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Batman'daki Biyogaz Potansiyelinin Değerlendirilmesi ve Alternatif Enerji Kaynakları ile Ekonomik Karşılaştırması

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Öz

Küresel enerji talebi artmaya devam ettikçe, yenilenebilir enerji kaynaklarının sürdürülebilirliği sağlamadaki rolü giderek daha önemli hale gelmiştir. Ancak bu enerji türlerinin birçoğunun mevsimsel veya coğrafi koşullara bağlı olması nedeniyle tek başına enerji talebini karşılama yeteneği sınırlıdır. Bu zorluk, özellikle ithal enerji kaynaklarına bağımlı ülkelerde, yerel enerji kaynaklarından yararlanma ihtiyacını ortaya çıkarmaktadır. Çeşitli ve yerel enerji kaynaklarının kullanılması, yalnızca ithal kaynaklara olan bağımlılığı azaltmak için değil, aynı zamanda enerji çeşitlendirmesini teşvik etmek için de kritik öneme sahiptir. Bu bakış açısından, biyogaz en erişilebilir enerji üretim teknolojilerinden biri olarak tanımlanabilir. Bu çalışma, artan enerji talebini karşılamak için biyogaz enerjisi, jeotermal enerji, dizel yakıtı, fueloil ve asfaltit yatırımları için Net Bugünkü Değer (NBD) ve Seviyelendirilmiş Enerji Maliyeti (LCOE) analizlerini incelemektedir. Batman ilindeki atık potansiyelinden yararlanan bir biyogaz tesisinin ekonomik değerlendirmesine odaklanarak, bölgesel alternatifler arasında en uygun enerji kaynağının belirlenmesi amaçlanmaktadır. Biyogaz enerji kaynağı için birim enerji maliyeti %6 faiz oranıyla 75,73$/MWh, %8 faiz oranıyla 80,65, %10 faiz oranıyla 85,89 ve %12 faiz oranıyla 91,41 olarak hesaplanmıştır. Biyogaz tesisinin 10 yıllık bir geri ödeme süresi olduğu tespit edilmiş ve 10 yıldan sonra yatırım kârlı hale gelmektedir. 20 yıllık ekonomik ömrü boyunca biyogaz yatırımının Net Bugünkü Değerinin yaklaşık 1,3 milyon dolara ulaşması öngörülmektedir.

Anahtar kelimeler: Biyogaz, Enerji ekonomisi, Net bugünkü değer analizi, Biyogaz potansiyeli

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Assessment of Biogas Potential in Batman and Its Economic Comparison with Alternative Energy Sources

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Abstract

The role of renewable energy sources in ensuring sustainability has become increasingly important as global energy demand continues to rise. However, many of these energy types have limited ability to meet energy demand alone due to their dependence on seasonal or geographic conditions. This challenge highlights the need for leveraging local energy resources, particularly in countries dependent on imported energy sources. Utilizing diverse and local energy sources is critical not only to reduce reliance on imported resources but also to promote energy diversification. From this perspective, biogas can be defined as one of the most accessible energy production technologies. This study conducts Net Present Value (NPV) and Levelized Cost of Electricity (LCOE) analyses for investments in biogas energy, geothermal energy, diesel fuel, fuel oil, and asphalted to help meet the growing energy demand. The research focuses on the economic evaluation of a biogas plant by utilizing organic waste potential in Batman province, aiming to identify the most suitable energy source among regional alternatives. For the biogas energy source, unit costs are calculated as 75.73 $/MWh at a 6% interest rate, 80.65 at 8%, 85.89 at 10%, and 91.41 at 12%. The biogas plant has a payback period of 10 years; after which it becomes profitable. Over its 20-year lifespan, the NPV is projected to reach approximately $1.3 million.

Keywords: Biogas, Energy economics, Net present value analysis, Biogas potential

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1. Introduction

Energy is essential for improving quality of life and supporting all aspects of a country's economy. With technological advancements, increasing industrialization has led to a rapid rise in energy demand. The wide use of energy resources has caused the depletion of fossil fuels such as oil, coal, and natural gas at an alarming rate. Recent studies indicate that oil reserves may be depleted by 2047, while natural gas could run out by 2068. Additionally, coal reserves are expected to last until 2140.In addition to the environmental destruction caused in the areas where fossil fuel plants are established, these fuels also have adverse effects that threaten the entire planet with global warming. The inevitable depletion of fossil fuels and their negative impacts on human life have made the sustainability of energy resources one of the most critical global issues. Due to these negative effects, countries have turned to renewable energy sources that are clean and sustainable.

Renewable energy refers to naturally replenished sources like wind, solar and biomass. Renewable energy sources play a crucial role in addressing the depletion of fossil fuels and combating adverse effects such as global warming and climate change. The use of fossil fuels leads to significant environmental pollution through carbon dioxide and greenhouse gas emissions. In contrast, renewable energy sources are clean, environmentally friendly, and economical. Research on renewable energy has seen a notable increase in recent years. Renewable energy sources include solar energy, wind energy, hydroelectric energy, geothermal energy, wave energy, hydrogen energy, and biomass energy.

