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Original Research Article

Economic analysis of biogas production from pineapple waste as alternative source of energy in a pineapple processing plant, case of Del Monte Kenya Limited

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ABSTRACT

This paper evaluates the economic aspect of utilizing biogas from pineapple waste as a source of energy in a pineapple processing plant, in the in the case of Del Monte Kenya Limited (DMKL). Del Monte Kenya Limited, a known exporter of canned pineapple, lies on approximately 10,000 acres of pineapple plantations. The company's processing capacity of 100,000 tons of pineapple annually produces approximately 23,000 tons of pineapple waste per year. Currently, these wastes are sold to local farmers as animal feed at $20 per ton. A study was conducted at Jomo Kenyatta University of Agriculture and Technology (JKUAT) that revealed that a ton of pineapple waste has the potential to generate 7.41 m^3/day of biogas. A cost-comparative analysis was conducted between employing an anaerobic digester to treat pineapple wastes to generate biogas for usage within the plant and selling the waste to locals for feeding the livestock. The results revealed that it is more economical to use waste to generate biogas as an alternative source of energy in the processing lines. The net present value (*NPV*) of $1,939,019, an internal rate of return (*IRR*) of 16%, and a payback period of 4 years were estimated. The positive value of *NPV* shows that the project is viable.

***Keywords*: biogas; pineapple waste; net present value; internal rate of return; payback period**

1. Introduction

Rising prices of fossil fuels and the risks of global warming have prompted industries to seek renewable sources of energy. In Kenya, biomass has contributed 70% to the final energy demand and meets the energy needs of more than 90% of rural households. The access to electricity in Kenya is still low despite the government's enthusiastic target to escalate electricity connectivity from 15% to at least 65% by the year 2022[1]. Kenya depends on imported fossil fuels to meet its energy demands, and the country spends nearly half of its yearly foreign exchange on petroleum and oil imports. The government is keen on lowering the cost of production by diversifying the sources of energy as well as identifying the best energy mix. Thus, the time

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is ripe to evaluate the full potential of alternative energy sources, including biomass. Kenya has the ability to generate electricity from biomass sources originating from agricultural waste such as sugar cane (biogas), sisal, timber (sawdust), and meat industries[2].

The main sources of biomass in Kenya consist of wood fuel, charcoal, and agricultural waste[3]. An attractive way to treat agricultural waste is by transforming it into biogas technologies. These biogas technologies are capable of reducing waste, generating clean and renewable energy, reducing emissions of greenhouse gases, and improving living conditions in developing countries.

In Kenya, biogas is broadly generated by more than 8000 biogas energy plants using several raw materials, such as household waste, slaughterhouse waste, agricultural waste, and municipal waste, among others. However, the situation is amorphous in the sense that there is no solid data on biogas production, making it difficult to determine the country's general capacity[4].A Kenyan food processing company, Del Monte Kenya Limited, operates in the cultivation, production, and canning of pineapple products[5]. Del Monte's pineapple plantation is estimated to produce around 2000 tons of pineapple on a daily basis. Taking into consideration such a huge production line, the extent of waste generation is enormous. Thika municipality bore the brunt of environmental pollution from the greenhouse gases emitted by such pineapple wastes. These wastes demand proper means of disposal as per the regulation by the National Environmental Management Authority (NEMA)[6].

The solid waste from the pineapples is normally sold to the local people who use the waste as animal feed. The remaining waste is heaped to decay, where it is later collected and taken to the farm as manure[6]. This is not an adequate solution, as a great fraction of these wastes still contaminate the environment through foul smells and greenhouse gas emissions. Therefore, an assessment is required to establish a sustainable business model out of these wastes to encourage investors to invest and make profits from investment.

The key objective of this study was to determine the economic analysis of biogas generation from the pineapple wastes produced in the factory to generate biogas as a substitute source of energy in the plant. This study considered the use of multi-criteria analysis (MCA) in selecting anaerobic digestion technology. MCA is a tool used to make decisions when one is faced with numerous alternatives and expectations to solve a problem and is in need of the perfect solution with regard to contrasting and often varying objectives. MCA is based on the assessment of various options according to particular criteria[7]. This consists of a performance matrix where the rows represent the options and the columns represent the performance of the criteria for each option**.** Technologies evaluated in this study included tubular, fixed dome, and floating drums. Criteria of evaluation were based on the investment cost, structure, lifespan, and sizing.

