e-ISSN: 2548-060X

International Journal of Energy Applications and Technologies

journal homepage: www.dergipark.gov.tr/ijeat

Original Research Article

Techno-economic assessment of biogas energy from animal wastes in central areas of Palestine: Bethlehem perspective

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ARTICLE INFO

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Received July 16, 2018
Accepted October 2, 2018

Published by Editorial Board Members of IJEAT

doi:

ABSTRACT

This study was carried out to assess the biogas potential at the central area of west bank at Palestine, mainly at Ramallah and Bethlehem regions. Due to the high demands and limitation of sources, Palestine suffers from electrical capacity shortage during winter time. However, the main objective of the study is to make an assessment of biogas potential and plant design at central regions at west bank. The study was implemented on one 33kV line with a power demand of 19.5 MVA. It is feeding the resident area of east Bethlehem villages. The digesters volume for the feedstocks was estimated and the material requirements for the digesters were also determined. The techno-economic analysis of the proposed project was also evaluated. Furthermore, the study clearly described the effects of the plant on the existing network with respect of voltage profile, power flow, and power losses. Finally, an economic analysis of the system will be evaluated. The results suggested that the proposed project was feasible, and it was concluded that the potential in Bethlehem region is capable of producing enough biogas to support the electric network.

Keywords: Biogas potential, Anaerobic digester, Renewable energy, Distribution generation, Voltage profile

1. Introduction

The natural resources in the form of fossil fuels are the raw materials from which electrical energy is generated and the day to day life of the people of today's world is mainly dependent on the electrical energy. The world's energy markets have relied heavily on the fossil fuels. However, biomass is the only other naturally occurring energy-containing carbon resource that is large enough in quantity to be used as a substitute for fossil fuels. The waste materials can be a good source of energy as the amount of waste is increasing every day and can help in meeting the electrical energy not only in Palestine but also in the world. Many countries are now switching to renewable energy sources as they are clean and a suitable substitute for fossil fuels. The production and utilization of biogas provides environmental and socioeconomic benefits for the society. Furthermore, utilization of the internal value chain of biogas production enhances local economic capabilities, safeguards jobs in rural areas and increases regional purchasing power. It improves living standards and contributes to economic and social development.

There is a large volume of published studies describing the methods and process of producing biogas by anaerobic digestion. Weiland [1] reviewed the literature from the period and compared the parameters which affects the gas yield in the anaerobic digestion. He examined the influence of the biochemical parameters and feedstocks on the microbial conversion and the gas output. A significant analysis and discussion on the enhancing the biogas production was presented by Yadvika et al. [2] Different methodologies for improving the gas production yield from solid substrates were examined. Grando et al. [3] traces the development of biogas production in anaerobic digestion plants. The study focused on the European Union countries and compared between academic published articles and technology development evolved from 1990 to 2015. Also, the study examined the potential of biogas throughout Europe. The current study found that Germany is the obvious leader in both academic and the commercial applications of the technologies, followed by Italy, Spain and Sweden.

A considerable amount of literature has been published by Hogs et al. [4]. He reviewed the research progress and challenges of anaerobic co-digestion technology, as well as the contribution of different techniques in biogas production. This study set out to designing and developing a framework, including various aspects to improve the biogas production is essential. Another paper by Chienet al. [5] reviewed the biogas production in food waste. The aim of the present research was to examine the potential of biogas of food waste and to intend methods for increased biogas production. A significant analysis and discussion on the subject was presented by Abdeshahian et al [6]. This study was designed to determine Potential of biogas production from farm animal waste in Malaysia. Together, this study indicates that the biogas potential from the organic waste obtained from animal farms in 2012 is about 4589.49 million m^3/year and could generate electricity up to 8.27×10^9 kWh per year. Another study by Igliński et al. [7] investigated the potential of biogas production in Poland. The most obvious finding to emerge from the analysis is that 39.44 PJ of energy could be obtained from biogas. This would result in meeting energy demand by 7.5% in Poland.

