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Research Article

Energy Recovery from Landfill Gas in Turkey; Example of Adana

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Abstract

The need for energy increases with the increase of the population in the world and in our country over time. In line with this increasing energy need, it becomes imperative for countries to turn to alternative energy sources. The increase in population growth creates a serious waste problem by increasing not only energy demand but also consumption. Especially, the collection of solid wastes, both recycling and converting them into energy becomes an important issue. Considering the environmental problems caused by garbage and the increasing energy demand, generating energy while eliminating garbage appears to be the best method to solve these problems.
In this study, LandGEM V302 mathematical calculation method was used in the study. Model constants are determined using literature information. A mathematical model study was carried out in order to determine the electrical energy and methane potential that may arise from approximately 7.810.662 tons of solid waste dumped in the sanitary landfill in Adana. It has been determined that 14.420.666 kWh of electrical energy can be obtained in 2026, the closing year. From 2020 to 2026, there was an increase of 521.5%. Considering the environmental problems caused by garbage and the increasing energy demand, generating energy while eliminating garbage appears to be the best method to solve these problems.

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Türkiye'de Depo Gazindan Enerji Eldesi Ve Adana İli Örneği

Özet

Zaman içerisinde dünyada ve ülkemizde nüfusun artmasıyla birlikte enerji ihtiyacı da artmaktadır. Artan bu enerji ihtiyacı doğrultusunda ülkelerin alternatif enerji kaynaklarına yönelmesi zorunlu hale gelmektedir. Nüfus artışındaki artış, sadece enerji talebini değil, tüketimi de artırarak ciddi bir atık sorunu yaratmaktadır. Özellikle katı atıkların toplanması, hem geri dönüştürülmesi hem de enerjiye dönüştürülmesi önemli bir konu haline gelmektedir. Çöpün neden olduğu çevre sorunları ve artan enerji talebi göz önüne alındığında, çöpleri ortadan kaldırırken enerji üretmek bu sorunları çözmenin en iyi yolu olarak görünmektedir. Bu çalışmada LandGEM V302 matematiksel hesaplama yöntemi kullanılmıştır. Model sabitleri, literatür bilgileri kullanılarak belirlenmiştir. Adana ili düzenli depolama alanına dökülen yaklaşık 7.810.662 ton katı atıktan kaynaklanabilecek elektrik enerjisi ve metan potansiyelinin belirlenebilmesi amacıyla matematiksel modelleme çalışması yapılmıştır. Tesisin kapanış yılı olan 2026'da 14.420.666 kWs elektrik enerjisi elde edilebileceği tespit edilmiştir. 2020'den 2026 yılına kadar elektrik üretim miktarında %521,5'lik bir artış yaşanmıştır. Katı atıklar sebebiyle meydana gelen çevre sorunları ve artan enerji talebi göz önünde bulundurulduğunda, katı atıklar yok edilirken aynı zamanda enerji üretilmesi, bu sorunların çözümlenmesi için en iyi yöntem olarak karşımıza çıkmaktadır.

Anahtar Kelimeler
Depo gazı,
Metan,
Yenilenebilir Enerji,
Adana

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INTRODUCTION

In today, developments in the field of technology, urbanization and the increase in consumption needs due to these factors increase the amount and type of waste released into nature. One of the most important environmental problems caused by the increase in living standards with the developing technology and urbanization is solid waste rich in variety [1,2]. The safe disposal of these solid wastes, which increase over time, without harming the environment in any way, is a very important issue in terms of sustainable development. Disposal of waste is one of the most important steps in effective solid waste management [3].

The landfill gas released in the landfill facility; Considering the negative effects on the environment and public health, it is seen that the main problem is here. The greenhouse effect of CH_4 gas in landfill gas (LFG) on the atmosphere is 25 times that of CO_2 gas [4]. CH_4 gas, which is formed by the decomposition of organic wastes in an anaerobic environment, has a greenhouse effect on the atmosphere as well as an explosion risk [4,5]. Considering today's conditions, it has become a necessity to find and maintain renewable energy sources [6,7]. One of the important factors in this situation is the formation of greenhouse gases due to intense fossil fuel consumption. Fossil fuel consumption causes environmental pollution and global warming [8]. It is of great importance to minimize the negative effects of the resulting landfill gas. For this purpose, the most effective one among the various methods used in the world, when considered economically; is the use of landfill gas as fuel and generating energy from landfill gas [6,9].