One of the most important methods for sustainable energy production and waste management is anaerobic digestion. Anaerobic digestion refers to a series of biological processes in which a microbial consortium breaks down organic matter in an oxygen-depleted environment. This process not only provides an alternative energy source but also offers a viable option for diverting organic waste from landfills and reducing greenhouse gas emissions. Consequently, it is a technology that can be effectively utilized by local governments and authorities to achieve waste management and sustainable environmental goals.

Biogas is a renewable energy source that can be used in various applications, including fuel for vehicles, heat, and electricity generation. A wide range of organic waste materials, such as animal waste/manure, food waste, organic municipal solid waste, industrial waste, sewage sludge, and agricultural residues, can potentially be utilized for biogas production. Among the different types of alternative and sustainable renewable energy sources, biogas is preferred due to its ease of production and its direct applicability as fuel for various devices, including generators, electrical and internal combustion engines, turbines, and fuel cells.

This study examines the economic analysis of biogas plant investments aimed at generating energy by determining the volume of potential waste that could be used as a biogas source in the province of Batman. The waste quantities are calculated based on the number of livestock in Batman, serving as the input for a biogas facility. An economic analysis of a potential biogas plant investment is conducted using the Net Present Value (NPV) approach under different financial scenarios. Additionally, a unit cost comparison is made through the Levelized Cost of Energy (LCOE) for energy produced from biogas and certain fossil-based fuels. Fluctuations in the raw material prices of energy sources like diesel and LPG have a positive impact on the economic sustainability of energy types like biogas, which are independent of external dependencies. This study bridges a critical gap in the field by combining biogas energy potential assessment with an in-depth economic analysis of various alternatives in terms of financial viability.

2. Literature Review

There is an extensive literature on the existence of biogas production plants and the amount of energy they generate. Studies identify biogas as an important renewable energy source for addressing both energy and waste management issues. Kılıç [1] explores the general state of biogas and its position in Turkey. The study emphasizes the importance of utilizing waste for energy production to address the country’s energy needs and resolve energy-related challenges. Chowdhury et al. [2] aim to evaluate biogas production from livestock waste in Bangladesh in 2016 and provide potential biological applications for converting and processing waste into biogas. The study presents the appropriate conversion technologies for calculating total biogas production and includes mathematical equations related to biogas production mechanisms from animal waste. It demonstrates that approximately 229 million tons of animal waste are produced in 2016, with a total biogas production potential of 16.68×10^7 MWh, equivalent to 16,988.97 million m³ of biogas. From an environmental perspective, the study indicates that net CO_2 emissions could be reduced by producing 4.42 million tons of diesel energy and 29 million tons of bio fertilizer.

Şenol et al. [3] investigate the availability of key resources for biogas production in Turkey. The study states that the country has an abundance of organic materials suitable for biogas production, most of which are in waste form. They highlight the importance of evaluating these waste materials for energy production. Yılmaz et al. [4] analyzed biogas production in Turkey and mentioned that there are 73 active biogas plants in the country, generating a total of 385 MW of power. The study highlights that animal, agricultural, and municipal waste are important resources for biogas production in Turkey. In 2019, Yılmaz [5] explores the biogas production and energy generation capacity of licensed renewable waste energy plants in Turkey. The study reveals that there are 122 licensed plants with a combined production capacity of 634.2 MW. Durmuş et al. [6] report that the annual animal waste in Batman province amounts to 797,871.32 tons, with an energy value of 4,333.64 TEP and a total energy equivalent of 69,618.95 TEB. Işıkyürek [7] designs a biogas plant to meet the energy needs of the Mediterranean University’s central campus. The study determines the total energy demand over three years and assesses the waste potential in the area, leading to the design and sizing of the biogas facility. It concludes that the plant will address both the waste problem and the electricity consumption costs.

