating electricity as well as plant capacity is mentioned in the methodology section.

It has been found that the highest electricity generation potential was found for process II, i.e., for gasification techniques (1630.77 GW h/year), where maximum comes from cow manure (1524.63 GW h/year). The number of animal cows is huge in Bangladesh; therefore, it shows the highest amount of potential compared to other animals in various techniques. The lowest electricity potential has been found for process I (27,361.45 MW h/year) due to different losses associated with energy conversion. There are various losses associated with process I; thus, it has the lowest electricity generation potential. The plant capacity for various techniques is presented in Fig. 13. The maximum plant capacity was found for process II among four energy generation techniques (1,86,161.38 kW), whereas the lowest plant capacity was found for process I (3123.45 kW). It can be concluded that, process II shows maximum electricity generation values, but they are still lower than theoretical as well as simulation results. In theoretical as well as simulation calculations, the operational losses are not properly considered, which results in variation in outputs.

3.5.2. *Economic benefits*

The economic benefits of different energy routes have been determined using levelized cost of energy (LCOE) 0.087 $/kWh [73]. The revenue earned from various processes of electricity selling is presented in Fig. 14. It has been found that the maximum revenue was earned from process II (141.87 M$), whereas the lowest was found for process I (2.38 M$). Process II shows maximum electricity generation potential (Fig. 12); therefore, the revenue earned from this process is also maximum. The revenue earned from cow, chicken, goat, and sheep manure through process II is 132.64 M$, 3.81 M$, 4.94 M$, and 0.47 M$, respectively. It has been found that in every energy generation technique, the maximum output comes from cow manure because of its numbers and highest manure production. The electricity generation through process I is minimal, therefore, it provides the least revenue. Though the maximum revenue comes from process II, but it has lower theoretical as well as simulation results.

3.5.3. *Environmental potentials*

The potential CO_2 minimization has been calculated with respect to the CO_2 generation from standard coal burning for power generation. The CO_2 reduction potential of various processes is illustrated in Fig. 15. It has been found that the maximum CO_2 reduction potential was found for process II (3,78,941.57 tons/year), whereas the lowest was found for process IV (6,3,047.23 tons/year). The CO_2 reduction potentials from cow, chicken, goat, and sheep manure gasification (process II) are 3,54,278.15 tons/year, 10,180.99 ton/year, 13,217.45 tons/year, and 1265.01 tons/year, respectively. Thus, the successful implementation of various energy generation processes is not only responsible for energy generation but also capable of reducing greenhouse gas emissions to the environment.

Table 9
Challenges and perspectives for implementing biomass gasification plants in Bangladesh.

	Challenges	Perspective
Economic factor	✓ Competition with other investments with biomass gasification plant installation. ✓ No certainty of return of the investments. ✓ Uncertainty about receiving financial assistance ✓ Initial investment is too high ✓ Lack of incentives	✓ Return on investment that is profitable. ✓ Financial assistance is available. ✓ Energy cost savings are possible. ✓ The availability of low-cost feedstock. ✓ Loans from a bank at a low interest rate. ✓ Getting the most out of biomass gasification projects. ✓ Third-party funding.
Technical support	✓ Problems with planning and installation ✓ Feedstock of poor grade. ✓ Unavailability of water ✓ There is no established technology. ✓ A scarcity of feedstock. ✓ Uncertainty in feedstock production ✓ Availability of land	✓ Methods of utilizing waste that are efficient. ✓ Bioenergy feedstock comes in a variety of forms. ✓ Based on the application. ✓ Technologies that are tailored to the processing of local feedstock.
Social awareness	✓ Feedstock's perceived detrimental environmental impact. ✓ Inadequate knowledge of biomass gasification to energy utilization. ✓ Inadequate knowledge of policies, technology, and so on. ✓ Political reluctance. ✓ Change apprehension. ✓ Differences in socio-economic status between urban and rural populations.	✓ Carbon emissions could be reduced. ✓ Environmental advantages rather than CO_2 reduction ✓ The rising renewable energy sector is appealing. ✓ End-user interest in bioenergy has grown. ✓ Political will to support green energy.
Biomassgas market	✓ Uncertainty in the energy market. ✓ Biomass gasification to energy market in its infancy. ✓ Primary end-user demand is low. ✓ Global carbon market participation is low. ✓ Insufficient private participation. ✓ Competitors include fossil fuels.	✓ Market opportunity or diversification. ✓ Bioenergy is adaptable. ✓ Natural gas prices are on the rise.
Organizational competence	✓ A scarcity of technical experts/services. ✓ Inadequate research and development. ✓ In biomass gasification initiatives, there is a lack of coordination. ✓ There is no one-of-a-kind platform for biomass gasification stakeholders. ✓ Inexperience with feedstock.	✓ System of environmental certification. ✓ People with genuine ambition. ✓ Image of the environment ✓ Long-term energy plan.
Government policy	✓ Uncertainty and complication. ✓ Insufficient government attention. ✓ Complexity in the bureaucracy. ✓ There is a lack of a concrete biomass gasification policy.	✓ Meeting the government's renewable energy goal. ✓ Climate change adaptation. ✓ Specific goal for biogas production.