The use of CH_4 gas in energy production has significant benefits such as reducing the greenhouse gas density, the odor problem in storage areas, the damage to plants by the gases released, and the risk of explosion caused by the combination of methane with air at certain rates [10]. The energy potential that can be obtained from landfill gas has brought with its studies on generating energy from this gas in recent years. There are many facilities around the world that produce electrical energy using landfill gas. In the studies conducted by the Environmental Protection Agency (EPA), it has been determined that 1380 MW of electricity has been produced from 450 power plants in the USA alone since 2007. In addition to these, the construction of 540 more power plants is planned, and these have the potential to generate 1280 MW of electricity [11].

The energy gas potential of one million tons of solid waste is thought to be 1.7-2.5 million m³. This rate can be used to generate 6.500-10.000 MWh of electricity per year and roughly equivalent to the average power demand of 1.500-2.200 EU households [12]. Obtaining electrical energy from landfill gas is also a common practice in European countries. For example; While the electricity requirement of three hundred thousand houses in Sweden is provided by landfill gas power plants, the heating of approximately one million houses is also met from these power plants [13]. Due to the development of our country's economic activities, energy consumption is also increasing rapidly. The amount of energy consumed between 2000 and 2015 is 5 times more than the amount consumed between 2000 and 2010, which is an indicator of an increase in energy consumption [7,13,14]. Turkey is a country rich in energy resources. In order to avoid problems in meeting its energy needs in the coming years, Turkey should definitely turn to renewable energy sources. Biogas is one of the renewable energy sources and it is very convenient in our country [15].

MATERIALS AND METHODS

Adana is the sixth most populous city in Turkey and has a population of 2.237.940 according to 2019 data [16]. In 2011, the "Adana Integrated Solid Waste Disposal Facility" started to work in the area located in the north-east of the city center in the Sarıçam district of Adana. Domestic wastes are transported to an integrated Adana solid waste disposal facility. The integrated facility consists of a medical waste sterilization facility, a power generation facility, a mechanical separation, a biomethanization system, and a sanitary landfill [17].

Information on Waste Characterization and Quantity

An average of 2.000 tons of domestic solid waste is brought to the Adana Metropolitan Municipality Integrated Solid Waste Disposal Facility per day.

The facility has a separation unit with a daily capacity of 2.000 tons which consists of 3 lines for mixed wastes. Wastes, packaging wastes, and organic wastes are separated according to their types and packaging wastes are sent to licensed recycling companies [17].

Adana Province Landfill Gas Plant

Sofulu Garbage Biogas Power Plant is located in the Sofulu region of the Yüreğir district of Adana. The power plant belonging to ITC-Ka Atik Energy company is Turkey's 590th and Adana's 24th largest power plant with an installed power of 15.6 MW. It is also Turkey's 5th largest biogas facility [18].

There are eight fermentation systems in the facility. Organic wastes are degraded by microorganisms in oxygen-free conditions, and in the meantime, CH_4 gas is produced. The released CH_4 gas is taken into balloons for storage and then sent to power generation facilities. The active gas collection system, which includes vertical and horizontal systems, has been established to collect the gas in the storage area. Methane gas produced in fermentation tanks and collected gas are directed to the power generation plant. There are 11 power generation engines in total at the facility. Gas engines use gas directly and convert it into energy. The capacity of the motors is 1.4 mW/h. Currently, there is a power generation facility with an installed capacity of 15.6 mW/h and two gas storage tanks of 16.000 m^3 each for the storage of the produced gas. The active gas collection system with horizontal and vertical systems for the collection of gas from the storage area is directed to the fermentation and methane gas energy generation plants produced in the gas tank. The facility can produce energy that can meet the electrical energy needs of an average of 50.000 households [18].

Determination of Methane Gas with LandGEM Program

LandGEM is an equation that measures emissions from the decomposition of solid wastes [19]. Estimated amount of methane gas to be generated from Adana Yuregir Sofulu landfill biogas power plant was calculated with the LandGEM version 3.02 program. The necessary information to run the model is as follows.