Santos et al. [8] analysed the energy generation and biogas potential from landfill and wastewater treatment plants in Brazil. The obtained electricity potential could supply 10% of the studied city. Mosayeb Nezhad et al. [9] conducted techno-economic analysis of biogas-fed combined heat power hybrid systems in a real wastewater treatment plant. The new configuration can increase the electricity coverage up to 15% in the existing network. A noteworthy analysis and discussion on the subject has been presented by Al-Maghalseh [10-15] on several real life case studies of embedded distribution generations. Many articles studied the production process and methane yield from animal manures. Amon et al. [16] studied the potential and production of methane from maize and dairy cattle manure. Cuéllar and Webber [17] analyzed the benefits of converting cow manure to biogas on the energy and environment by reduce the emissions. Pham et al. [18] tested the methane production and potential of pig manure, cow manure and cellulose using batch fermentation. Another article by Svanberg et al. [19] analysed the production of biogas from horse manure. Recently, Meyer et al. [20] studied the potential of biogas from several type of animal manures, straw by-products from cereal production, and excess grass from rotational and permanent grasslands and meadows. The results show that The biogas energy potential corresponds to 2–3% of the average EU gross energy consumption in the period between 2005 to 2015.

The main aim of this study is to investigate biogas potential in central regions at West Bank in Palestine. The techno-economic feasibility study of the proposed biogas plant in the region was also discussed. Furthermore, the study clearly described the effects of the plant on the existing network with respect of voltage profile, power flow, and power losses.

2. Biogas Potential and Sizing the Digesters

A biogas potential study has been encountered to determine the different available sources for biogas energy. Different statistics were studied to determine the available animals manure. The available animal manure in this region is cows, sheep & goats, chickens [21]. Table 1 and 2 show the statistics of animal waste (manure) available at both Ramallah and Bethlehem regions. Table 1 show that the total manure available from several type of animals at Bethlehem region expected to be as the following: Cows: 52,260, Sheep: 79,798, Goats: 55,282, and Chicken: 34,176 kg/day. From table 2, the total manure available at Ramallah region expected to be as the following: Cows: 14,700, Sheep: 71,176, Goats: 48,191, and Chicken: 82,908 kg/day.

Several methods are used for designing the biogas digesters. However, several theories such as Total Solid (TS), Hydraulic Retention Time (HRT), Fresh Discharge (FD), and the Liquid Part (LP) are needed for the sizing the digester. It is assumed that the HRT is 50 days for the average temperature of 30 ºC. Table 1 presents the solid and liquid content of the cow and chicken manures [6].

Table 1. The solid and Liquid content of common fermentation materials [6].

Materials	Dry Matter Content (%)	Water Content (%)	TS value of fresh discharge (% by wt.)
Cow	16	84	16
Chicken	20	80	20

The Fresh Discharge (FD) can be calculated as the following:

$$FD = Total\ Manure\ \left(Kg/day\right) \times Dry\ Matter\ Content\ \left(\%\right) \quad (1)$$

The fresh discharge need to be mixed with additional water in order make the total solid value reach 8% for the favourable conditions. Consequently, the total influent (Q) shall be calculated as the following:

$$Q = \frac{\text{FD}}{TS\%} \quad (2)$$

The required water need to be added to the fresh discharge in order to make the total solid 8%, can be calculated as the following:

$$W = Total\ Discharge - Q \quad (3)$$

Different digesters were introduced depending on the type of manure. The volumes of the digesters were calculated from the following equations [22]:

$$V_d = Q \times HRT \quad (4)$$

$$V_d = V_{gs} + V_f + V_c + V_s \quad (5)$$

where, V_d is the volume of the digester in cubic meters, Q is the total infant in kilograms, HRT is the retention time in days, and V_c, V_{gs}, V_f, V_s, V_H are the volumes of gas collecting chamber, gas storage chamber, fermentation chamber, sludge layer and hydraulic chamber, respectively.

