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Role of Biogas in Achieving Sustainable Development Goals in Rohingya Refugee Camps in Bangladesh

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Abstract: Energy is an essential need of people; however, people living in displacement settings are often deprived of this basic need. Connecting refugee camps through the main grid is challenging due to their locations. Biogas is an energy source that can be implemented to address the energy need of refugee camps. Implementation of biogas technology can help to reach sustainable development goal-7 (SDG 7) and its synergies in refugee camps. Therefore, in this study, the contribution of biogas in achieving sustainable development goals is presented to address the current gap in the literature. For this, Rohingya refugees in Bangladesh were considered as a case study. The waste situation in Rohingya refugee camps is highlighted and considered. Generated biogas from the organic fraction municipal solid (OFMSW) was used to determine the LPG cylinder reduction potential in Rohingya refugee camps. Approximately 497,587 LPG cylinders can be replaced if biogas is used in cooking activities. Moreover, compared to wood fuel, biogas used in cookstoves emits 85% less greenhouse gas. This study underlines the importance of further research to determine the prospective use of biogas in clean cooking in refugee camps.

Keywords: Rohingya refugee; biogas; sustainable development goals; displacement settings; Bangladesh; clean cooking

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1. Introduction

The number of people forced to flee their houses due to violence, conflicts, human rights violations, and fear of persecution was 89.3 million in 2021. This number is more than double that of people forcibly displaced a decade ago, and is likely to increase in the near future [1]. These people have a variety of needs, but one of the most crucial for preserving a respectable standard of living is food security. Humanitarian actors generally focus on addressing these challenges by focusing on food access and availability, whereas food utilization, a vital pillar of food security is frequently overlooked [2]. Malnutrition and poor health are caused by a lack of technology for using food appropriately and safely. Additionally, this contributes to the rising case of mortality and creates a situation of ongoing emergency.

Food safety and security are the main concerns of humanitarian emergency responses. However, most of the food supplied by these organizations must be prepared before consumption. Nutrition is greatly influenced by how food is cooked. In Niger, for instance, the supplied food is cooked in the hot water (3 or 4 times a day). Rations are either consumed dry (reducing the nutritional content) or cooked in un boiled water (increasing the danger of diseases) because traditional boiling typically needs a large amount of fuel and takes time [2].

Sustainable energy solutions in this context can be crucial in ensuring effective, consistent, and fair access to fundamental services such as cooking and food preservation. In humanitarian settings, the problem of having access to adequate cooking energy or fuel is directly or indirectly related to other problems, such as protection, host-displaced relationships, ecological damage, and excessive use of natural resources. [3]. A report found that 97% of refugees are deprived of electricity, and at least 80% of people depend on firewood for cooking purposes [4]. In a refugee camp, people, especially women and children, have to travel long distances to gather firewood for cooking purposes, exposing them to physical and sexual attacks and abuses. Women generally handle fuel collecting activities, which increases their security concerns due to the unsafe environment in refugee camps [5]. Women and children suffer from respiratory diseases such as pneumonia and asthma due to smoke created by inefficient cooking appliances [3]. Additionally, refugees frequently sell or trade some of their food allotments to get firewood for cooking the left-over food. In regions where fuelwood is the primary resource, such as Sub-Saharan Africa, rivalry for access to fuel can lead to conflicts between the host populations and refugees. The collection of firewood may result in the deforestation or the destruction of green spaces, having a long-term impact on the ecosystem in the area [3,6]. More than 64,000 acres of land are burnt annually by refugees residing in camps worldwide [3]. The deforestation rate in some of the host countries due to the refugee influx can be seen in Table 1.

Table 1. Deforestation rate due to refugee influx in host countries [3].

Location	Origin	Number	Reference Period	Deforestation Rate
Sudan (Darfur)	Sudan	2 million	2003–2008	The firewood consumption rate is calculated at 1500 tons per day.
DRC (Virunga region)	Rwanda	≈730,000	1994–1996	The firewood consumption rate is estimated at 1000 tons per day
Tanzania (North-Western)	Rwanda	524,000	1994–1996	The firewood consumption rate is measured at 585,000 m^3 per year in Ngara district
Zimbabwe	Mozambique	-	1985–1994	58% reduction in woodland cover around the camps
Malawi	Mozambique	>1 million	1985–1995	The firewood consumption rate is estimated between 500,000 and 700,000 m^3 per year.

The global community is pushing hard to remove these significant burdens and achieve worldwide energy access until 2030. One of the three aims of sustainable development goal 7 (SDG 7) is to "ensure access to reliable, affordable, and sustainable energy for all". This is also linked to several other SDGs [7]. Thus, achieving SDG 7 will secure the accomplishment of other related SDGs [8]. The goals of SDG 7 have been recently updated to provide clean energy in these settlements to address the energy demand and needs of these displaced people and refugees [9]. The United Nations High Commissioner for Refugees (UNHCR) and other organizations and governments have launched an ambitious goal of providing electricity in all displacement settings by 2030 and achieving SDG 7. However, meeting this goal is challenging as many camps are set up in rural and off-grid places [10]. Therefore, the only option is to use the locally available resources of the refugee camps. Renewable energy resources such as biogas can play an essential role in meeting the cooking demands of these refugees. Meeting the cooking demands of these refugees can ensure the UNHCR's goal of achieving SDG 7 for refugees. There has been however, a lack of research on these issues in previous studies. To fill this gap, this study shows how biogas can ensure the achievement of SDG 7 for refugees. The energy situation of Rohingya refugees is highlighted, which has also been lacking in previous studies. Preference has been given to the camp's waste situation, which can be utilized to produce biogas. For this, we used the data in our previous research that deals with waste generation and biogas production in different Rohingya refugee camps [11]. This present study highlighted the role of biogas in cooking activities and future LPG cylinder replacement potential from biogas. A comparison was made between biogas and wood fuel cookstoves to determine the emission reduction potential of biogas. No literature is available to discuss biogas technology's role in fulfilling the SDG 7 and its synergies in refugee camps. Therefore, we believe that this is the first study linking SDG goals and small-scale biogas technologies for refugees. Moving forward, host communities must formulate alternative energy policies for refugees. The results of this study will be helpful for other displacement settings to frame policies regarding clean and sustainable cooking.