Very good: 5, Good: 4, Moderate: 3, Poor: 2, Very poor: 1.

4. Discussions and future recommendation

4.1. Opportunities and challenges of biomass gasification process

Despite abundant feedstock, the number of biomass gasification plants in Bangladesh is very low. The biomass gasification process has various benefits, including producing bio-energy and bio-fertilizer, as well as other socio-economic and environmental benefits [79–81]. It may help reduce greenhouse gas emissions and improve crop nutrient utilization. Many countries have established waste management systems that involve biogas production to address environmental challenges through biomass gasification techniques [82]. The biomass gasification plants have various advantages, such as being suitable for a variety of sources, they could be tailored to certain regions and economies. Bangladesh is an agriculture-based economy with ample indigenous resources to create biogas on a massive scale through biogas technology. Despite having an abundance of adequate resources, the country's biogas production has stalled [45]. An abundance of resources acts as a driver for biogas production through the gasification process in Bangladesh. In the previous section, it was found that the gasification process shows better performance than any other conversion process. Therefore, the overall comparison of biomass to energy generation pathways by means of economic-environmental effects is investigated and presented in Table 8. It has been found that the gasification process has various advantages as well as being more environmentally friendly than any other process. Table 9 illustrates both the challenges and perspectives for utilizing biomass gasification plants in Bangladesh. It has been found that the removal of the barrier to biomass gasification plants could help generate a huge amount of energy through this technology. Therefore, related authorities should come forward to remove obstacles to the successful implementation of biomass gasification plants in Bangladesh.

4.2. Social impact and management strategy for biomass gasification

Waste management can lead to new work possibilities, reducing Bangladesh's unemployment. Throughout the procedure, manpower will be required. Each district will have a processing plant. The collection and delivery of this garbage will be paid for, reducing unemployment. Farmers will benefit since harvesting costs will be reduced, lowering food prices. Handling and processing waste will produce jobs for 20,000 people in Bangladesh, and this number will grow in the future [84]. The reduction in unemployment is also projected to reduce crime rates. People will be better aware of garbage handling and the waste-to-energy possibilities in Bangladesh. Some policies must be initiated immediately to support farmers and people.

- ✓ Proper equipment should be provided for the biomass gasification plant. For a smaller plant, a larger subsidy should be provided.
- ✓ Farmer cooperation should be fostered to assure the supply of raw resources. This can be accomplished by providing enough training facilities for them.
- ✓ To secure the development of this sector, the private sector's involvement should be promoted. Various non-governmental organizations (NGOs) should be established in rural regions to assist in raising awareness among local residents. Aside from that, waste management policies must be modified every two years to address ongoing waste issues.
- ✓ Because this country is endowed with agricultural resources, research in this field should be prioritized. Priority should be given to collaboration between universities, research officials, and agencies.

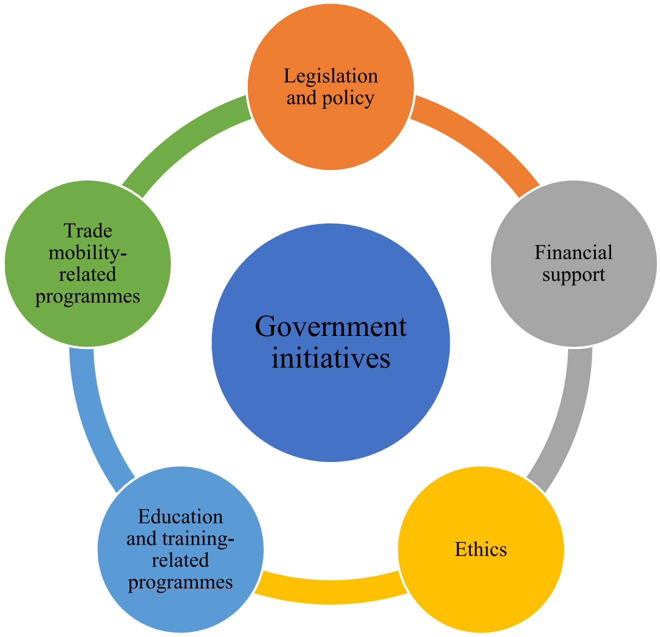

Fig. 16. The government activities aimed for adoption of renewable energy technologies in Bangladesh.