Table 2 presents the geometrical assumption for the digester design [22]. The calculations for the proposed digester for the potential of the cow manure at Bethlehem were presented at the table. Similar procedure can be repeated for the sizing of other digesters.

Table 2. Geometrical assumption for digester design

For Volume	For Geometric Dimensions	Calculated
Vc ≤ 5% V	D = 1.3078 × 101$^{/3}$	22.69505
Vs ≤ 15% V	V1 = 0.0827 ^{D3}	966.71602
Vgs+Vf = 80% V	V2 = 0.05011 ^{D3}	585.75743
Vgs = VH	V3 = 0.^{3142D3}	3672.8195
	R1 = 0.725D	16.453911
Vgs = 0.5 (Vgs + Vf + Vs)K, where K is the Gas production rate per m3 per day.	R2 = 1.0625D	24.11349
	f1 = D/5	4.5390099
	f2 = D/8	2.8368812
	S1 = 0.^{911D2}	469.22446
	S2 = 0.^{8345D2}	429.82197

Table 3. Biogas potential in Bethlehem region.

Animal	Heads at Bethlehem	Manure (kg/day)	Total Manure (kg/day)	FD (kg)	The total influent (Q)	Water (kg)	Digester Volume (m^3)
Cow	1742	30	52260	8362	104520	52260	5226
Sheep	43981	1.82	79798	12768	159596	79798	7979.78
Goat	30469	1.82	55282	8845	110564	55282	5528.20
Chicken	227839	0.15	34176	5468	68352	34176	3417.59
The Potential of Biogas				**The Potential of Methane**			
Animal	**Biogas (L/Kg)**	**Biogas (L/day)**	**Methane %**		**Methane (L/day)**	**Methane (m^3/day)**	**Electricity (kWh)**
Cow	40	2090400	60		1254240	1254	2621.36
Sheep	60	4787868	63		3016357	3016	6304.17
Goat	60	3316922	63		2089661	2090	4367.39
Chicken	70	2392310	70		1674617	1675	3499.95
The Total electricity (kWh)							**16792.8884**

Table 4. Biogas potential in Ramallah region.

Animal	Heads at Ramallah	Manure (kg/day)	Total Manure (kg/day)	FD (kg)	The total influent (Q)	Water (kg)	Digester Volume (m^3)
Cow	490	30	14700	2352	29400	14700	1470
Sheep	39229	1.82	71176	11388	142352	71176	7118
Goat	26561	1.82	48191	7711	96383	48191	4819
Chicken	487696	0.17	82908	13265	165817	82908	8291
The Potential of Biogas				**The Potential of Methane**			
Animal	Biogas (L/kg)	Biogas (L/day)	Methane %		Methane (L/day)	Methane (m^3/day)	Electricity (kWh)
Cow	40	588000	60		352800	353	737.352
Sheep	60	4270555	63		2690450	2690	5623.04
Goat	60	2891489	63		1821638	1822	3807.22
Chicken	70	5803582	70		4062508	4063	8490.64
The Total electricity (kWh)							**18658.26**

3. Integrate The Plant into The Grid

Based on this study, it was considered that the best location for the Biogas plant would be in Zatara. Za'atara is located 11 kilometers southeast of Bethlehem.The town is in the Bethlehem Governorate central West Bank. Many reasons behind the selection of this location:

1. It is closed to many animal farms that produce a large amount of animals manure and this will help reduce transportations costs.

2. Availability and proximity to the high tension 33kV line that will drastically reduce connections and electrical infrastructure fees.
3. There exists adequate supply of water.
4. The land is very well ventilated and has a good exposure to sunshine most of the day time.
5. Availability of enough space and land to build up the biogas plant.
6. The relatively low cost land prices in comparison to others in the considered district.