- The annual amount of waste stored or the total amount of waste in the storage area
- Methane generation rate constant (k)
- Methane generation potential (Lo).

The first-order kinetic equation used in the model is given below.

$QCH_4 = L_{\circ} . R . (e - kc - e - kt)$ [20]. (1)

Q_{CH_4} expected gas generation rate in the t^{th} year, m^3/yr

L_0 methane generation potential (m^3 CH_4/ tons of waste)

R annual waste amount (ton/year)

k Methane generation rate constant (yr^{-1})

c number of years after the site was closed (yr)

t time passed on since the first waste began to be stored (yr) [20,21].

RESULT AND DISCUSSIONS

The rates of domestic waste arriving daily to the solid waste landfill facility from the province and 15 central districts are shown in Figure 1.

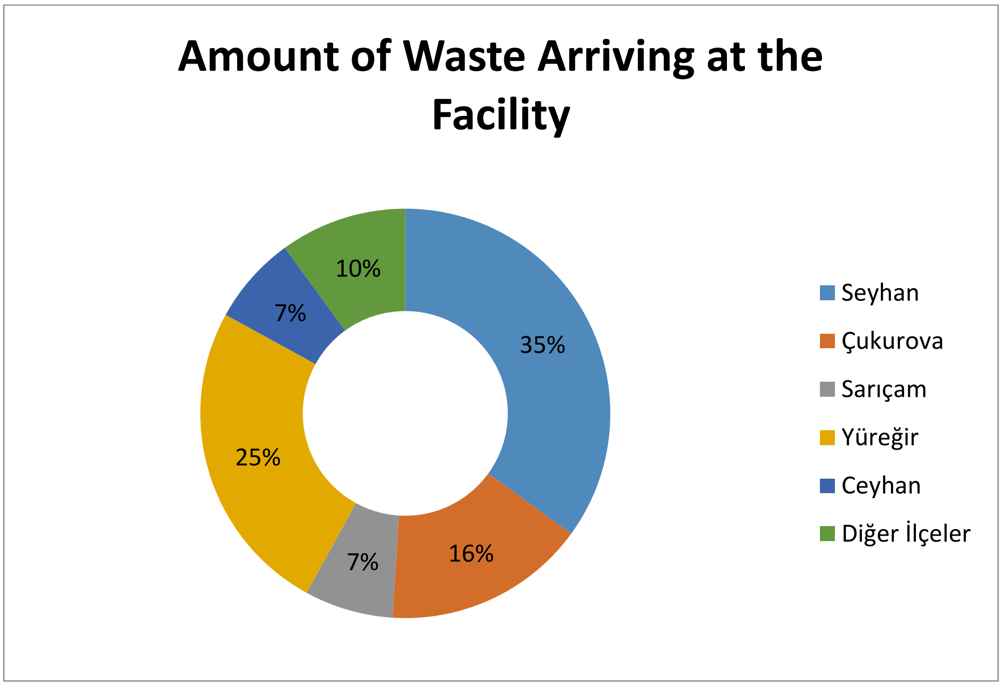

Figure 1. Waste rates by districts[17]

According to TUIK's municipal waste statistics for 2018,The average daily amount of waste collected per person has been calculated as 1.16 kg [22]. Considering the population change between 2011-2026; In order to determine the amount of waste that will be generated, it is necessary to determine the population in the coming years [17]. For this reason, first of all, population projections were created and in Table 1, the population information of the previous years of Adana province, which was created by using the data of the Adana Ministry of Environment and Urbanization, is given. In this study, the Ilbank method, which is a projection method used through Ilbank, was used in estimating the future population. In the method in which the increase is limited due to the geometric increase principle, the rate of increase is shown by the multiplying coefficient. The coefficient of proliferation indicated by 'C' is calculated using the formula below.

$$C = [(Ns / Ni) 1 / (ts - ti) - 1] . 100 \qquad (2)$$

In this equation;

C Multiplication coefficient

N_s last population value

N_i first population value

t_s last population value year

t_i first population value year [23].