Studies identify significant potential for biogas production from organic waste in residential areas, including animal, plant, industrial, and municipal waste. Arıcı et al. [8] investigate the biogas energy potential derived from livestock (cattle, sheep, goats) and poultry waste in Turkey's Eastern Anatolia region. Their study identifies the annual biogas potential in several provinces, with Ağrı contributing 95,511.586 m³/year, Ardahan 37,711.934 m³/year, Bingöl 36,056.08 m³/year, and Bitlis 35,834.288 m³/year. Other provinces include Elazığ with 44,578.567 m³/year, Erzincan 30,250.968 m³/year, Erzurum 108,746.365 m³/year, and Hakkari 38,114.012 m³/year. Additionally, Iğdır contributes 49,812.987 m³/year, Kars 76,560.456 m³/year, Malatya 32,547.220 m³/year, Muş 75,253.808 m³/year, Şırnak 29,026.576 m³/year, Tunceli 20,701.560 m³/year, and Van 130,354.586 m³/year. Aybek et al. [9] research the potential for biogas production from agricultural and animal waste in Kahramanmaraş province. Their study concludes that biogas production from agricultural waste (100 TJ/year) and animal manure (2077 TJ/year) would provide economic, social, and environmental benefits. Abdeshahian et al. [10] evaluate the biogas potential from organic waste derived from farm animals and slaughterhouses in Malaysia, showing an annual biogas production potential of 4589.49 million m³, which could generate 8.27×10^9 kWh of electricity in 2012. Taşova [11] assesses the biogas potential from poultry waste in Tokat province, concluding that the biogas produced could meet the annual electricity needs of 3,654 households. Karaca [12] examines the potential for biogas production from animal manure in Hatay province, estimating that 15 million m³ of biogas could be produced, equivalent to 8,000 tons of petroleum. Kocabey [13] analyzes biogas potential from animal waste in Balıkesir, finding a 112 MW biogas energy potential in the province. Atılğan and Yılmaz [14] examine the biogas potential from animal manure in Mardin, estimating that the biogas production could meet the energy needs of 51,852 people. Khalil et al. [15] provide technological suggestions for utilizing waste, particularly animal waste, for energy production in Indonesia. They estimate that Indonesia’s animal waste amounts to approximately 9597.4 million m³ annually, with the potential to produce 1.7×10^6 kWh of electricity. Wine has also been identified as a high potential source for biogas production. The production of biogas from wine presents both economic and environmental benefits. Wine vinegar has a low carbon-to-nitrogen ratio, meaning that complementary materials, such as animal manure, industrial organic waste, and lime fertilizers, should be added to enhance biogas yield. Globally, 22.4 gigaliters of wine are produced, with the potential to generate 407.68 gigaliters of biogas, making it a significant renewable energy source. Parsaee et al. [16] summarize the properties of wine and its potential for biogas production, investigating the optimal conditions for biogas production and the advantages of biogas from wine.

Anaerobic digestion of organic waste offers several benefits, including reduced odor emissions, pathogen reduction, and low requirements for organic sludge. Additionally, the processed organic waste can be used as a mineral fertilizer for arable land or as an organic substrate for greenhouse cultivation. Nasir et al. [17]

evaluate the anaerobic treatment performance of cow manure and palm oil mill wastewater in terms of biogas production and volatile solid reduction. The study indicates that increasing the inoculum ratio has a significant impact on the biogas production rate. The results indicate that the average biogas yield is 0.346 m^3/kg volatile solids when palm oil mill wastewater is used as the inoculum. Abraham et al. [18] research the inclusion of a pre-treatment step in anaerobic digestion processes, showing that it increases the digestibility of lignocellulosic biomass and promotes the removal of lignin and complex biomass structures, thus improving biogas yield. The study also demonstrates that when ionic liquids are used as a pre-treatment strategy for anaerobic digestion, biogas production improves by 1200%. Dehhaghi et al. [19] review recent technologies related to the application of nanomaterials in enhancing biogas production, investigating the effects of nanomaterials on both the quantity and quality of biogas produced. They state that nano-sized iron particles can increase biogas production rates.

Economic analyses of biogas energy in the literature consistently demonstrate its viability as a renewable energy source. Studies across different contexts, including composite material digesters Obileke et al. [20] cow manure processing Muharia at al. [21] and sugar factories Ogrodowczyk at al. [22] all report positive economic indicators. The economic performance of biogas projects varies regionally and depends on the type of waste utilized. For instance, Ogrodowczyk at al. [22] report an Internal Rate of Return (IRR) of 12.48% for a biogas investment, while [20] estimate this figure at 8.5%. Interestingly, some studies show IRR values as high as 249.8% Muharia at al. [21]. Similarly, payback periods for investments range from 8 years Ogrodowczyk at al. [22] to 6 years Al- Wahaibi at al. [23] and as low as 2 years Obileke et al. [20].

From the literature review, it is seen that most studies focus on estimating the biogas production potential in specific regions or analyzing its technical feasibility. However, a significant gap exists in the economic evaluation of biogas plants relative to other energy sources, particularly in terms of their comparative financial sustainability. Variation in economic outcomes of the biogas in the literature underscore the need for region specific analyses of biogas energy investments. To address this, the present study focuses on Batman province, aiming to evaluate the economic feasibility of biogas energy in this particular region, utilizing detailed NPV and LCOE calculations. By doing so, it provides a practical framework for assessing the viability of renewable energy investments in regions with high biogas potential. The analysis compares the economic viability of biogas against energy sources such as diesel, geothermal, fuel oil, and asphalted. The economic parameters used in these analyses are based on data provided by Kat [24], which is detailed in the following section.