2. Current Cooking Energy Situation in Rohingya Refugee Camps

More than 671,000 Rohingya fled from the Rakhine state of Myanmar in 2017 due to armed violence and political instability. This led to an increase in the Rohingya population in Bangladesh from 225,000 to 850,000 [12]. Several makeshift camps were established in Coxsbazar, Bangladesh, to provide shelter for these people (Table 2). Recently, many of these refugees have been relocated to an island named Bashan char [5]. This population is projected to increase, as seen in Table 2. Several national and international agencies are working to provide the basic needs of these people. However, the energy condition of these refugees remains unknown. A report claimed that in 2018 the refugees collected 80% of their fuel from nearby forests [13]. The daily fuel demand for Rohingya refugees is estimated to be 800 tonnes of fuelwood, considering an average of one kilogram of fuelwood per day. On average, 4 ha of forest area is cleared daily, resulting in colossal deforestation [14]. Approximately 95,000 households were provided with compressed rice husks (CRH) as an alternative fuel, and by early 2020, 200,000 LPG stoves were supplied among Rohingya households to ensure clean energy access in the camp [13]. There is a plan to expand the LPG distribution project in the future. A survey reported that the present distribution of LPG does not fulfil refugee's needs [15]. However, firewood remains a significant source of primary energy in the camp. The health and climate impact of using LPG fuel has been highlighted in previous literature [16]. In addition to environmental problems, ecological and biodiversity damage from deforestation has resulted in a staggering financial loss of USD 285 million for the Bangladesh Government [17]. Biogas can be used to fulfil the cooking demand of this camp. However, the current problems that hinder the development of biogas in Rohingya refugee camps are the greater space requirement required for biogas tank technology, making it less suitable in the denser parts of the camps, and the higher investment cost in comparison to on-site sanitation options [15].

Table 2. Rohingya populations in different camps of Cox'sbazar [11].

Camp	Population (2019)	Projected Population (2025)
Kutupalong-Balukhali Expansion1 (Case 1)	439,623	545,618
Kutupalong Registered Camp (Case 2)	25,743	31,950
Leda Makeshift (Case 3)	24,026	29,819
Nayapara Registered Camp (Case 4)	34,557	42,889
Shamlapour (Case 5)	26,326	32,674
Hakimpara (Case 6)	55,181	68,486
Thangkhali (Case 7)	29,704	36,866
Unchiprang (Case 8)	30,384	37,710
Jamtoli (Case 9)	33,298	41,327
Moynarghona (Case 10)	21,464	26,640
Chakmarkul (Case 11)	10,500	13,032

3. Material and Methods

This study presents a strategy to determine the benefits of biogas in achieving sustainable development goals in Rohingya refugee camps in Bangladesh. Different scientific articles, reports, and websites were accessed to collect the necessary data, and numerical analysis was applied afterwards.

3.1. Household Digesters

In Bangladesh, the most used household digesters are fixed dome digesters [18]. In the Rohingya refugee camp, the average number of household members is 6.4 [19]. Considering an average of 1.3–1.95 $\frac{m^3_{biogas}}{household - day}$ is required to supply the cooking demand in a household, a digester of 13 m^3 is required in a Rohingya refugee household.

The needed capital costs to establish a digester on households depending on firewood are estimated as [20].

$$\mathrm{CAPEX_{TD}} = \mathrm{CAPEX_D} \times \mathrm{H_f} \quad (1)$$

where $\mathrm{H_f}$ = households depending on firewood, $\mathrm{CAPEX_{TD}}$ = Capital costs of the digester (USD/digester), and $\mathrm{CAPEX_{TD}}$ = Capital costs of digesters for households depending on firewood (USD).

The number of households having access to electricity is also unknown. Although the area has a grid connection, the families are not connected [21]. It has been reported that diesel generators are powered to supply electricity to two health centres in refugee camps, and cost 200 USD daily [21]. Therefore, it is assumed that 80% of households do not have access to electricity. Small-scale generators can be deployed to the camps to provide electricity to these families.

The capital expenditure required to build household digesters for the people depending on firewood is estimated from the following equation [20].

$$CAPEX_{TE} = H_e(CAPEX_D + CAPEX_E) \quad (2)$$

where: H_e—families without electricity.

$CAPEX_E$—Capital cost of biogas generator (USD/generator).

$CAPEX_{TE}$—Capital costs of electric generator units for households without access to electricity (USD).

In our previous studies, the estimation of biogas was made from OFMSW, as seen in Figure 1 (please check Supplementary File for details). From the figure, it can be seen that about 14 Mm^3 biogas is available in the refugee camps. This biogas can be used for cooking and energy generation purposes. Considering 1 kg of fuel (firewood) per person, a refugee household's monthly average fuel consumption is 198 kg. To replace the consumption of firewood, biogas energy required ($\frac{TJ}{Household-year}$) is estimated from the following equation [20].

$$e_{biogas} = \frac{\left(12\, m_f LHV_f\right)\eta_f}{\eta_{biogas}} \times 10^{-9} \quad (3)$$

m_f—mass of firewood (198 kg/month).