Ease of issuing the required licenses for such a biogas plant being far enough from the populated areas. The design of the plant depends on many factors, the expected available manure and amount, the requested power production, and the maximum capacity of the line. Considering the available manures in the area, the amount of generated electricity will be up to 16.8 MWh at Bethlehem and 18.7 MWh in Ramallah. The proposed capacity for the biogas plant will be up to 7 MWh, due to the limitation on the network and maximum power demand at the proposed location. The design will include twelve digesters (six main digesters and six post digesters). Considering the expected amount of gas generated in the digesters and the targeted power production, seven gas engines with the capacity of 1MW will be used. Combined heat and power (CHP) type will be used. The electricity power will be injected into the grid and the heat power will be used for heating the digesters. The digester containers must be absolutely gas and water proof, as well as airtight. They are built from ferroconcrete and each digester should contain a stirrer, which is very important for keeping the substrate homogeneous and guaranteeing that the gas produced is evenly discharged. Figure 1 shows the general design for the biogas plant.

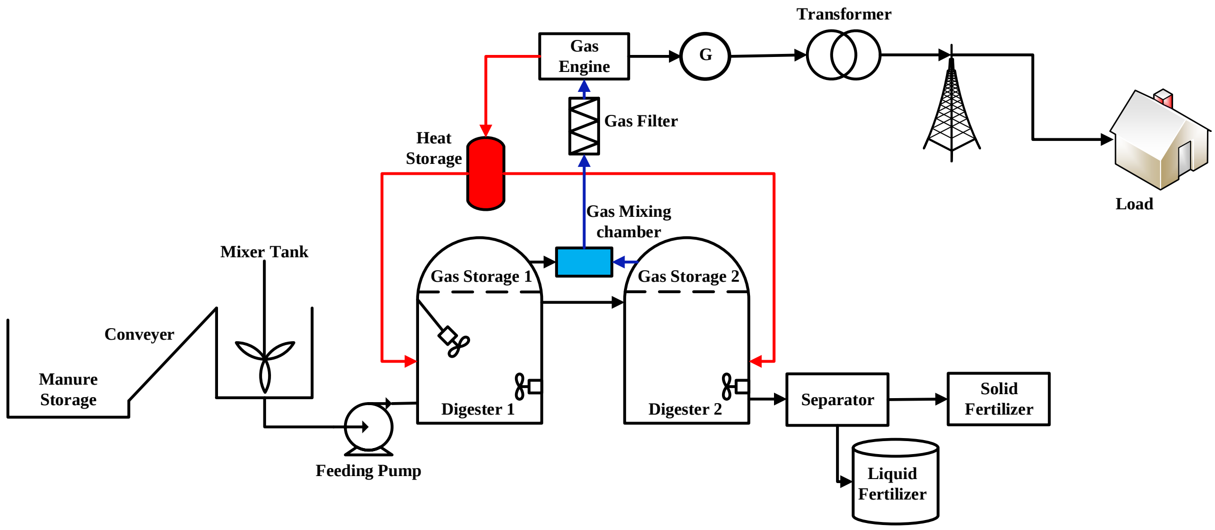

Figure 1. General design for the biogas plant

The integration of the biogas plant to the 33kV grid network is shown in Figure 2. The existing 33kV network consists of 46 buses with maximum load of 19.5 MVA. The proposed location of the new biogas plant is located between buses 37 and 38. The proposed capacity of the plant is about 7MWh. Open Distribution Source Simulator (OpenDSS) program was used to study the impact of generation plant on different technical parameters. The simulation study will make the required technical assessment for the proposed location and its impact on the 33kV grid. All line parameters and loads was gathered and a simulation study was carried out using OpenDSS simulator for simulating several cases of load and proposed biogas plant generation.