3. Material and Method

3.1. Biogas

Biogas is a colorless and odorless gas that is produced through the anaerobic (oxygen-free) fermentation of organic waste materials, such as animal, plant, industrial, and municipal waste. It is lighter than air due to its density of 1.2 kg/m^3. When burned, biogas produces a bright blue flame. The components of biogas include methane (CH_4), carbon dioxide (CO_2), water vapor (H_2O), nitrogen (N_2), oxygen (O_2), hydrogen (H_2), ammonia (NH_3), and hydrogen sulfide (H_2S). The methane (CH_4) content typically ranges between 40-75%, the carbon dioxide (CO_2) content ranges from 15-60%, and the water vapor (H_2O) content varies from 1-5% [25]. Table 1 summarize the volume of basic components of biogas.

Table 1. Basic Components of Biogas

Component	Volume
Methane (CH_4)	40-75 %
Carbon Dioxide (CO_2)	15-60 %
Water Vapoe (H_2O)	1-5 %
Nitrogen (N_2)	0-5 %
Oxygen (O_2)	<2 %
Hydrogen (H_2)	<1 %
Ammonia (NH_3)	0-500 ppm
Hydrogen Sulfide (H_2S)	0-5000 ppm

One cubic meter of biogas is equivalent to 4.7 kWh of electricity, 0.62 liters of gas, 0.66 liters of diesel, 0.43 kg of butane, 0.25 meters of propane, 1.46 kg of coal, and 3.47 kg of wood [26]. Figure 1 illustrates the energy content of 1 cubic meter (1 m^3) of biogas compared to various conventional energy sources. The bar chart demonstrates that 1 m^3 of biogas is equivalent to approximately 4.7 kilowatt-hours (kWh) of electricity, highlighting its relatively high energy density. In comparison, equivalent energy values for gasoline, diesel, butane, propane, coal, and wood are significantly lower, indicating that biogas offers a more concentrated energy source. This underscores the potential of biogas as a valuable and versatile energy carrier, capable of substituting for a range of traditional fuels.

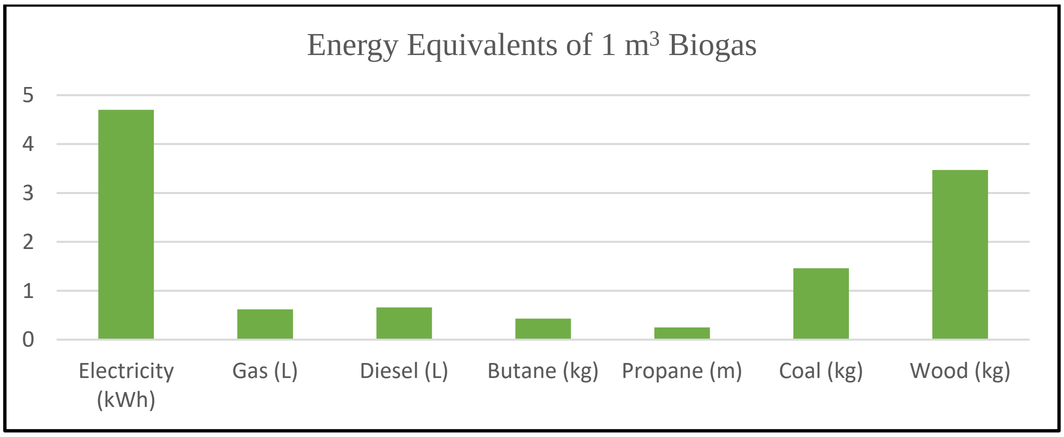


Figure 1. Energy Equivalents of 1 m^3 of Biogas

The size of a biogas plant varies depending on the purpose of usage. These plants are classified into four categories based on their capacity: family, farm, village, and industrial types as presented in Table 2 [27].

Table 2. Types of Biogas Production Plants

Plant Type	Production Capacity (m^3)
Family-Type Biogas Plant	6 - 12
Farm-Type Biogas Plant	50 – 100 - 150
Village-Type Biogas Plant	100 - 200
Industrial-Type Biogas Plant	1000 - 10000

3.2. Main organic wastes used in biogas production

In Turkey, organic waste constitutes approximately two-thirds of the total waste. The significant share of organic waste in the total waste is a great advantage for the country. However, leaving the waste to decompose or discarding it in the environment also presents disadvantages. The conscious utilization of organic waste materials is of great importance both in terms of energy production and environmental pollution. Various organic wastes are used in biogas production [27].

3.2.1. Animal organic wastes

Animal organic wastes are typically derived from cattle, sheep, goats, or poultry. The amount of manure generated by these animals varies depending on their feeding methods. On average, one cattle produces 3.6 tons of manure per year, one sheep or goat produces 0.7 tons per year, and one poultry animal produces 0.022 tons per year. These animal wastes represent a significant potential for biogas production, with 33 m^3 of biogas obtained from 1 ton of cattle manure, 58 m^3 from 1 ton of sheep or goat manure, and 78 m^3 from 1 ton of poultry manure [28].