η_f—efficiency of firewood cooking stove or system (4.4%).

η_{biogas}—efficiency of biogas cooking stove or system (57%).

LHV_f—Lower heating value of firewood (16.9 MJ/kg).

Furthermore, the necessary biogas energy required ($\frac{TJ}{year}$) to replace the consumption of firewood at a community level can be estimated from Equation (4) [20].

$$E_{cook} = H_f \times e_{biogas} \quad (4)$$

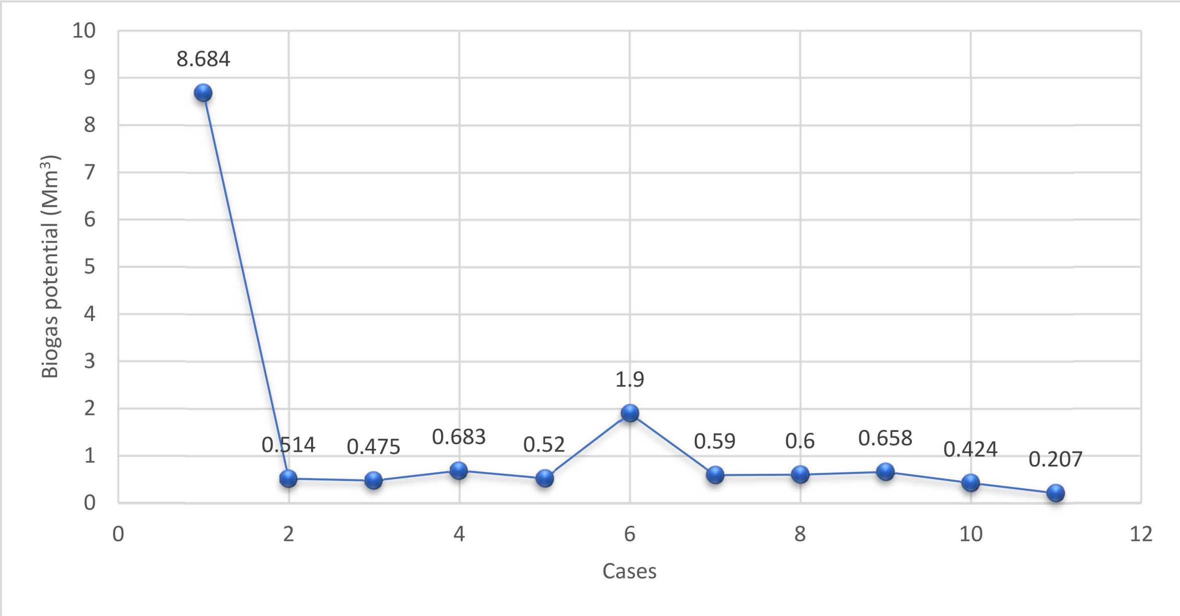

Figure 1. Biogas potential at Rohingya refugee camps.

Basic subsistence consumption (BSC) is the monthly average electricity consumption needed to fulfil basic human needs. According to the UN, the annual minimum energy requirements to meet basic human demand are 100 kWh of electricity and 100 kg of oil equivalent fuels, which match the emission threshold of 0.41 tCO_2 eq. per capita [22]. Therefore, the average energy $\left(\frac{TJ}{year}\right)$ required to meet the BSC of the refugee community can be estimated from Equation (5) [20].

$$E_{elect} = BSC \times 12 \times 3600 \times H_{we} \times 10^{-9} \tag{5}$$

H_{we}—Households having no access to electricity.

3.2. Environmental Analysis

In our analysis, the global warming potential (GWP) of firewood and biogas was determined. A comparison was made between substitute fuel and biogas to determine the GHG emission from biogas production and application. Consequently, a comparison was made between the combustion of biogas and substituted firewood to calculate the GWP of CH_4, CO_2, N_2O, and CO emissions. The amount of methane that must be produced per unit of energy supplied to heat water was calculated using Equation (6) [23].

$$M_p(f_l) = \frac{1}{SEC_{CH_4} \times 0.57(1 - f_l)} \tag{6}$$

where:

$M_p(f_l)$—amount of methane that is required to be generated per unit of energy supplied to heat water (kg MJ^{-1});

f_l—fraction of biogas lost through intentional releases or leakages;

SEC—specific energy content of CH_4 (59 MJ/kg).

Value of 0.57—biogas stove efficiency.

It was reported that from small-scale biogas plants, 40% of biogas could be lost through leakage [23–25]. This study considered this worst-case and took 40% as a reference.

Subsequently, the amount of lost CH_4 per unit of energy delivered is as follows:

$$M_l(f_l) = f_l M_p(f_l) \tag{7}$$

After that, the method from Bruun et al. was followed to calculate the GWP per unit of energy delivered (g CO_2-eq. MJ^{-1}), highlighted in Equation (8) [23,24].

$$IPB_{GW}(f_l) = M_l(f_l)CF_{CH_4} + ECB_{CH_4}CF_{CH_4} + ECB_{N_2O}CF_{N_2O} + ECB_{CO}CF_{CO} + ECB_{CO_2}CF_{CO_2} \tag{8}$$

where:

ECB—(g GHG) GHG emissions during fuel combustion.

CF—(g CO_2-eq. g^{-1}) characterization factor of CO_2, CH_4, N_2O and CO. For CO, CO_2, N_2O, and CH_4, the values are 1.9, 1, 295, and 25 g CO_2-eq. g^{-1}, respectively [23–25].