The techno-economic evaluation was set up based on the anaerobic digestion technology selected. In this study, the net present value (*NPV*), the internal rate of return (*IRR*), and the payback period were evaluated when biogas was considered for direct heating in the factory processing lines.

2. Materials and methods

2.1. Determining the Anaerobic Digestion (AD) technology

Selection of anaerobic technology was based on research reviews and other sources with information regarding small-scale biogas technologies in Kenya. These components were evaluated based on the features of the pineapple wastes generated from Del Monte Kenya Limited in order to identify effective digester for treating pineapple wastes. Multi-criteria Analysis (MCA) was the method used to compare technologies.

Multi-criteria analysis

The MCA is a useful tool when making decisions, and it is based on the assessment of various options according to particular criteria. It is used to determine the most desired option, give ranking to the options, and determine acceptable and unacceptable possibilities[7].

There are eight steps in the development of MCA, according to the report from the Department for Environment, Transport, and the Regions[7] as highlighted below:

- Establish the decision context. What are the aims of the MCA, and who are the decision makers and other key players?
- Establish the options.
- State the objectives and criteria that reflect the value associated with the consequences of each option.
- Describe the expected performance of each option against the criteria.
- Assign weights to each of the criteria (weighting) to reflect their relative importance to the decision.
- Combine the weights and scores for each of the options to derive the overall value.
- Scrutinize the results.
- Perform a sensitivity analysis of the results for changes in scores or weights.

This method consists of a performance matrix where the rows represent the options and the columns represent the performance of the criteria for each option[7]. **Table 1** below illustrates the performance matrix used.

Table 1. The performance matrix of the multi-criteria analysis.

Criteria	**Criteria1**	**Criteria 2**	**Criteria 3**	**…**	**Criteria *n***
Options	W_1	W_2	W_3	…	W_n
Option 1	S_{11}	S_{12}	S_{13}	…	S_{1n}
Option 2	S_{21}	S_{22}	S_{23}	…	S_{2n}
Option 3	S_{31}	S_{32}	S_{33}	…	S_{3n}
…	…	…	…	…	…
Option *i*	S_{i1}	S_{i2}	S_{i3}	…	S_{in}

where, W_n: represent the weight of the criterion n; S_{in}: represent the score of option i corresponding to the criterion n.

For consistency in scoring between the criteria, it is standard to use a scale of range between 0 and 100, where the value 0 is assigned to the lowest performance and 100 to the highest one[7]. When the two extreme values correspond to the values 0 and 100, this generates a linear graph where the vertical axis represents the score and the horizontal axis represents the value of the option for the criteria. In such cases, the scores for the other values can be directly obtained by interpreting the vertical axis of the graph.

Another rating technique is direct rating. This technique is applied in cases where there is no set scale of measurement or when there is no time or resources for quantifying the components concerned. The approach can vary since the evaluations are based on the judgment of the evaluator. Similarly, the scores in this case are also given in the range of 0 to 100[7].

Several techniques are applicable in obtaining the final results from the MCA. There are simple and complex techniques used in conducting a MCA. They are based on the purpose and objectives of the analysis. The technique applied in this study was the linear additive model, where each score given is multiplied by the criterion weight. These values are then summed up to obtain overall weighted scores for each option[7] as shown in Equation (1).

$$S_i = \sum_{j=1}^{n} w_j S_{ij} = w_1 s_{i1} + w_2 s_{i2} + \ldots + w_n s_{in} \quad (1)$$

The various parameters that influence biogas adoption, output, and plant size selection have been established. Substrate availability, income, environmental awareness, and local political governance are among the factors[8].

The aim of the MCA in this study is to identify which of the technologies could better suit the characteristics of the pineapple wastes generated by Del Monte Kenya Limited. This is helpful in defining the model for the techno-economic analysis. Technologies evaluated in this study included tubular, fixed dome, and floating drum digesters, and the criteria evaluated were investment cost, structure, and lifespan.

- **The investment costs**

The investment costs are the initial total costs required to implement the biogas energy plant. The investment costs include the digester, pipes, and other structures needed for biogas production. For this study, the value of land was not factored in, assuming that the structure could be installed within the existing factory. The variables, such as materials, the capacity of the digester, and the training of the personnel, are different for each specific case. For this study, the technologies below are listed from the lowest to the highest investment cost[9]:

1) Tubular digester
2) Fixed dome digester
3) Floating drum digester

A direct rating was used for scoring this criterion. The highest score is given to the lowest investment cost technology (tubular digester), and the lower score is given to the highest investment cost technology (floating drum digester). The score of the other technology is obtained by interpolating the line graph obtained from the first two.