3.2.2. Plant organic wastes

Plant organic wastes play a significant role in biogas production. In Turkey, 65 million tons of agricultural waste are produced annually from crops such as cotton, tobacco, barley, wheat, rice, etc. These wastes contribute significantly to environmental pollution. However, biogas production from these wastes is crucial both for environmental benefits and energy production [3]. The methane (CH_4) content of biogas produced from corn stalks and residues is 59%, while the methane content in biogas produced from wheat and barley straw is 60%. Approximately 185 m^3 of biogas can be obtained from 1 ton of corn silage [29].

3.2.3. Industrial and urban wastes

Industrial development, urbanization, and rapid population growth have led to the production of various wastes (such as sewage, leather, paper, food, and textile industry wastes), which are utilized in biogas production. Two methods are used to produce biogas from urban and industrial wastes: the biomethanization method and anaerobic fermentation. The biomethanization method involves separating the organic components of industrial and urban wastes and producing biogas through anaerobic fermentation. The use of the biomethanization method in biogas production increases the efficiency of gas production. The anaerobic fermentation method directly produces biogas from the waste [30].

3.3. Biogas potential of Batman province

In Batman Province, there are 121,631 cattle, 859,003 sheep and goats, and 76,440 poultry animals. A total of 11,250 families engages in animal husbandry in the province [31]. The annual manure production from cattle in Batman Province is 437,871.6 tons, from sheep and goats is 601,302.1 tons, and from poultry is 1,681.68 tons. If the manure produced by these animals is converted into biogas, 14,449,762.8 m^3 of biogas can be obtained from cattle, 34,875,521.8 m^3 from sheep and goats, and 131,171.04 m^3 from poultry. When the produced biogas is converted into electrical energy, it would yield 67,913,885.16 kWh from cattle, 163,914,952.5 kWh from sheep and goats, and 616,503.888 kWh from poultry, totaling 232,445,341.5 kWh of electrical energy. Table 3 shows the overall biogas potential in Batman. It has been determined that, with efficient and conscious use of the animal manure in Batman Province, significant energy could be generated.

Table 3. Biogas Potential of Batman

Animal Type	Animal Quantity (head)	Waste Quantity (tons)	Biogas Production Potential (m³)	Electricity Production Potential (kWh)
Cattle	121,631	437,871.6	14,449,762.8	67,913,885.16
Sheep and Goats	859,003	601,302.1	34,875,521.8	163,914,952.5
Poultry	76,440	1,681.68	131,171.04	616,503.888
Total	**1,057,074**	**1,040,855.38**	**49,256,455.64**	**232,445,341.5**

3.4. Method

Energy investments are typically long-term investments, and thus, the financial efficiency of such projects needs to be calculated based on varying economic conditions. The most commonly used method for the economic evaluation of energy projects is the Net Present Value (NPV) approach. The economic analysis is performed by calculating the present value of the planned project's current cost and the future cash flows, taking into account the interest rate. A positive NPV indicates that the project is profitable and that the investment is viable. The NPV value can be calculated as follows:

$$NPV = \sum_{t=1}^{N} \frac{R_t}{(1+r)^t} - I_0 \tag{1}$$

The parameters in Equation (1) are defined as follows;

R_t : Net cash flow of the project in year t (revenue - cost)
r : Interest rate of the cost of capital
N : Economic life of the project
I_0 : Initial installation cost of the project

When calculating the net cash flow of the project, it is determined by subtracting the total operating costs, maintenance and repair costs, fuel costs, and other cost items from the revenue generated from the sale of produced electricity. In NPV calculation, the selection of a suitable discount rate is essential. This rate reflects the cost of capital or the required rate of return, accurately representing the project's risk profile and the opportunity cost of capital. NPV is highly sensitive to the discount rate; a higher rate reduces the present value of future cash flows, potentially rendering a project with a positive NPV at a lower rate unprofitable. Therefore, a thorough sensitivity analysis, varying the discount rate, is essential.

Another widely used method in the economic evaluation of energy investments is the Levelized Cost of Energy (LCOE), which is defined as the cost per unit of energy produced over the economic life of an energy source. This value is obtained by dividing the total present value of the project's cash flows by the amount of energy produced, as shown in Equation (2).

$$LCOE = \frac{Total\ cost\ over\ economic\ life\ (NPV)}{Present\ value\ of\ electricity\ produced\ over\ economic\ life}$$

$$LCOE = \frac{NPV}{\sum_{t=1}^{N} \frac{E_t}{(1+r)^t}} \tag{2}$$

In Equation (2), E_t represents the amount of electricity produced in year t when calculating the unit energy cost. When calculating LCOE, a detailed breakdown of all cost components is crucial, including capital expenditures, fixed and variable operating costs, fuel costs (if applicable), and decommissioning costs. Accurate estimation of energy output over the project's lifetime is also required, considering factors like capacity factors, resource availability, and technology performance. When comparing LCOE values across different projects, it is vital to use a consistent discount rate to ensure a fair comparison. It is important to note that while NPV assesses profitability of the total investment, LCOE focuses on per-unit energy cost.