Equation (9) was employed to estimate the impact potential of emissions from the replaced fuels (g CO_2-eq. MJ^{-1}) since the GWP emissions of substituted fuel (wood) are not linked to the losses of CH_4 of biogas plants:

$$IPR_{GW} = ECR_{CH_4}CF_{CH_4} + ECR_{N_2O}CF_{N_2O} + ECR_{CO}CF_{CO} + ECR_{CO_2}CF_{CO_2} \tag{9}$$

where:

CF—(g CO_2-eq. g^{-1}) characterization factor of CO_2, CH_4, N_2O and CO

ECR—(g GHG) GHG emissions during replaced fuel combustion

Then, Equation (10) was utilized to measure the emission prevented due to the use of biogas instead of firewood.

$$\text{Avoided GHG emissions} = \frac{\text{GHG emissions of firewood} - \text{GHG emissions of biogas}}{\text{GHG emissions of firewood}} \times 100 \tag{10}$$

4. Results and Discussion

4.1. Present Waste Situation and Economic Benefit of AD

Generally, 2 and 10 m^3 biogas digesters with a 40–90 days retention time are built in a household [26,27]. The average cooking demand of a household for biogas ranges between 0.2 to 0.3 $\frac{m^3_{biogas}}{person - day}$, while the volumetric production rate of biogas typically varies from 0.15 to 0.30 $\frac{m^3_{biogas}}{m^3_{digester}\ day}$ [22]. There are several biogas digesters available on the market. Tubular designs have lower costs, and floating drum designs have the highest capital cost among biogas digesters. Fixed dome designs have a higher cost than tubular designs, but their lifespan is longer [28,29].

In the previous analysis, we estimated that in 2019, 110.98 Mt of waste was generated in the eleven refugee camps hosting Rohingya refugees, and it was also predicted that the camps would see an alarming rise in waste generation soon [11]. The expected waste increase was estimated to be 136.56 Mt in 2025. Municipal solid waste (MSW) has a devastating effect on the environment since it can contaminate air, soil and water. The poor management of MSW poses a significant danger to human health. This situation is observed in the Rohingya refugee camps. A report published by UNDP highlighted the waste situation in the refugee camps as severe [30]. Therefore, the best way to handle this situation is to use this waste to produce sustainable bioenergy effectively. Generally, MSW constitutes 46% of organic fraction, trailed by paper waste (17%), plastics waste (10%), glass 5%, metal 4%, and other miscellaneous waste (18%) [31]. If the Organic Fraction MSW (OFMSW) can be utilized systematically, it could be a valuable feedstock for generating renewable bioenergy. Various technologies are adopted to use OFMSW, and anaerobic Digestion (AD) has emerged as the most suitable way to utilize this waste and other substrate for bioenergy production. AD is a feasible and economical technology for waste management. AD converts OFMSW into biogas which can be further used to generate electricity or heat. It is a well-established technology since over 560 plants are running worldwide currently. OFMSW has a high bioenergy production potential of up to 200 m^3 (400 kWh) per ton; and is highly biodegradable. About 330 L CH_4 can be produced per kg of volatile solids [32]. Furthermore, AD of organic waste produces energy and biogas and has the advantage of preventing odor release and minimizing pathogens. Refugee camps are taken as a temporary solution to existing circumstances. Moreover, their transitory nature usually discourages the execution of multiple critical concepts such as sustainability, environmental impact, and the circular economy, among many others. Nevertheless, some refugee camps remain in operation for several years while some eventually transform to provide permanent living conditions. Implementation of AD can help towards sustainability and a circular economy in these refugee camps, and setting up an AD plant requires little investment and cost. Figure 2a shows the cost of pretreatment technologies, while Figure 2c shows the price of composting technologies in Bangladesh.