4.3. Government initiatives and subsidies for the biomass gasification plants

It is possible that government activities will have an impact on and actualize the deployment of an environmentally friendly technology like biomass gasification. Governmental activities can affect and increase the viability of the use of a sustainable technology [85]. Governmental activities, as depicted in Fig. 16, include legislative and policy changes as well as financial assistance, teaching and training, exchange portability, and other associated projects, among other things.

There are numerous examples of effective biogas dissemination from which lessons can be drawn. Sweden is becoming a paradigm for biogas diffusion by combining waste management with biofuel production through biogas technology [86,87]. Germany has long been successful in implementing biogas-based transportation systems and electricity generation in several places [88]. The key catalyst for the spread of the biogas sector in Thailand was government subsidies [89]. India and Pakistan are two neighbouring South Asian countries focused on biogas production through community-based waste management systems [90,91].

The primary reasons for the effective diffusion of biogas in various regions of China [92] have been a financial subsidy scheme as well as an appropriate waste management system. In Ghana, the government is working on pilot-scale biomass gasification plants [93]. Proper waste management, increased institutional capacity, and policy are the actors that will help expand biomass gasification technology on a larger scale in Bolivia [94]. The researchers found numerous factors for proper biogas diffusion, with a particular emphasis on policy instruments.

4.4. Policy framework for biomass gasification plant in Bangladesh

Biogas can be generated from the anaerobic fermentation of biomass, animal waste, municipal waste, etc. In a plant. The existing resources of biogas in our planet can give us a perspective on global production. Only a very small part of this potential is utilized today. It is critical to the establishment of any policy to have certain goals that must be met.

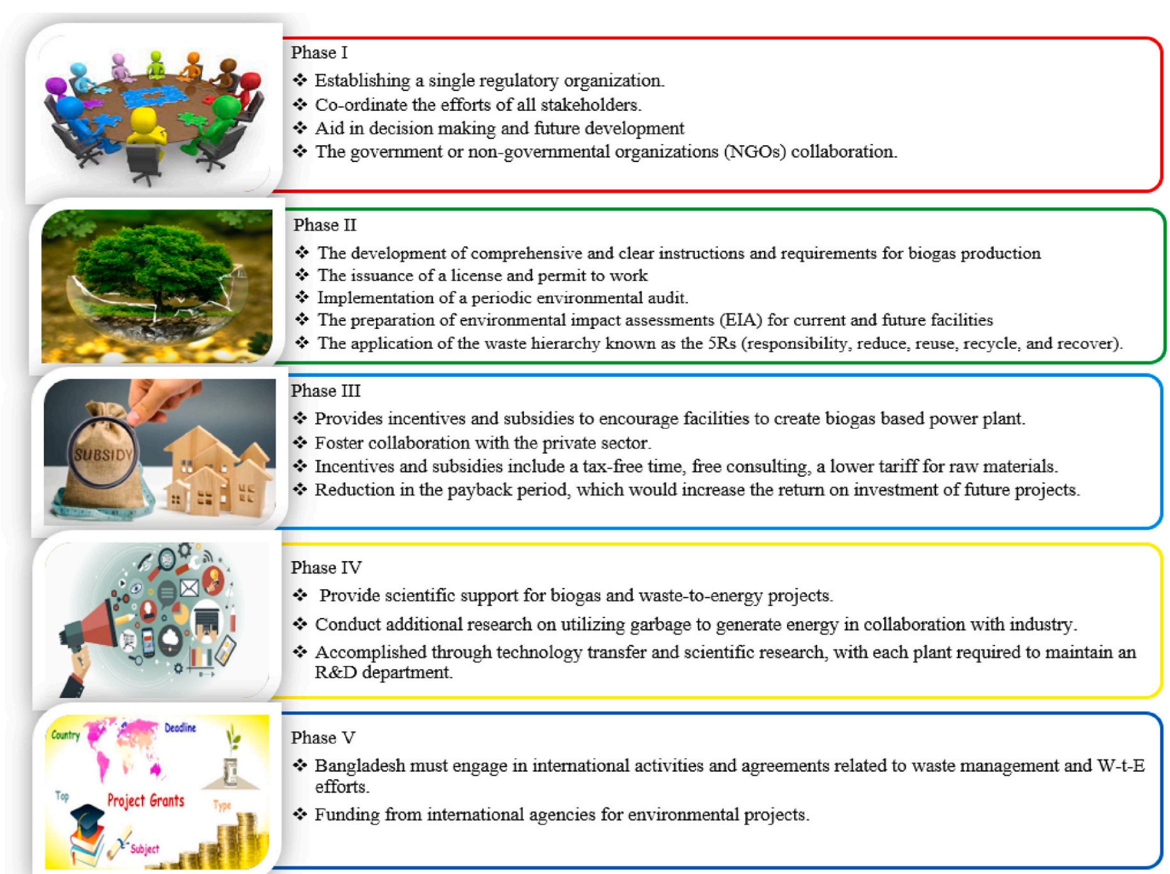

Fig. 17. Policy framework for biomass gasification in Bangladesh.