4. Numerical Results

This section presents the economic evaluation of a biogas plant, assessing waste potential in Batman province. The Net Present Value (NPV) and Levelized Cost of Energy (LCOE) methods, as detailed in Section 3.4, are applied. To provide a comprehensive comparison, energy sources prevalent in the Batman region—diesel, geothermal, fuel oil, and asphaltite—are also economically evaluated. Economic parameters, derived from [20] and detailed in Table 4, form the basis of these analyses.

Table 4. Economic Parameters of Energy Production Technologies

Type (By Source)	Lifetime (Years)	Efficiency Factor	Initial Cost ($/MW)	Fixed Cost ($/MW)	Variable Cost ($/MWh)	Fuel Cost ($/MWh)	Annual Electricity Production (MWh/Yıl)
Biogas	20	0.4	2500000	90000	1	13.75	7446
Geothermal	30	0.0001	3750000	40000	10	-	7446
Diesel	30	0.54	900000	11600	2.66	91.75	7446
Fuel Oil	30	0.54	900000	11600	2.66	54.05	7446
Asphaltite	30	0.45	1200000	40000	4	6.89	7446

The biogas plant, with a 20-year lifespan and 0.4 efficiency factor, is evaluated with an initial cost of $2,500,000/MW, fixed costs of $90,000/MW, variable costs of $1/MWh, fuel costs of $13.75/MWh, and an annual electricity production of 7,446 MWh. An NPV analysis, assuming an electricity sale price of $100/MWh and an 8% interest rate, is presented in Figure 2.

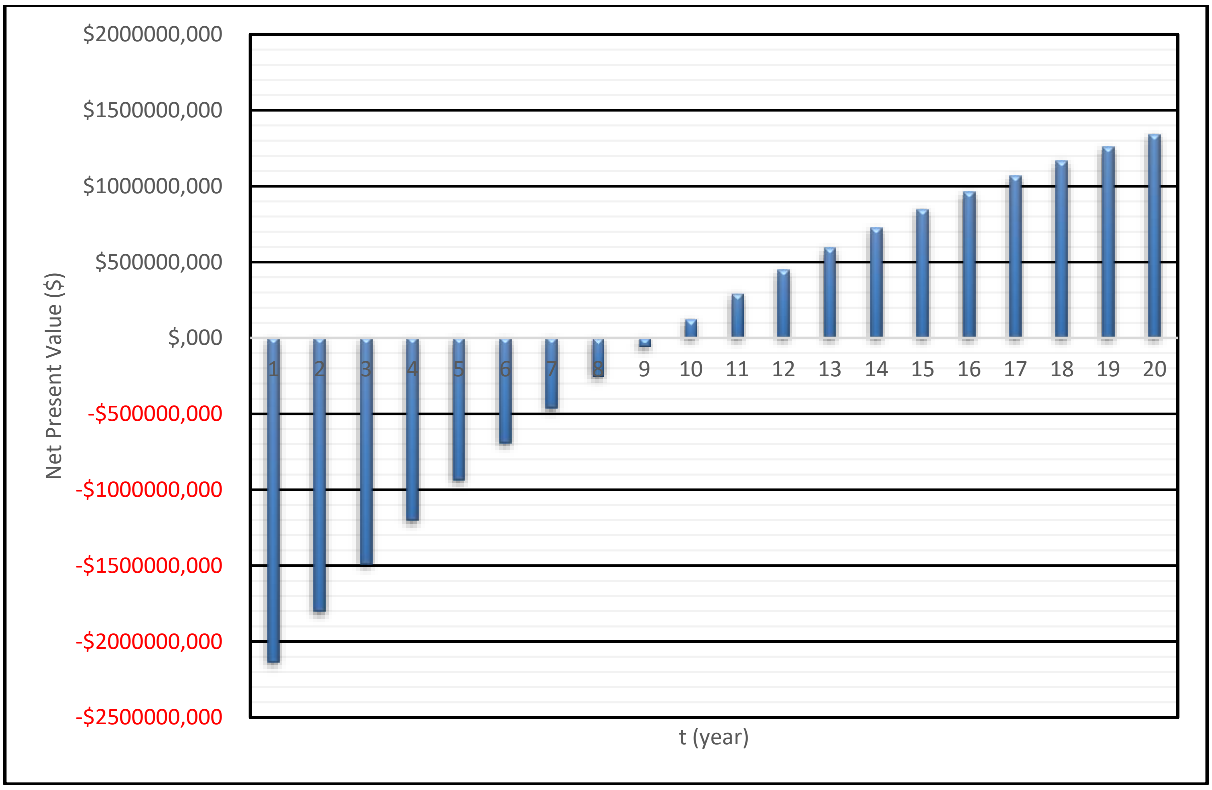
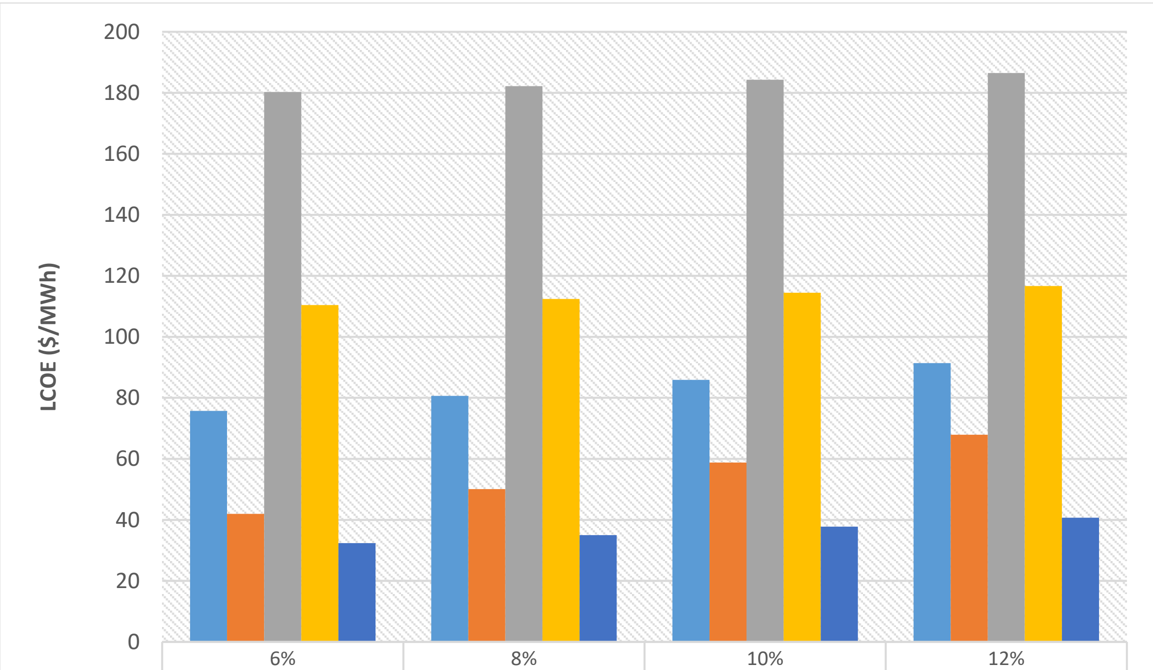