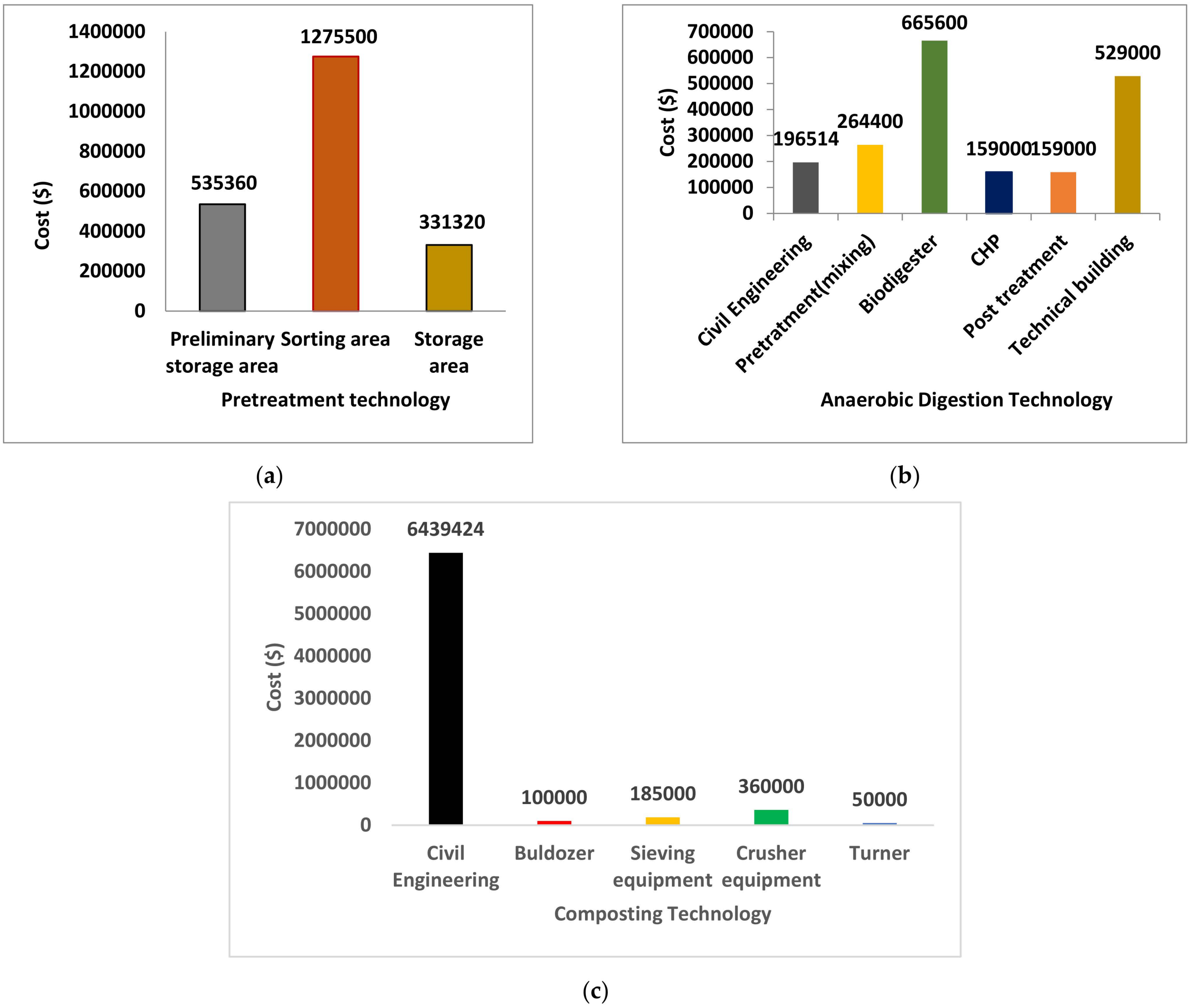

Figure 2. Costs related to pretreatment, anaerobic digestion and composting in Bangladesh [33].

Figure 2b shows the cost of setting up an anaerobic digestion plant in Bangladesh. As stated earlier, the Rohingya refugee camps' waste situation is getting worse, and small-scale AD plants can be used to transform this waste into bioenergy. In total, 137,426 households will be dependent on firewood if no other alternative is proposed. Considering 6.6 person in every household, a 13 m^3 biodigester will be needed per household. It will require a capital investment of USD 510, USD 1243, and USD 2383 to build up a polyethylene, geomembrane and fixed dome digester, respectively, for a single-family (based on the data from Table 3). Therefore, capital expenditure of 327.48 million USD will be required to build up fixed dome digesters for every household, while 70 million and 170.82 million USD will be necessary for polyethylene and geomembrane digesters. Determining repair and maintenance expenses during the lifespan of digesters is also needed to evaluate factors that presently cause the limited success of this technology in rural families globally. In some cases, the availability of organic waste probably justifies considering large-scale communal digesters to supply several households. Moreover, the number of households without electricity will be 109,941. A 5 m^3 digester will be needed considering a BSC of 100 kWh electricity/month [20], and 198 USD will be required to build up a polyethylene digester. The cost of different digester technologies is shown in Table 3.

Table 3. Capital and operational expenditures of different digesters [20].

Digester Size (m^3)	CAPEX (USD)			OPEX (USD/year)			Total (USD)		
	Poly.	Geo.	Fixed	Poly.	Geo.	Fixed	Poly.	Geo.	Fixed
4	-	-	1083	-	-	43	-	-	1949
5	198	480	-	794	961	-	992	1441	-
6	-	-	1333	-	-	53	-	-	2399
8	-	-	1583	-	-	63	-	-	2849
10	392	956	1833	1568	1912	73	1960	2868	3299
15	585	1431	-	2341	2863	-	2926	4294	-

Geo.—Geomembrane, Poly.—Polyethylene.

Furthermore, to produce 0.85–1 KW of power, a biogas generator is needed at an average expense of 100 USD per unit. Accordingly, 32.76 million USD will be required to build an electricity generator combined with a digester system in the Rohingya refugee community lacking electricity (Equation (2)). However, it should also be noted that this cost will increase considering the cost of training facilities and labour in refugee camps. The proposed biogas plant will not only cover treatment of organic waste but also will support recycling and composting facilities because there is a vast market potential for recyclable materials in Cox'sbazar. The cost of setting up these facilities is provided in Figure 2. The collection rate of materials was 75% in Coxsbazar in 2020, and this is projected to be 90% in 2025 [33]. Metals, textiles, and plastic are mostly recoverable materials (Table 4) and can be sold to earn revenue. Each household's estimated revenue after selling these materials is 186 taka/month [33]. Compost can be generated from the surplus of organic waste. This compost can be sold to local markets to earn revenue. From one ton of organic waste, 0.25-ton compost can be produced [34]. An estimated 10–11 USD can be earned annually from selling this compost.

Table 4. Recoverable materials and revenue earned from waste collection.