Examples of targets achieved include sustainable development for environmental elements, communicating clear waste management norms and regulations, enacting environmental laws to control related activities, and so on. A biomass gasification policy is made up of five phases, which are: phases I–V, presented in Fig. 17.

Phase I: Establishing a single regulatory organization to analyze and monitor the problems of various stakeholders who are being affected by biomass gasification projects, as well as help in decision-making and future development by appointing a single focal point. This focal point might come from either the government or non-governmental organizations (NGOs), which will help achieve national goals.

Phase II: It involves the development of clear instructions as well as requirements for biomass gasification plants, which include the management strategy of raw materials, disposal of biomass wastes, the preparation of environmental impact assessments (EIA) for current and future facilities, the application of the waste hierarchy known as the 5 R s (responsibility, reduce, reuse, recycle, and recover), license issuance, permit to work, the implementation of cyclic environmental audits, etc.

Phase III: It provides incentives and subsidies to encourage facilities to create biomass gasification plants and expand their contribution to the economy, as well as foster collaboration with the private sector to ensure a green economy. A scheme like this will aid biomass gasification facilities in their repair and waste management efforts. Incentives and subsidies include a tax-free time, free consulting, a lower tariff for raw materials for the manufacturing process, and a reduction in the payback period, which would increase the return on investment of future projects, mitigating the biomass gasification sustainability concerns. Unexpected obstacles must be planned for in contingency plans. The energy sector is vulnerable to a variety of factors that can impact the energy market, including wars, natural disasters, and, most recently, the COVID-19 pandemic, which has caused oil prices to plummet dramatically and has had a bad impact on the industry.

Phase IV: This will provide scientific support for biomass gasification and waste-to-energy projects. This is important in order to implement the best environmental practices (BEP) and most advanced technology available (BAT). This can be accomplished through technology transfer and scientific research, with each plant required to maintain an R&D department. The ministry of higher education or any other competent entity in a country can pay universities and plants to conduct additional research on utilizing garbage to generate energy in collaboration with industry.

Phase V: It is essential to attend international conventions. Bangladesh must engage in international activities and agreements related to waste management and WTE efforts, such as the Basel Conventions (Basel, 2020). With this engagement, various international agencies like the German Technical Cooperation (GTC), the Japan International Cooperation Agency (JICA), and the United States Agency for International Development (USAID) will be able to fund environmental projects.

5. Conclusions

The research examines the theoretical energy potential and environmental emissions reduction potential of the major animal manure sources in Bangladesh. The assessments take into account the annual manure generation for four major livestock species and determine the physiochemical properties of the manure. Furthermore, the technological potential of energy generation has been examined using four different energy routes. In addition to that, mathematical models for the various energy paths have been developed with likely losses and availability variables. A simulation was also performed to compare the calculated findings. The important outcomes of this investigation are listed below.

- The total theoretical energy potential from the available livestock is estimated at 30,545.76 TJ, of which cow manure has the highest potential at 28,517.47 TJ. The ascending order of the energy potential found Sheep (101.34 TJ) < Chicken (819.53 TJ) < Goat (1106.91 TJ) < Cow (28,517.47 TJ).
- Process II (gasification and cogeneration) offers the highest energy output (26,564.64 TJ) compared to the other three paths in terms of technical potential. In this process, the cow manure generates the highest potential. The process with the lowest energy potential (4419.74 TJ) among the four-energy generation processes is combustion (process IV). In descending order of the energy generation process, it would be process II > process I > process III > process IV.
- The biogas simulation results follow the pattern of energy generation routes. The simulation shows a total of 1789.41 million m^3 of bionatural gas per year can be extracted annually from the four animal manures. The amount is equivalent to 6800 MW h of electric energy and 8052.34 MW h of thermal energy per year. In this calculation, the maximum potential comes from cow manure in the country.
- The result shows that about $141.87 million in electricity can be generated annually if the available manures are properly utilized through process II (gasification and cogeneration). Most of the revenue comes from electricity produced by cow manure. The lowest revenue comes from Process I ($2.38 million). The ascending order of revenue generation for various processes would be process I < process IV < process III < process II.
- The CO_2 emission reduction potential result reveals that, when compared to coal combustion for the same quantity of power production, process II achieved the highest CO_2 reduction (3,78,941.57 tons/year). On the other hand, the lowest amount of CO_2 reduction potential was obtained from process IV (63,047.23 ton/year). The descending order of CO_2 reduction potential of various energy generation processes, process II > process I > process III > process IV.