Five case studies are considered under this study, these are: Case (1): Study network behavior at minimum load and without biogas plant generation. Case (2): Study network behavior at maximum load and without biogas plant generation. Case (3): Study network behavior at maximum load and with minimum biogas plant generation. Case (4): Study network behavior at minimum load and with maximum biogas plant generation. Case (5) Study network behavior at maximum load and with maximum biogas plant generation.

Fig. 3 shows the voltage profile at the network. It can be seen from the figure that the voltage profile enhanced on all the buses at the network. However, the high improvement was noticed at the onward buses from the source. The enhancement was in between 1.5% to 4% depending on the situation of load and generation, while the voltage profile enhancement decreases when moving closer to the source bus. On the other hand, the voltage profile was limited within the regulation of ± 5%.

Fig. 4 shows the total power losses in the system. It can be seen that the power losses in the system decreased significantly by 85% for the case 4 compared to that of case

1 and by 58 % for the case 5 compared to that of case 2. Consequently, the proposed Biogas plant is significantly improved the system performance and enhance the network quality.

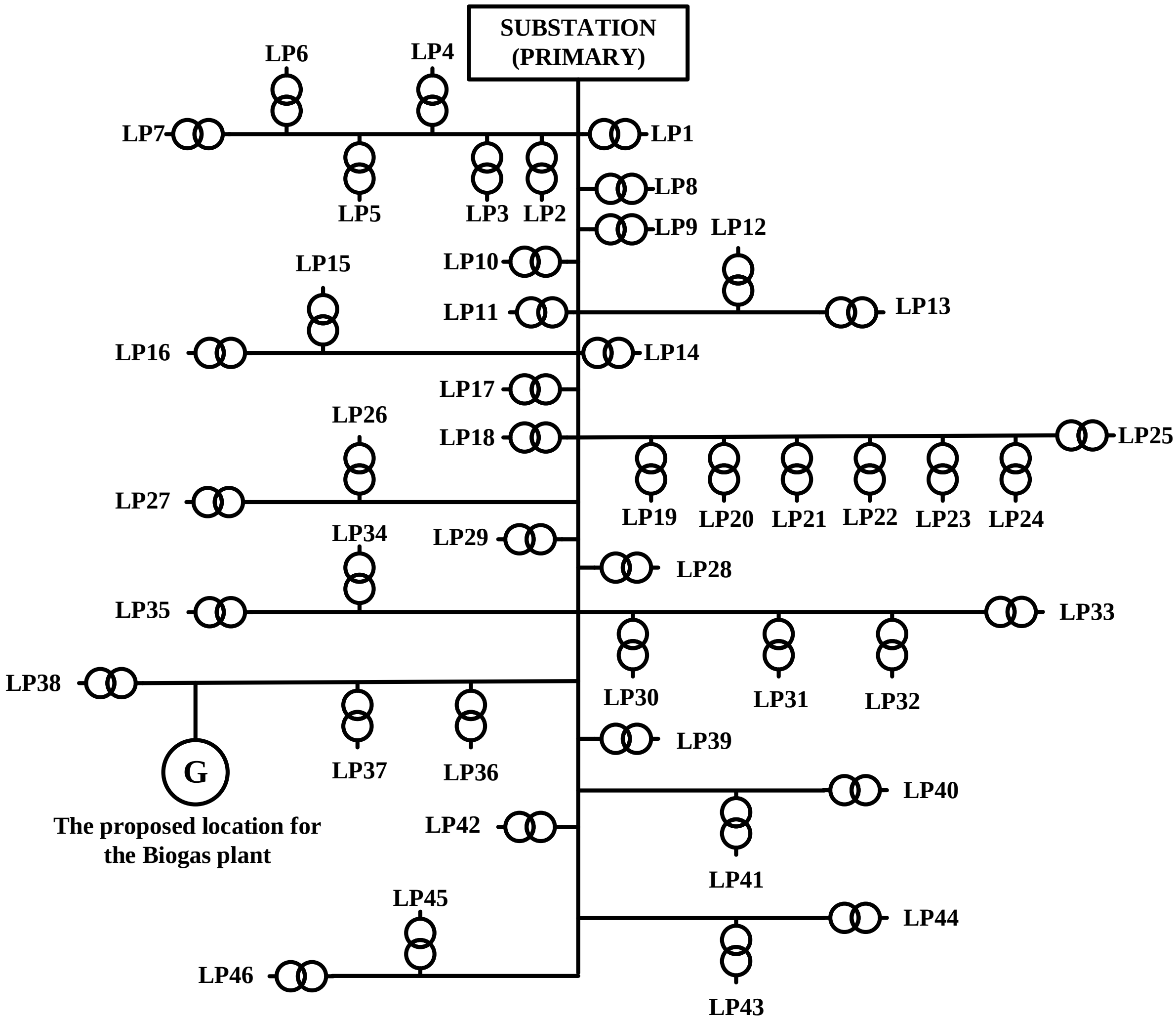

Figure 2. 33kv electrical grid with Biogas plant proposed location