- **Structure**

The physical structure of the biogas digester should provide a good anaerobic condition inside the digester for the development of the microorganisms[10]. Considering the nature of pineapple waste at Del Monte Kenya and the climatic conditions, the digester's structure should also provide a good insulation system. The weather conditions in Thika and its surroundings are extreme, and temperatures fluctuate throughout the year. The average annual highest temperature in Thika is 27.8 °C (82.0 °F). The average annual lowest temperature in Thika is 12.1 °C (53.8 °F), and July is the coldest day on average. Therefore, based on this reason, the structure of the digester should be able to keep the temperature inside the digester constant. This is crucial because temperature affects the level of activity of the microorganisms as well as their growth and, thus, their biogas production.

Again, the direct rating technique was applied to give scores for this criterion. The digester with a robust structure that could better adapt to the cold weather of Thika is given the highest score. The other scores are given according to the level of structural strength and sensitivity to low temperatures.

- **Lifespan**

The lifespan of the digester indicates the period of time (years) available for using the technology before it is necessary to replace it with a new unit. This criterion is important because it is necessary to ensure heat generation, and therefore, it is preferred to have a long lifespan to avoid long-term disruptions in the heat supply. The lifespan of the technology is also related to its maintenance. Periodic preventive maintenance is necessary in order to have good performance for biogas production.

For this study, considering optimum and regular maintenance of the digesters, the technologies are listed from the lowest to the highest life spans (years)[9]:

1) Tubular digester
2) Floating drum digester
3) Fixed dome digester

To provide the scores for this performance, the idea of a value function in which the two extreme values correspond to the values 0 and 100 was applied[7].

- **Plant capacity**

The capacity of a biogas energy plant is the maximum total volume of gas and slurry that it can accommodate. The total volume of the plant is the sum of two components: the digester volume and the gas storage volume. This is measured in.

The digester volume is the maximum amount of slurry that the plant can hold, while the gas storage volume is the amount of gas it can hold when full of slurry.

2.2. Economic analysis

A preliminary economic study was conducted to evaluate the feasibility of setting up a biodigester to treat pineapple waste from DMKL. The Rehau home gas system in JKUAT was fed with pineapple waste co-digested with livestock waste, which acted as the inoculants. The aim of the biogas produced is to replace the heavy fuel oils used in the production line. This is to reduce the cost of energy and carbon emissions. The biomass production rate is estimated based on the experiments carried out for economic evaluation, as reported in **Table 2**.

Table 2. Estimated biogas production.

Parameters	Values
Amount of pineapple fruits processed	108,528 tons/year
Amount of pineapple wastes generated annually (23% of pineapple fruits)	24,961 tons/year
Quantity of biogas derived from experiments	7.41 m^3/ton/day
Methane content in the biogas	65.4%
Amount of methane produced	4.85 m^3/ton/day
Total amount of methane produced from pineapple wastes	121,060 m^3/year

In this study, the economic parameters analyzed were net present value (*NPV*), internal rate of return (*IRR*) and payback period (*PB*).

2.2.1. Net present value (*NPV*)

The net present value (*NPV*) is the method used to determine the viability of the project. This method expresses the difference between the present values of cash inflows and outflows for a given period of time. According to Ogrodowczyk et al.[11], *NPV* evaluates the present rate of the total investment cost, taking into consideration the changes in the value of capital for a given period of time. Therefore, with the value of the *NPV* obtained, one can evaluate the profitability and viability of the project. A positive value of *NPV* implies that the project is profitable and a negative value shows that it is not. The *NPV* is calculated from Equation (2) below:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0 \quad (2)$$

where, T is the number of time periods (years); C_t is the cashflow in year t(USD); C_0 is the total initial investment (USD); r is the discount rate (%); t is the time period (year).

According to the Central Bank of Kenya as on 29 September 2022, the discount rate was 8.25%. This is the discount rate set for this study and the number of periods considered to be 20 years based on technology selected[12].