Finally, after analyzing the overall energy potential, electricity generation potential, yearly revenue, and CO_2 emission reduction potential, it can be said without any hesitation that gasification and cogeneration (process II) show better results among various energy generation pathways. Therefore, successful implementation of this process not only manages a huge amount of animal waste but also provides us with a huge amount of energy potential, which is really impressive for a developing country like Bangladesh. Moreover, the process will also offer a scientific guideline for investors as well as researchers for generating renewable and sustainable energy, which will mitigate the energy crisis in the near future.

CRediT authorship contribution statement

The credit author statement only includes one author contribution. The Accurate contributions are is follows:Md. Sanowar Hossain (Conceptualization, investigations, and conduction- major activities), Nahid Imtiaz Masuk (writing and Review),Barun K. Das (Review and Editing),Arnob Das (Writing and calculation),Md. Golam Kibria (Writing and calculation),Miftahul Mobin Chowdhury (Writing and review),Imtiaz Ahmed Shozib (writing).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Nomenclature

Symbols Description

a_f	Availability factor
b	Biogas yield
e	specific electricity demand for drying, kWh/kg of evaporated water
E	Energy potential (kJ)
FBC	Fluidized bed combustion
HHV	Higher heating value (kJ/kg)
H	Hydrogen content (wt. %)
IC	Internal combustion
LHV	Lower heating value (kJ/kg)
M	Moisture content (wt. %)
N	Nitrogen content (wt. %)
O	Oxygen content (wt. %)
ORC	Organic ranking cycle
q	Specific heat demand for drying, kWh/kg of evaporated water
VM	Volatile matter (wt. %)
VS	Organic matter (wt. %)
η	Efficiency (%)