Figure 2. NPV Change of the 1 MW Biogas Plant Over the Years

The project's initial investment of $2.5 million is recouped after approximately 10 years, with the NPV turning positive. The project reaches an NPV of approximately $1.3 million by the end of its 20-year lifespan. The Internal Rate of Return (IRR) is calculated to be 14.6%, indicating the project's financial viability at interest rates below this threshold.

In such analyses, the interest rate plays a significant role, significantly affecting the investment viability and profitability of the project. One of the key economic indicators in this area is the IRR which is the interest rate that makes the NPV equal to zero. This rate is the interest rate that balances the initial cost when discounting the future cash flows to their present values. When the interest rate is equal to the IRR, the investment yields neither profit nor loss. For the investment to be considered profitable, the interest rate must be lower than the IRR value. According to the cash flow shown in Figure 2, the IRR is calculated to be 14.6%. This means that if the interest rate exceeds 14.6%, the project is not financially viable under the given economic conditions.

A comparison of biogas with other generation technologies reveals their relative costs based on the Levelized Cost of Energy (LCOE), which indicates the per-unit production cost of energy over the economic lifespan of a power plant and serves as a critical benchmark for investment decisions. Figure 3 illustrates the LCOE values for biogas, asphaltite, diesel, geothermal energy, and fuel oil, calculated at different interest rates, providing a clear comparison of which technologies are cheaper or more expensive under varying financial conditions.