Recyclable Materials	Cost (USD/kg)	Recovery Rate (%)	Revenue Earning	Collection Fee (USD/month)
Paper	0.16–0.21	40	Normal Collection rate	1.37
Plastic	0.25–0.29	50	Collection rate (CR) + 5% increase	1.44
Glass	0.21–0.22	Not available	CR + 15% increase	1.58
Metal	0.39–0.43	80	CR + 30% increase	1.78
Others (textile) [a]	0.17–0.18	75	CR + 50% increase	2.06

1 Taka—0.011 USD; [a]—Textile is generally collected at cities, so the cost will come down to 10 tk/kg.

However, the implementation of AD requires overcoming several obstacles. For energy production, any biodegradable organic material can be digested. However, the physical and chemical properties of feedstock often pose a significant challenge in selecting the appropriate technology. Moisture content and feedstock size need to be considered when selecting technology. Excessive or low moisture content affects bacterial growth in the system and creates problems in digester feeding. The primary feedstock candidate is animal manure and agricultural residues containing cellulose, hemicellulose, and lignin-based materials. However, the biodegradability of the organic substrate is decreased with increased lignin content resulting in a slower hydrolysis stage. However, different chemical, thermal and mechanical pretreatment processes are available to enhance the solubility or hydrolysis of the digester's organic materials. For example, conventional heating of organic materials improves their hydrolysis [35]. Piping in the AD process is subjected to freezing during the winter season. Any piping that regularly contains even tiny amounts of water should be heat-traced and properly insulated to avoid freezing [36]. Moreover, pumps in the AD process are vulnerable to failure. Pumps can be damaged due to a lack of fluid movement (blocked discharge). A pressure gauge on each side of the pump can help to avoid this situation [36].

4.2. Emission and LPG Reduction Potential

Our previous analysis estimated the biogas production from OFMSW in several Rohingya refugee camps. In 2019, approximately 7.16 million m^3 (Mm^3) of biogas could have been produced, which will rise to 14.43 Mm^3 in 2025. From Kutupalong- Balukhali Expansion 1 camp, an average of 4.31 Mm^3 of biogas can be generated annually, rising to 8.68 Mm^3/year in 2025 [11]. Since the collection factor has a significant effect on waste collection and thus leads to biogas production, increasing the collection rate can significantly boost biogas production. It has been found that a 25% increase in collection rate would yield 50% more biogas than before. This biogas can be used to meet the Rohingya's cooking demand. Considering 29 m^3 biogas equivalents in a 1 LPG Cylinder of 14.2 kg, an estimated 497,587 LPG cylinders can be replaced in 2025 (a sample calculation is given in the Supplementary File). Among eleven camps, approximately 299,435 LPG cylinders can be replaced from Kutupalong- Balukhali Expansion camp 1 alone (Figure 3). From camp 6, 87% fewer LPG cylinders can be removed compared to camp 1. Considering the CO_2 emission factor and the calorific value for LPG (63 g/MJ and 46.4 MJ/kg [37,38], respectively), we estimated the total CO_2 avoidance if biogas is used instead of LPG. The analysis found that a total of 20.69 million kg of CO_2 could be avoided from these camps if biogas were used in cooking activities (Figure 4). Approximately 12.43 M kg of CO_2 could be reduced from the first camp, which would be 88% higher than camp 6. The lowest CO_2 avoidance would be from camp 11, at 0.3 M kg. The global warming potential of the biogas of firewood was also determined. To determine the global warming potential of biogas instead of wood fuel, we followed and applied the methodology of [23–25] (detailed calculation in the Supplementary File). Around 3 TJ/year of energy is required for a single-family to replace firewood consumption, while to guarantee BSC to the energy-deprived people, 474.94 TJ of energy is needed annually. It was also observed that 85% of greenhouse gas can be avoided if biogas is used in a standard biogas stove rather than wood fuel (based on the data from Table 5). From Table 5, it can be seen that the emission of GHG is very high when wood fuel is combusted instead of biogas. If wood fuel is used instead of biogas, this results in 90% greater emissions of CH_4. The combustion of biogas also generates carbon dioxide, but there is no net increase in atmospheric carbon dioxide because the amount of carbon dioxide fixed in the biodegradable feedstock equals the amount released through biogas combustion. Nevertheless, AD is associated with several greenhouse gases, namely methane, carbon dioxide, and nitrous oxide. Drastic steps should be taken to decrease these emissions. Several measures such as avoiding leakage, use of flares to avoid methane discharge, enhancement of efficiency of combined heat and power units, proper use of cover, and enhancement of an electric power utilization strategy, can be used to exploit as much thermal energy as possible [39].