References

[1] S. Rahman, et al., A ranking scheme for biodiesel underpinned by critical physicochemical properties, Energy Convers. Manag. 229 (2021), 113742.
[2] T. Mahlia, et al., Patent landscape review on biodiesel production: technology updates, Renew. Sustain. Energy Rev. 118 (2020), 109526.
[3] O. Chasnyk, G. Sołowski, O. Shkarupa, Historical, technical and economic aspects of biogas development: case of Poland and Ukraine, Renew. Sustain. Energy Rev. 52 (2015) 227–239.
[4] M. Tabatabaei, et al., A comprehensive review on recent biological innovations to improve biogas production, part 1: upstream strategies, Renew. Energy 146 (2020) 1204–1220.
[5] H. Yaqoob, et al., The potential of sustainable biogas production from biomass waste for power generation in Pakistan, J. Clean. Prod. 307 (2021), 127250.
[6] V. Paolini, et al., Environmental impact of biogas: a short review of current knowledge, Journal of Environmental Science and Health, Part A 53 (10) (2018) 899–906.
[7] H. Afazeli, et al., An investigation of biogas production potential from livestock and slaughterhouse wastes, Renew. Sustain. Energy Rev. 34 (2014) 380–386.
[8] W.M. Budzianowski, Sustainable biogas energy in Poland: prospects and challenges, Renew. Sustain. Energy Rev. 16 (1) (2012) 342–349.
[9] X. Meng, et al., Greenhouse gas balances and yield-scaled emissions for storage and field application of organic fertilizers derived from cattle manure, Agric. Ecosyst. Environ. 345 (2023), 108327.
[10] M. Nehra, S. Jain, Estimation of renewable biogas energy potential from livestock manure: a case study of India, Bioresour. Technol. Rep. 22 (2023), 101432.
[11] M.U. Khan, et al., Biogas production potential from livestock manure in Pakistan, Sustainability 13 (12) (2021) 6751.
[12] F. Battini, et al., Mitigating the environmental impacts of milk production via anaerobic digestion of manure: case study of a dairy farm in the Po Valley, Sci. Total Environ. 481 (2014) 196–208.
[13] A. Whiting, A. Azapagic, Life cycle environmental impacts of generating electricity and heat from biogas produced by anaerobic digestion, Energy 70 (2014) 181–193.
[14] V. Fantin, et al., Environmental assessment of electricity generation from an Italian anaerobic digestion plant, Biomass Bioenergy 83 (2015) 422–435.
[15] B. Morero, E. Groppelli, E.A. Campanella, Life cycle assessment of biomethane use in Argentina, Bioresour. Technol. 182 (2015) 208–216.
[16] M. Karrabi, et al., A comprehensive review on biogas production from lignocellulosic wastes through anaerobic digestion: an insight into performance improvement strategies, Fuel 340 (2023), 127239.
[17] R. Langendoen, Grameen shakti: pioneering and expanding green energy revolution to rural Bangladesh, in: Global Humanitarian Technology Conference (GHTC), 2012 IEEE, 2016, https://doi.org/10.1109/GHTC.2012.50 no. May.
[18] L. Hellqvist, H. Heubaum, Setting the sun on off-grid solar?: policy lessons from the Bangladesh solar home systems (SHS) programme, Clim. Pol. 23 (1) (2023) 88–95.
[19] P. Halder, N. Paul, M. Beg, Assessment of biomass energy resources and related technologies practice in Bangladesh, Renew. Sustain. Energy Rev. 39 (2014) 444–460.
[20] M.R. Islam, M.R. Islam, M.R.A. Beg, Renewable energy resources and technologies practice in Bangladesh, Renew. Sustain. Energy Rev. 12 (2) (2008) 299–343.
[21] M. Uddin, et al., Renewable energy in Bangladesh: status and prospects, Energy Proc. 160 (2019) 655–661.
[22] M. Ilbas, L.O. Antari, M. Sahin, Biogas production from domestic resources as an alternative energy source: a comprehensive feasibility study, Int. J. Energy a Clean Environ. (IJECE) 23 (1) (2022).
[23] F. Ameen, et al., Co-digestion of microbial biomass with animal manure in three-stage anaerobic digestion, Fuel 306 (2021), 121746.
[24] S.I. Khan, et al., Production of biogas by the co-digestion of cow dung and crop residue at University of the Punjab, Lahore, Pakistan, Afr. J. Environ. Sci. Technol. 12 (2) (2018) 91–95.
[25] J.H. Jeung, W.J. Chung, S.W. Chang, Evaluation of anaerobic co-digestion to enhance the efficiency of livestock manure anaerobic digestion, Sustainability 11 (24) (2019) 7170.
[26] C.A. Moreno-Camacho, et al., Sustainability metrics for real case applications of the supply chain network design problem: a systematic literature review, J. Clean. Prod. 231 (2019) 600–618.
[27] L. Dong, et al., Efficient biogas production from cattle manure in a plug flow reactor: a large scale long term study, Bioresour. Technol. 278 (2019) 450–455.
[28] K.M. Rahman, M. Harder, R. Woodard, Energy yield potentials from the anaerobic digestion of common animal manure in Bangladesh, Energy Environ. 29 (8) (2018) 1338–1353.
[29] P.K. Sahu, et al., Combustion characteristics of animal manures, J. Environ. Protect. 7 (2016) 951, 06.
[30] V. de Holanda Pasolini, et al., Drying of poultry manure for biomass applications in the combustion, Biomass Conversion and Biorefinery (2023) 1–11.
[31] B. Abubakar, N. Ismail, Anaerobic digestion of cow dung for biogas production, ARPN J. Eng. Appl. Sci. 7 (2) (2012) 169–172.
[32] R. Alvarez, G. Lidén, Low temperature anaerobic digestion of mixtures of llama, cow and sheep manure for improved methane production, Biomass Bioenergy 33 (3) (2009) 527–533.
[33] O.O. Obiukwu, M.O. Nwafor, Comparative evaluation of batch and continuous process biogas production from animal wastes, Int. J. Ambient Energy 37 (1) (2016) 29–35.
[34] L. Castrillón, et al., Methane production from cattle manure supplemented with crude glycerin from the biodiesel industry in CSTR and IBR, Bioresour. Technol. 127 (2013) 312–317.
[35] S. Mandal, B.K. Das, N. Hoque, Optimum sizing of a stand-alone hybrid energy system for rural electrification in Bangladesh, J. Clean. Prod. 200 (2018) 12–27.
[36] R. Hassan, B.K. Das, M. Hasan, Integrated off-grid hybrid renewable energy system optimization based on economic, environmental, and social indicators for sustainable development, Energy 250 (2022), 123823.
[37] S.A. Sarker, et al., Economic feasibility and determinants of biogas technology adoption: evidence from Bangladesh, Renew. Sustain. Energy Rev. 123 (2020), 109766.
[38] S. Hossain, et al., Energy, exergy and sustainability analyses of Bangladesh's power generation sector, Energy Rep. 6 (2020) 868–878.
[39] M.A.H. Baky, M.M. Rahman, A.S. Islam, Development of renewable energy sector in Bangladesh: current status and future potentials, Renew. Sustain. Energy Rev. 73 (2017) 1184–1197.
[40] Bangladesh Power Development Board. [cited 2023 06.07]; Available from: 06.07.2023 https://www.bpdb.gov.bd/site/page/e7f4aaea-7605-4588-a705-e615c574cb88/-.
[41] A.G. Kaviri, et al., Exergoenvironmental optimization of heat recovery steam generators in combined cycle power plant through energy and exergy analysis, Energy Convers. Manag. 67 (2013) 27–33.
[42] M.H. Masud, et al., Renewable energy in Bangladesh: current situation and future prospect, Int. J. Sustain. Energy 39 (2) (2020) 132–175.
[43] P. Halder, et al., Energy scarcity and potential of renewable energy in Bangladesh, Renew. Sustain. Energy Rev. 51 (2015) 1636–1649.
[44] B. Bank, The Real Economy, July 2019 - June 2020. Available from: https://www.bb.org.bd/pub/annual/anreport/ar1920/index1920.php.