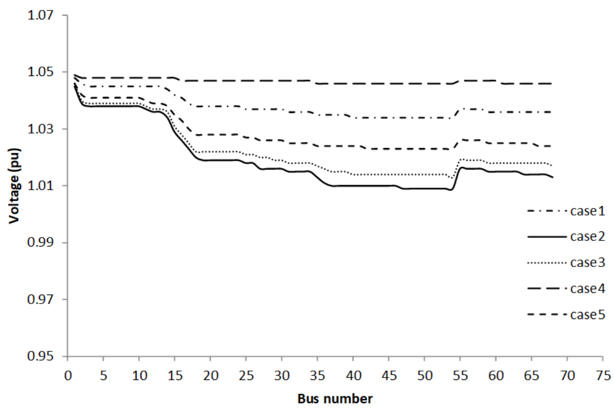

Figure 3. The voltage profile (pu) at each bus at the network

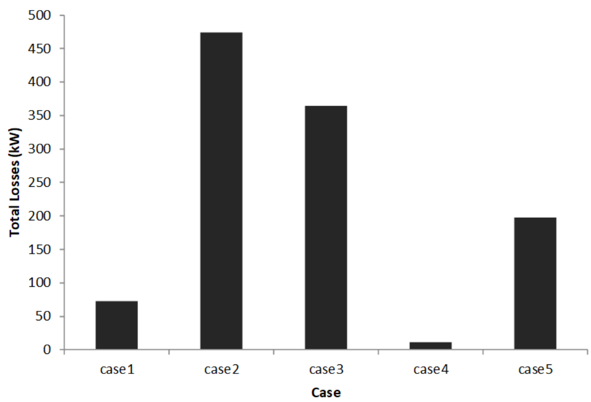

Figure 4. The Power losses at the system

4. The Economic Analysis

The economic analysis for the project was used to evaluate the visibility and profitability of the biogas plant investment. The economic indicators considered the investment costs, the total operational costs, total income and revenues, cost comparison, cost annuity comparison, profitability, Pay Back Period (PBP), Net Present Value (NPV) and Internal Rate of Return (IRR). Cost annuity is the annual total cost of the biogas digester [13, 23]:

$$A_K = K_0 + \left(1_0 - L\right) \times R_F\left(i,t\right) + L \times (i) \tag{6}$$

where: A_K is the cost annuity ($), K_0 is the operating costs per unit of time ($), is I_0 the investment costs ($), L is liquidation yield (years), is R_F is recovery period (years) and is a function of assumed interest rate and the project duration, i is the assumed interest rate (%), and t is the project duration (years).

Return on investment (ROI) is the average profit per time interval on an investment project or the profit of the plant per annum [23].

$$ROI = \left(\frac{N_p}{K_A}\right)\times 100 \tag{7}$$

where: ROI is the return on investment (US $), N_P is average net profit per time interval, and K_A is the average capital invested.