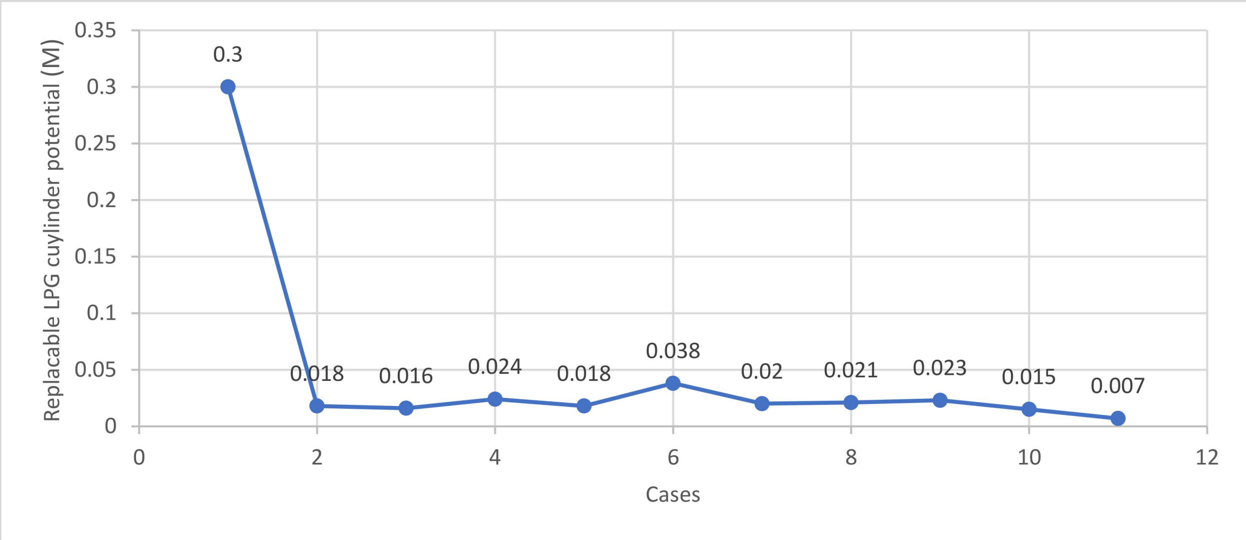

Figure 3. LPG cylinder reduction in refugee camps.

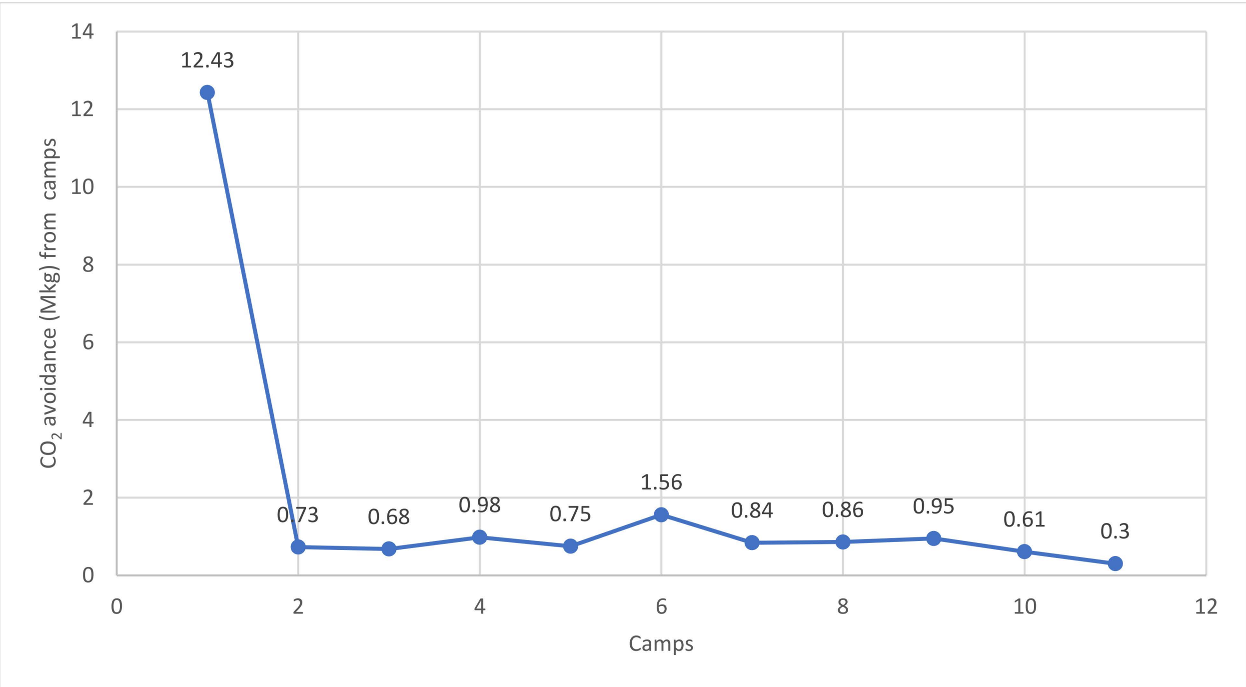

Figure 4. CO_2 avoidance from different camps after using biogas as cooking fuel.

Table 5. Emission of GHG gas during the combustion of wood and biogas [23].

Emission of Gas during per MJ of Supplied Energy	CO (g)	CO_2 (g)	N_2O (mg)	CH_4 (mg)
Biogas	0.1	81.5	5.4	57
Wood	14	532	4.3	600

5. Biogas for Meeting SDG in Refugee Camps

This section highlights the contribution of biogas in obtaining three pillars of sustainable development such as environmental, economic and social. Details of biogas and its contribution can be found in Table 6.

Table 6. Endowment and interrelations of biogas to sustainable development dimensions (SDDs) and sustainable development goals (SDGs).

Sustainable Development Goals	Contribution of Biogas	Sustainable Development
SDG 1: No poverty	• Generating jobs.	Economic
	• Eliminates the complex issue of fertilizer supply chain and assists the smallholder by providing valuable fertilizer [40,41]	
SDG 2: Zero hunger	• Enrich yields by supplying fertilizer.	Economic
	• Recirculating nitrogen (N), phosphorus (P), potassium (K) throughout the digestion process [40,42].	
	• Improving the soil condition by retrieving carbon, organic matter, and lost nutrients.	
SDG 3: Good Health and Well-being	• Diminishing methane emission [40,43]	Social
	• Decreasing the vulnerability to hazardous materials by burning the biogas [40,44]	
SDG 4: Quality Education	• Growing energy accessibility in rural areas will enhance the rate of education [40].	Social
SDG 5: Gender Equality	• Supplies an inexpensive source of energy to the local residents in the rural area, which leads to enhancing the quality of life of women and children [45]	Social
SDG 6: Clean Water and Sanitation	• Wastewater treatment facilities are enhanced due to energy availability, and thus, water quality is upgraded [46].	Environment
	• In remote locations, decentralized wastewater treatment facilities can be provided.	
SDG 7: Affordable and Clean Energy	• Enhancing overall energy storage capacity, energy supply reliability, sustainability, and affordability [47].	Environment
SDG 8: Decent work and Economic Growth	• Reusing waste materials reduce the carbon footprint and increases the GDP [48,49].	Economic
SDG 9: Industry, Innovation, and Infrastructure	• Enabling sustainable infrastructure. Value-added to waste materials as it converts into energy.	Economic
	• Acts as a renewable energy resource for a small-scale industrial farm [50].	
SDG 11: Sustainable Cities and Communities	• Improvement of waste management processes enhances air quality as bad odors are decreased [40].	Social
	• Access to electricity is increased [51].	
SDG 12: Responsible Consumption and Production	• Enhance in waste utilization improves the resource utilization efficacy, and thus, air and water pollution are decreased [52].	Environment
SDG 13: Climate Action	• Reduce GHG and methane emissions from landfills and livestock industries [40,53].	Environment
SDG 14: Life Below Water	• Reduced land-based pollutions contribute to lower marine pollutions.	Environment