2.2.2. Internal rate of return (*IRR*)

IRR is a discount rate that makes the net present value (*NPV*) equal to zero. Thus, the *IRR* is the case where the present value of the costs and the present value of the benefits are the same[12]. If the value of *IRR* obtained is higher than the discounted rate, then the investment is profitable and should be carried on whereas, if *IRR* is lower than discount rate the investment should not be conducted.

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_0 = 0 \quad (3)$$

2.2.3. Payback period (*PB*)

Payback period (*PB*) is the number of years required to recover the initial money invested in the project. The project is more desirable when the payback period is shorter. *PB* can be calculated by Equation (4) below:

$$PB = \frac{Total\ amount\ invested}{Annual\ cash\ flows} \quad (4)$$

2.3. Data sources

2.3.1. Experimental data

The fresh pineapple waste (less than one day old) was collected in plastic buckets and transported on the same day by road to the experimental site at Jomo Kenyatta University of Agriculture and Technology. The experimental parameters were optimized using Box-Behnken design (BBD). The optimal content of methane in biogas from the experiments was determined to be 65.4%. Since the biogas produced was aimed at replacing the heavy fuel oils for direct heating, the determination of its calorific value was crucial. The heating value of biogas was obtained to be 23,544 KJ/m^3.

According to Ayedun[13], the actual calorific value (KJ/m^3) of biogas produced is determined by Equation (5):

$$H_{ac} = (V_{CH4}/V_{tot}) \times \rho CH_{4,act} \times H_u \quad (5)$$

where, H_{ac} = actual calorific value of biogas produced in KJ/m^3; V_{CH4}/V_{tot} = methane proportion in biogas, %; $CH_{4,act}$ = actual biogas density (kg/m^3); where, biogas density at STP is assumed as 0.72 kg/m^3.

Thus, the actual biogas density = pressure gauge reading (Pa) $\frac{273K}{Actual\ temperature\ (K)}$

H_u = calorific value of biogas at standard condition, kJ/kg (assumed as 50,000 kJ/kg or 36,000 J/m^3).

2.3.2. Data collected from Del Monte Kenya Limited

Waste generation from the cannery is based on the shift operations. Depending on the demands, three 8-hour shifts are possible. The tons of pineapple fruits in production vary depending on weather, season, or demand from customers. The amount of waste generated depends on the total amount of pineapple fruit processed in a particular shift or day. When all conditions are considered constant, the value of waste generated is equivalent to 23% of the total tons of fruits processed. Using a summary of data for the year 2021, it was determined that the total tons of fruits processed were 108,528, which implies that the annual waste generated was 24,961 tons.

Currently, the factory has been selling these wastes to locals as animal feed at a cost of $20 per ton, generating a net income of approximately $400,000 per year. Part of the waste is decomposed and used as manure in pineapple farms.

The raw data collected from DMKL revealed that the factory utilizes approximately 4,909,535 L of oil annually, based on 2021 data. This oil is bought at approximately $0.662/L.

Meaning, annual energy cost on production line = 0.662 × 4,909,535 = $3,250,112.17.

3. Results and discussion

3.1. Anaerobic digestion technology selected

The selection of the AD technology to treat wastes from DMKL was based on the multi-criteria analysis method described in section 2 of this paper. The various technologies under consideration were the fixed dome, floating drum, and flexible tube digesters. The general characteristics of the pineapple waste from DMKL were taken into consideration while evaluating these digesters. The chosen technology should be optimum for working at fluctuating temperatures around Thika town and be able to cover all the waste generated from the cannery of DMKL.

Four criteria were selected for the analysis: investment cost, lifespan, structure, and capacity. The scores in this study were given in the range of 0 to 100, which were based on literature and the author's judgment. The lowest performance was given a score of 0 and 100 to the highest one.

This generates a linear graph with the vertical axis representing the score and the horizontal axis representing the value of the option for the criteria. In this way, the scores for the other values can be directly read from the graph on the vertical axis.

The weighing was done by equally distributing 100 points between the criteria. Each criterion was assigned 25 points out of 100 (i.e., 0.25). The best technology from the MCA results shows that the fixed dome digester scored the highest points and thus was the better technology for treating pineapple waste from DKL. The scores are summarized in **Table 3** below.

Table 3. Performance matrix of the digester's MCA.