	6%	8%	10%	12%
Biyogaz	75,73444	80,65912	85,89932	91,41206
Jeotermal	41,96124	50,10917	58,79763	67,89534
Dizel	180,2467	182,2022	184,2875	186,4709
Fueloil	110,43	112,39	114,47	116,66
Asfaltit	32,39178	34,99912	37,77943	40,6907

Figure 3. LCOE values for different energy production types at varying interest rates ($/MWh)

In Figure 3, we present a clustered bar chart comparing the LCOE in dollars per megawatt-hour ($/MWh) for five different energy sources: biogas, geothermal, diesel, fuel oil, and asphaltite. The X-axis represents varying interest rates, specifically 6%, 8%, 10%, and 12%, while the Y-axis displays the LCOE values. Each energy source is represented by a distinct color, with the corresponding LCOE value for each interest rate displayed within the respective bar. It effectively illustrates the impact of changing interest rates on the LCOE of these energy sources, revealing that as interest rates increase, the LCOE rises across all sources as expected. Notably, geothermal and asphaltite consistently exhibit the lowest LCOE values, indicating their economic competitiveness, while diesel maintains the highest LCOE, suggesting it is the most expensive option. Biogas and fuel oil fall within the middle range, with biogas showing a more moderate increase in LCOE as interest rates rise compared to fuel oil.

Our economic analysis of a biogas plant in Batman province aligns with the broader literature demonstrating the viability of biogas energy. Our estimated IRR of 14.6% and payback period of 10 years fall within the range of values reported in studies on biogas production from various feedstocks, such as composite materials [20], cow manure [21], and sugar factory waste [22]. While our IRR is higher than some reported values [20], it is lower than the exceptionally high returns found in other studies [21], likely due to regional variations in factors such as feedstock costs, energy prices, and policy incentives. Our LCOE analysis further reinforces the cost-competitiveness of biogas, particularly compared to traditional liquid fuels. These findings underscore the potential of biogas to contribute to a more sustainable and secure energy future by utilizing waste streams, reducing reliance on fossil fuels, and mitigating climate change. Future research should explore strategies to optimize biogas production and further enhance its economic viability in diverse regional contexts.

When comparing the cost values calculated for biogas with other alternative energy sources, it is observed that biogas has higher costs than geothermal energy and asphalt, but lower costs compared to liquid fuels such as diesel and fuel oil. The findings in Figure 3 reveal that the highest unit cost is 50.11 $/MWh for diesel. The most cost-effective option is geothermal energy. Geothermal energy stands out not only due to its cleaner and renewable nature but also because of its favorable cost. The cost differences between biogas and geothermal/asphaltite can be attributed to several factors. Geothermal energy's lower LCOE stems from its inherent resource availability and lower fuel costs, as it leverages the earth's natural heat. Asphaltite, a locally sourced solid fuel, benefits from lower fuel acquisition and processing costs compared to biogas, which involves more complex biological processes and feedstock management. These findings underscore the importance of tailored energy policies that consider regional resource availability and economic factors. For Batman province, while biogas presents a viable alternative to liquid fuels, incentives and technological advancements are needed to enhance its cost-competitiveness. Policies regarding biogas should focus on supporting the development of geothermal resources, given their cost effectiveness and sustainability.

5. Conclusion

This study evaluates the economic potential of a biogas plant for assessing waste potential in Batman province. Net Present Value (NPV) and Levelized Cost of Electricity (LCOE) methods are used for the calculations. The economic comparison of biogas, along with other energy sources such as diesel, geothermal, fuel oil, and asphaltite, is made. The economic parameters used in these analyses are selected based on the data presented by [24].

For the local energy source, biogas, in Batman province, an initial investment cost of $2.5 million corresponds to an annual net cash flow of $362,220. The payback period of the plant is 10 years; after which it starts generating profit. Over the following years, the project continues to generate profit, and by the end of the 20th year, the NPV reaches approximately $1.3 million.

In the coming years, the potential implementation of a carbon tax further reduces the costs of clean energy types. However, it should be noted that geothermal and many other renewable energy sources may not always provide electricity on demand due to seasonal conditions or other constraints. Therefore, ensuring energy diversity is essential for uninterrupted energy access. According to the results of this study, biogas is more cost-advantageous compared to diesel and fuel oil. Moreover, the import of liquid fuels in Turkey results in a significant current account deficit. Biogas, on the other hand, can be entirely considered within a circular economy, as it generates electricity while disposing of waste without the need for imports. These findings suggest that biogas may help reduce dependence on foreign energy sources.

Future research should explore the integration of hybrid energy systems, combining biogas with other renewable sources like solar or wind, to enhance reliability and reduce costs. Detailed lifecycle assessments, including environmental and social impacts, are also crucial.

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7. Author Contribution Statement

Süleyman Atılgan is responsible for the design of the study, conducting the literature review, and preparing the sections related to biogas. Umut Ercan contributes the introduction, the design of the study, writing and editing of the manuscript. Muzaffer Alım conducts the economic analysis, presents the numerical results, and proofreading the paper.

8. Ethics Committee Approval and Conflict of Interest

It is not necessary to obtain approval from any ethics committee for the article being prepared. There are no conflicts of interest with any individual or institutions in relation to the content of the article.

9. Ethical Statement Regarding the Use of Artificial Intelligence

No artificial intelligence-based tools or applications were used in the preparation of this study. The entire content of the study was produced by the author in accordance with scientific research methods and academic ethical principles.

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