The Pay-back period is the time at which the capital invested in an investment project will be recovered by the annual returns.

$$n = \frac{capital\ investment}{annual\ return} \tag{8}$$

where: n is the payback period (years)

Net present value (NPV) of an investment project is the sum of the present values of all the cash inflows and outflows linked to the investment [23].

$$NPV = \left(R \times PF\right) + L_T \times q^{-T} \tag{9}$$

where: NPV is the Net present value ($), PF is the present value factor (years), R is annual returns (US $), L_T is the liquidation yield at the end of service life (years), and q^{-T} is discount factor (years).

Internal rate of return (IRR) of an investment project is the achievable interest tied-up in the investment [23].

$$IRR = i_1 - NPV_1\left(\frac{i_2 - i_1}{NPV_2 - NPV_1}\right) \tag{10}$$

where: IRR is the Internal rate of return, NPV_1 is the Net present value 1, NPV_2 is the Net present value 2, i_1 and i_2 are discount rates

The annuity is the constant annual payment for an investment [23].

$$A = NP \times RF\ \left(iT\right) \tag{11}$$

where: A is the annuity, T is a known planning period in years, and i is discount rate.

The investment costs for the digesters were calculated and the results are summarized in Table 4. Table 5 shows the economic analysis data for the investment project. The calculated values on Table 5 were obtained through the mentioned equations on procedures for the financial evaluation. The capital cost is calculated to be 21600000 $. For our case, A NPV of the income stream is nearly 7392000 $ and the ROI for the project during a 25-year lifespan is about 15%, with annual positive cash flows occurring 8 years after development.

Table. 4. Investment Cost of the project

Description	Quantity	Unit price $	Total price $
Civil Works	1	3,000,000	3,000,000
Gas pipes	250	30	7,500
Generator set	7	2,500,000	17,500,000
Digesters	12	20,000	240,000
Manure Tanks	6	15,000	90,000
pretreatment	1	30,000	30,000
pumps	6	3,500	21,000
Heat storage	6	4,500	27,000
Distribution transformers	7	15,000	105,000
Medium voltage switchgear	15	12,000	180,000
Medium voltage metering unit	1	10,000	10,000
Medium voltage cables	600	15	9,000
Medium voltage accessories	1	20,000	20,000
Labor	20	1,000	20,000
Heat exchangers	7	20,000	140,000
Land	10	10,000	100,000
Consultants	1	50,000	50,000
packages	7	5,000	35,000
Others	1	20,000	20,000

Table. 5. Economic Analysis of the project

Investment costs (k$)	21600
Operating costs (k$)	5,108
Labor (k$)	1,500
Maintenance and generators reinstallation cost (k$)	22,100
Cost annuity (k$)	600
ROI	15%
Payback period	8 years
NPV (k$)	7,392

5. Conclusion

An investigation has been made to determine the biogas production potential from poultry, bovine, goat, sheep animal manure in addition to the food waste in Bethlehem region in reference to 2013 statistics. Our findings show promising results for the amount of electricity that can be produced in the district from this source of renewable energy that is estimated to be 28 MW which is equivalent to almost one third of the district load that year. Moreover, it contributes to addressing the environmental issue of disposal of these wastes in addition to the production of the organic fertilizers. In the design of the biogas plant, many factors and constrains should be thoroughly considered, such as land price, transportation, electricity infrastructure and government rules. In our study, Za'tara region has been chosen as the candidate site for the plant location. Digesters sizing and gas engines were selected according to the calculated values of the goat and sheep manure potential. Electricity line capacity (20 MW) was the most crucial barrier in our design. An economical study was also conducted in addition to the simulation for the integration of the proposed plant to the grid for min/max load and generation for critical points. It is worth mentioning that similar studies should be carried out for other Palestinian cities to figure out the potential of their biogas since such important projects will significantly help in decreasing the dependency on the Israeli side in the energy sector mainly in the absence of the Palestinian traditional energy sources.

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