Criteria	**Investment cost**	**Structure**	**Lifespan**	**Capacity**	**Total score**
Digester	**0.25**	**0.25**	**0.25**	**0.25**	
1) Tubular	100	0	0	0	25.0
2) Fixed dome	66	100	100	100	91.5
3) Floating drum	0	66	88	100	63.5

The facts supporting this selection include the digester's underground construction, which saves space and protects the digesters from temperature fluctuations[14]. Thus, the technology will favor the field conditions around DMKL throughout the year. The structure of a fixed-dome digester also has minimum obstructions from external activities within the plant.

Based on previous studies, this digester can last more than 20 years[12,15], which is a greater lifespan as compared to tubular and floating drum types of digesters. The fixed-dome digester's volume of up to 120 m^3 will adequately accommodate pineapple waste generated on a daily basis.

3.2. Economic analysis

3.2.1. Investment costs

The data used for techno-economic analysis in this study were based on the technology selected. Therefore, the investment cost represents the total amount of money invested in a fixed-dome biogas plant. The lifespan is considered to be 20 years, which is the average lifetime of this digester as presented by previous studies[12,15].

The cost of land will not be included in the investment cost since there is enough space within the factory for setting up the system. The values used here are taken from different literature sources as well as experts' consultations.

The project capital cost for the technology includes equipment purchase, fabrication and installations, labor, insurance, duties and taxes, and miscellaneous costs for a total of $4,487,055 as detailed in **Table 4**.

The operational and maintenance costs include wages, salaries, overheads, maintenance and administrative expenses, etc., at $159,141 per annum, as detailed in **Table 5**. The maintenance costs of a biogas plant are assumed to be 2% of the total cost of investment[16].

Table 4. DMKL proposed biogas plant-project capital costs.

Description of item	**Cost (USD)**
1) Main equipment costs (mixing tank, digester, methane reactor, biofilter, burners)	2,595,000
2) Bio-gas plant gas scrubbers filtration, compressor, desulphurizing units, storage vessels/cylinders fabrication and civil works etc.	800,500
3) Piping, instrumentation, and control	40,000
4) Equipment installation (labor)	1,035,000
5) Management costs, insurance, and other misc. costs	8555
6) Duties and taxes	8000
7) Total project capital cost	4,487,055

Table 5. Annual operational and maintenance (O&M) costs.

Description of item	**Cost (USD)**
1) Operational labor (3 persons)	25,200
2) Maintenance of the plant	89,741
3) Administrative expenses	44,200
4) Total O&M cost	159,141

3.2.2. Incomes

The incomes will be generated from heat benefits, fertilizer production, and carbon credits. It is assumed that the amount of waste to be treated is 23% of the total amount of fresh fruits harvested from the farm to be processed in every production shift. The operational hours of the biogas plant are assumed to be equivalent to canary operational time, which is approximately 3069 operational hours a year.

From the experiments carried out, the calorific value of the biogas was obtained as 23,544 KJ/m^3 with a methane content of 65.4%, which is nearly the same as the findings of Jena et al.[17] but higher than those of

Mukawa et al.[18]. Biogas will be utilized for direct heating to replace heavy fuel oils thus will be able to save \$3,250,112 used to import oils annually.

Carbon credits are calculated as the avoided emissions of producing heat energy from biogas instead of using fossil fuels. These are presented in the form of the possible revenues that can be generated by using renewable sources of energy. According to Salomon et al.[19], calculations of the carbon credit monetary value are obtainable from Equations (6) and (7).

$$TACO_2 = TGE \times CIF \tag{6}$$

$$Certificates\ revenue\ USD/a = TACO_2 \times VCAE \tag{7}$$

where, $TACO_2$: total avoided CO_2 in ton CO_{2eq}/year; TGE: total amount of generated electricity in MWh/year; CIF: carbon intensity factor in tonCO_{2eq}/MWh; VCAE: value of the certificates of avoided emissions in USD/ton CO_{2e} .

In this case study, the proposed biogas energy plant for DMKL will utilize pineapple waste from Canary Island to generate biogas that would replace the current use of heavy fuel oils in the production line. In this study, the proposed biogas energy plant was projected to produce 24,961 tons of pineapple waste input annually. These have the potential to generate 121,060 m^3/year of methane, as presented in **Table 2**. The biogas generated had a calorific value of 23.5 MJ/m^3, and it has been reported that 1 m^3 of biogas corresponds to 0.5–0.6 L of diesel fuel, or about 6 kWh[20,21].This translates to a net income of \$161,252 per year from biogas.