[45] T. Chowdhury, et al., Latest advancements on livestock waste management and biogas production: Bangladesh's perspective, J. Clean. Prod. 272 (2020), 122818.
[46] U.S. Wise, Dollars to Bangladeshi Takas Today, 2023. Available from: https://wise.com/gb/currency-converter/usd-to-bdt-rate.
[47] A. Reza, T. Islam, Current status of running renewable energy in Bangladesh and future prospect : a global comparison, Heliyon 9 (3) (2023) e14308, https://doi.org/10.1016/j.heliyon.2023.e14308.
[48] E.U. Khan, A.R. Martin, Review of biogas digester technology in rural Bangladesh, Renew. Sustain. Energy Rev. 62 (2016) 247–259.
[49] K. Singh, et al., Anaerobic digestion of poultry litter: Review 26 (4) (2010) 677–688.
[50] K. Singh, et al., Anaerobic digestion of poultry litter: a review, Appl. Eng. Agric. 26 (4) (2010) 677–688.
[51] F.H. Chang, Energy and sustainability comparisons of anaerobic digestion and thermal technologies for processing animal waste, in: 2004 ASAE Annual Meeting, American Society of Agricultural and Biological Engineers, 2004.
[52] J. Watson, et al., Gasification of biowaste: a critical review and outlooks, Renew. Sustain. Energy Rev. 83 (2018) 1–17.
[53] M. Tańczuk, et al., Assessment of the energy potential of chicken manure in Poland, Energies 12 (7) (2019) 1244.
[54] N. Taupe, et al., Updraft gasification of poultry litter at farm-scale–A case study, Waste Manag. 50 (2016) 324–333.
[55] J. Brammer, A. Bridgwater, Drying technologies for an integrated gasification bio-energy plant, Renew. Sustain. Energy Rev. 3 (4) (1999) 243–289.
[56] P. Billen, et al., Electricity from poultry manure: a cleaner alternative to direct land application, J. Clean. Prod. 96 (2015) 467–475.
[57] A. Toptas, et al., Combustion behavior of different kinds of torrefied biomass and their blends with lignite, Bioresour. Technol. 177 (2015) 328–336.
[58] S. Hossain, M. Jahan, F. Khatun, Current status of dairy products in Bangladesh: a review on supply and utilization, International Journal of Business, Management and Social Research 11 (2) (2022) 609–618.
[59] P.w.m.s.i. Bnagladesh, CDM Project Potential in the Poultry Waste Management Sector in Bangladesh, 2005. Available from: http://wasteconcern.org/wp-content/uploads/2016/04/Poultry-Final.pdf.
[60] C.i.a. out, Cow in and Out, 2020. Available from: http://fergusonfoundation.org/lessons/cow_in_out/cowmoreinfo.shtml#:~:text=Manure%20%2D%20A%20cow%20produces%2065,to%2015%20times%20a%20day.
[61] C. Osuhor, J. Alawa, G.J.T.G. Akpa, Research note: Manure production by goats grazing native pasture in Nigeria 36 (2) (2002) 123–125.
[62] C. Osuhor, J. Alawa, G. Akpa, Research note: manure production by goats grazing native pasture in Nigeria, Trop. Grassl. 36 (2) (2002) 123–125.
[63] M.A. Hossain, M.M. Rahman, M.A. Hashem, Productive performances of native sheep in Bangladesh, Meat Res. 3 (1) (2022) 1–7.
[64] G. Quiroga, et al., Physico-chemical analysis and calorific values of poultry manure, Waste Manag. 30 (5) (2010) 880–884.
[65] H.L. Choi, S.I. Sudiarto, A. Renggaman, Prediction of livestock manure and mixture higher heating value based on fundamental analysis, Fuel 116 (2014) 772–780.
[66] N. Touray, et al., Thermochemical and pore properties of goat-manure-derived biochars prepared from different pyrolysis temperatures, J. Anal. Appl. Pyrol. 109 (2014) 116–122.
[67] Sheep Manure. [cited 2023 05.06]; Available from: 05.06.2023 https://phyllis.nl/Biomass/View/2772.
[68] P. Abdeshahian, et al., Potential of biogas production from farm animal waste in Malaysia, Renew. Sustain. Energy Rev. 60 (2016) 714–723.
[69] Biogas Calculator, 2022 [cited 2022 12.03]; Available from: https://www.renergon-biogas.com/en/anaerobic-digestion-biogas-calculator/. (Accessed 12 March 2022).
[70] T. Ayodele, A. Ogunjuyigbe, M. Alao, Economic and environmental assessment of electricity generation using biogas from organic fraction of municipal solid waste for the city of Ibadan, Nigeria, J. Clean. Prod. 203 (2018) 718–735.