Table 6. *Cont.*

Sustainable Development Goals	Contribution of Biogas	Sustainable Development
SDG 15: Life on Land	• Replacement of solid fuels contribute to lower deforestation rate [40].	Environment
	• Improvement in both freshwater ecosystem and land-use productivity [54].	
SDG 16: Peace and Justice Strong Institutions	• Increase in power accessibility and affordability is interconnected to peace in some extent [40]	Social

From Table 6, it is clear that biogas has a considerable role to play in fulfilling the sustainable development goals in refugee camps. Among these goals, biogas has a significant effect on SDG 7. Generated biogas in refugee camps can be used to either provide electricity or cooking fuel. Refugee camps not connected to the grid can become self-sufficient in terms of energy by utilizing biogas. Biogas can be stored in a small-scale gas holder and a digester when excess gas is available, or injected into an existing grid with other energy sources to fulfil base and peak loads. Unlike other fossil fuels, biogas has fewer environmental effects. The burning of biogas causes less environmental damage than diesel. Land-use change and fossil fuels contribute 38×10^{15} and 33×10^{15} tons, respectively, of GHG annually. Greenhouse gas emissions, depletion of cultivated area and desertification can be reduced if a household digester is used. Using biogas in cooking activities can ensure health benefits for children and adults. According to Zhang et al., the primary cause of premature death in China is indoor air pollution [55]. More than 420,000 premature deaths occur each year due to indoor air pollution. Exposure to indoor air pollution increases the risk of pneumonia, responsible for 45% of the deaths of children under five years [56]. This situation is very severe in a refugee camp since fewer ventilation facilities exist. In Rohingya refugee camps, almost 200,000 households need to change their cooking facilities [56]. A bottle gas scheme using biogas can be highly beneficial in this regard, as clearly outlined with SDG 3 and 13. As previously stated, the impact of refugees on firewood collection can increase desertification and deforestation. The incoming of Rohingya have increased the possibility of deforestation in Coxsbazar, and soil quality and land cover were altered after the arrival of refugees [57,58]. After the production of biogas, the leftover liquid and solid fractions could be used as fertilizer to improve the fertility rate of the soil. This would improve agriculture productivity and will ensure SDG 2 and 15.

Furthermore, biogas can help achieve SDG 5 and 6 in refugee camps. Rohingya in refugee camps have fewer facilities for pure drinking water [59]. Biogas produced from wastewater AD can be used to run a desalination plant to produce clean water. Access to electricity will also ensure the security of women, which can improve their lifestyles. Setting up a biogas plant in a refugee camp can ensure employment opportunities. In 2019, 23,000 full-time operational positions and about 335,000 temporary construction jobs had been created by the biogas business. In China, 209,000 workers are supported by the biogas business [60]. Therefore, setting up a biogas plant in refugee camps can help achieve SDG 8 and 9.

6. Conclusions

Biogas is the most promising fuel to provide electricity in refugee camps. The contribution of biogas in achieving sustainable development goals in refugee camps was investigated in detail in this study. Expected waste generation in the Rohingya refugee camp in 2025 will be 136.56 Mt. From this waste, 14.43 Mm^3 of biogas can be generated in 2025. A significant contribution of biogas was found in achieving SDGs 2, 3, 7, 8 and 9, 11, 12, 13 for refugees. The environmental benefits of using biogas in cooking activities instead of wood were observed in this study. It was found that 85% of emissions can be avoided if biogas is used for cooking activities rather than wood fuel. Moreover, if biogas is used in cooking activities, 20.69 million kg of CO_2 will be avoided, making it a positive option for policymakers. Furthermore, 497,587 LPG cylinders will be replaced if biogas is used in refugee camps. Using biogas in cooking will also protect women's health, and a reduction in air pollution will avoid premature deaths. To build an electric generator combined with a digester system in the Rohingya refugee community lacking electricity would cost 32.76 million USD. Despite the availability of mini-scale bio-digesters in rural households, the application of these plants for energy generation and clean cooking in refugee camps have not been thoroughly investigated. Thus, it is recommended to adopt a holistic approach to collect more data to estimate actual biogas generation and application in refugee camps. Future studies should determine the applicability of hybrid cookers consisting of biogas and solar in these camps.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su141911842/s1, Table S1: Emission of GHG gas during the combustion of wood and biogas.

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Nomenclature

LPG	Liquefied petroleum gas
MSW	Municipal Solid Waste
SDG	Sustainable Development Goals
UNHCR	United Nations High Commissioner for Refugees

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