The plant will also benefit from the production of biofertilizers (digestate), which can be applied back to pineapple plantations or sold to local farmers. Bio-fertilizer produced from anaerobic digestion has the potential to improve crop production and productivity for sustainable agriculture at a low cost[22]. This technology can produce approximately 1573 tons of dry bio-fertilizer per year based on the annual waste generation. Considering the current Kenya market price of \$28.5 per 50 kg bag of fertilizer, a net income of \$896,610 per year is attainable.

The possible income from carbon credit was estimated based on Equations (6) and (7) and using the data collected from the factory. The CO_2 emission from the burning of oil is 2.52 kg CO_2 per liter (which is equivalent to 3.15 kg CO_2 per kg and 0.245 kg per kWh)[23]. According to Wang and Corson[24], about \$20 can be earned for every ton of CO_2 avoided per year. Based on data collected from DMKL, an average income of \$247,440 can be achieved through carbon offsets.

The *NPV*, *IRR* and payback period were evaluated to determine the profitability of the investment. **Table 6** shows the results of the economic analysis. It shows a positive value of *NPV* implying that the project is economically viable.

Based on the results, a positive *NPV* indicates that setting up the biogas plant at DMKL to treat pineapple waste is feasible. A negative value could imply that the investment should be disregarded. The value obtained shows that the installation of the biogas energy plant is financially viable. This is in agreement with Al-Maghalseh[25]. On the other hand, the internal rate of return (*IRR*) was evaluated as another determinant of profitability. In this evaluation, since the *NPV* is greater than zero and the *IRR* (16%) is greater than the discount rate (8.25%), the realization of the project is profitable to embark on. This implies that the installation of the biogas plant will add value. Therefore, the study concludes that *NPV* and *IRR* make this possible regarding the benefits of the project. At this point, the internal rate of return of 16% calculated was said to be the rate at which the *NPV* was generated. Notably, the rate of return on investment is estimated to be 4 years. In a case where the *IRR* is less than the discount rate, then the essence of the project is defeated or destroyed and should not be embarked on. Comparing these results with the current sales of the wastes to the locals as animal feed, the net income of $1,146,161 per year from this investment is much better than the $400,000 per year from sales of waste.

Table 6. Economic results of the study based on *NPV* model.

		Present	1	2	5	10	15	20
Investment								
Initial investment cost								
Cash flow	−4,487,055							
Expenses								
Labor cost			−25,200	−25,200	−25,200	−25,200	−25,200	−25,200
Periodic maintenance			−89,741	−89,741	−89,741	−89,741	−89,741	−89,741
Administrative								
Incomes								
Heat benefit			161,252	161,252	161,252	161,252	161,252	161,252
Biofertilizers benefit			896,610	896,610	896,610	896,610	896,610	896,610
Carbon credits			247,440	247,440	247,440	247,440	247,440	247,440
Salvage			-	-	-	-	-	897,411
Total cash flow			1,146,161	1,146,161	1,146,161	1,146,161	1,146,161	1,146,161
Cumulative cash flow		−4,487,055	−3,340,894	−2,194,733	1,243,750	6,974,555	12,705,360	18,436,165
Net present value (*NPV*)	1,939,019							
Internal rate of return (*IRR*)	16%							
Payback period (years)	4							

4. Conclusion

The organic waste generated from DMKL was estimated to be 24,961 tons per year. The technology selected for treating this amount of pineapple waste was the fixed dome type of digester. This technology better suits the nature of waste generated in comparison to the other small-scale biogas technologies evaluated when analyzing the investment cost, lifespan, structure, and capacity. The technology selected aided in evaluating the net present value, internal rate of return, and payback period. The calculated *NPV* of $1,939,019 and *IRR* of 16% proved that the investment is financially feasible. In addition, biogas obtained with a calorific value of 23,544 KJ/m^3 can replace heavy fuel oils in the production line.

The study revealed that DMKL would benefit from this investment through heat benefits, biofertilizers, and carbon credits. Environmental benefits from the biogas plant would also be realized based on the avoided emissions. This could lead DMKL to make an active contribution to the mitigation of climate change.

Author contributions

Conceptualization, EOO and RK; methodology, EOO; software, EOO; validation, EOO, RK and UNM; formal analysis, EOO; investigation, RK; resources, UNM; data curation, RK; writing—original draft preparation, UNM; writing—review and editing, UNM; visualization, RK; supervision, RK; project administration, UNM; funding acquisition, RK. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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