[71] A. Ogunjuyigbe, T. Ayodele, M. Alao, Electricity generation from municipal solid waste in some selected cities of Nigeria: an assessment of feasibility, potential and technologies, Renew. Sustain. Energy Rev. 80 (2017) 149–162.
[72] I. Irena, Renewable energy technologies: cost analysis series, Concentrating solar power 4 (5) (2012).
[73] Electrical tarrif rate. [cited 2022 10.20]; Available from: 20.10.2022 http://nesco.gov.bd/site/office_citizen_charter/e4d863a0-cc99-415a-9400-131067b06c71/-.
[74] C. Jin, et al., Anaerobic digestion: an alternative resource treatment option for food waste in China, Sci. Total Environ. 779 (2021), 146397.
[75] D. Panepinto, M. Ravina, M. Zanetti, An overview of thermal treatment emissions with a particular focus on CO2 parameter, Sustainability 14 (23) (2022), 15852.
[76] A.D. Cuéllar, M.E. Webber, Cow power: the energy and emissions benefits of converting manure to biogas, Environ. Res. Lett. 3 (3) (2008), 034002.
[77] A.W. Larsen, T. Astrup, CO2 emission factors for waste incineration: influence from source separation of recyclable materials, Waste Manag. 31 (7) (2011) 1597–1605.
[78] ECO-YAP, Turning Dung Into Gold. https://eco-yap.com/turning-dung-into-gold/.
[79] A. Shane, S.H. Gheewala, Missed environmental benefits of biogas production in Zambia, J. Clean. Prod. 142 (2017) 1200–1209.
[80] W.J. Florkowski, A. Us, A.M. Klepacka, Food waste in rural households support for local biogas production in Lubelskie Voivodship (Poland), Resour. Conserv. Recycl. 136 (2018) 46–52.
[81] M.K. Awasthi, et al., A critical review of organic manure biorefinery models toward sustainable circular bioeconomy: technological challenges, advancements, innovations, and future perspectives, Renew. Sustain. Energy Rev. 111 (2019) 115–131.
[82] H.D. Beyene, A.A. Werkneh, T.G. Ambaye, Current updates on waste to energy (WtE) technologies: a review, Renewable Energy Focus 24 (2018) 1–11.
[83] T.P.T. Pham, et al., Food waste-to-energy conversion technologies: current status and future directions, Waste Manag. 38 (2015) 399–408.
[84] M.S. Reza, et al., Acacia holosericea: an invasive species for bio-char, bio-oil, and biogas production, Bioengineering 6 (2) (2019) 33.
[85] T. Urmee, A. Md, Social, cultural and political dimensions of off-grid renewable energy programs in developing countries, Renew. Energy 93 (2016) 159–167.
[86] A. Lindfors, et al., Developing biogas systems in Norrköping, Sweden: an industrial symbiosis intervention, J. Clean. Prod. 277 (2020), 122822.
[87] A.M. Hasan, et al., Drivers and barriers to the implementation of biogas technologies in Bangladesh, Biofuels 13 (5) (2022) 643–655.
[88] D. Balussou, et al., A model-based analysis of the future capacity expansion for German biogas plants under different legal frameworks, Renew. Sustain. Energy Rev. 96 (2018) 119–131.
[89] P. Aggarangsi, et al., Overview of livestock biogas technology development and implementation in Thailand, Energy for Sustainable development 17 (4) (2013) 371–377.
[90] N. Yasmin, P. Grundmann, Adoption and diffusion of renewable energy–the case of biogas as alternative fuel for cooking in Pakistan, Renew. Sustain. Energy Rev. 101 (2019) 255–264.
[91] S. Mittal, E.O. Ahlgren, P. Shukla, Future biogas resource potential in India: a bottom-up analysis, Renew. Energy 141 (2019) 379–389.
[92] M. Gao, et al., Biogas potential, utilization and countermeasures in agricultural provinces: a case study of biogas development in Henan Province, China, Renew. Sustain. Energy Rev. 99 (2019) 191–200.
[93] M.K. Commeh, et al., Experimental study of ferrocement downdraft gasifier engine system using different biomass feedstocks in Ghana, Sustain. Energy Technol. Assessments 31 (2019) 124–131.
[94] T. Lönnqvist, et al., Large-scale biogas generation in Bolivia–a stepwise reconfiguration, J. Clean. Prod. 180 (2018) 494–504.