According to the data obtained from the past censuses, the population of the province to be estimated in the future has a proliferation coefficient at five-year intervals. The arithmetic mean of the multiplying coefficients found is calculated with the help of the formula given in Equation 3 [24].

$$Cmean = (C1 + \cdots . + Cn) / n \qquad (3)$$

If $C_{mean} < 1$ then C=1; If $1<C_{mean}<3$ then $C=C_{calculated}$; If $C_{mean} > 3$ then C=3 [24].

In the light of this information, the reproduction coefficients for Adana province;

C_1= 0.94 (to expand for 2010-2014)

C_2= 0.65 (to expand for 2014-2019)

C_{mean} = 0,8

The data of the past persons in Table 1, including the previous ones, remained separately, by substituting them in Equation 1.

$$Nfuture = Npast . [1 + (Cmean /100)] n \qquad (4)$$

In this equation;

N_{past} = Last census

N_{future} = Future population calculation

t_{future}= Year in which the population will be determined

t_{past} = Year of population

n = ($t_{future} - t_{past}$) year [24].

Since Adana Integrated Solid Waste Facility started to operate for 15 years, the population data for the years 2011-2026 are calculated and presented in Table 1.

Considering the amount of solid waste produced per person per day accepted for Adana and the estimated populations calculated, the amount of solid waste to be produced in the solid waste facility between 2011 and 2026 is calculated in Table 1.

Table 1. Estimated solid waste amounts to be produced in Adana province between 2019-2026

Years	Population	Waste Production (kg/person-day)	Total Waste (kg/day)
2019	2.237.940	1.16	2.596.010
2020	2.245.400	1.16	2.604.664
2021	2.267.854	1.16	2.630.710
2022	2.290.532	1.16	2.657.017
2023	2.313.437	1.16	2.683.586
2024	2.336.571	1.16	2.710.422
2025	2.359.937	1.16	2.737.526
2026	2.383.536	1.16	2.764.490

The estimated amount of methane gas from the Adana Yuregir Sofulu Garbage Biogas Power Plant was calculated with the LandGEM version 3.02 program. In the model, there are two different options for the disposal of hazardous and non-hazardous wastes in the same place and for the disposal of hazardous wastes in a different place. Since hazardous wastes are not stored together with household waste in Adana, there is no option to dispose of them together. A site-specific L_0 and k value is not known in the model. For this reason, the empirical values given in the model can be used for the CAA or AP-42 options. In this study, CAA empirical values were used for k and L_0 values [21].

Table 2. LandGEM model results for Adana province biogas power plant

Years	Amount of Waste Stored (ton/year)	Cumulative Amount of Waste (ton/year)	Landfill Gas Amount (ton/year)	Landfill Gas Amount (m^3/year)	Landfill Gas Amount (ton/year)	Landfill Gas Amount (m^3/year)
2019	948.193	0	0	0	0	0
2020	951.354	948.193	1,968E+04	1,433E+07	5,258E+03	7,165E+06
2021	960.867	1.899.547	3,847E+04	2,801E+07	1,028E+04	1,400E+07
2022	970.475	2.860.414	5,655E+04	4,116E+07	1,510E+04	2,058E+07
2023	980.180	3.830.889	7,393E+04	5,382E+07	1,975E+04	2,691E+07
2024	989.982	4.811.069	9,068E+04	6,601E+07	2,422E+04	3,300E+07
2025	999.881	5.801.051	1,068E+05	7,775E+07	2,853E+04	3,888E+07
2026	1.009.730	6.800.932	1,224E+05	8,907E+07	3,268E+04	4,453E+07

As a result of the calculations, it was concluded that a total of 185,065,000,000 m^3/year of methane gas was formed in the field for the CAA constant until 2026.

The amount of CH_4 in the landfill gas is between 45-60% and the amount of CO_2 is in the range of 40-60% [9]. Since the CH_4 and CO_2 measurement values from the facility are not available, it was assumed that the landfill gas consisted of 50% CH_4 and 50% CO_2 gas at the beginning of the model. Accordingly, it has been determined that a total of 370.150.000.000 m^3/year of landfill gas will be generated for CAA in the field.

Electricity Generation from Landfill Gas for Adana Province

In this study; energy production from landfill gas operating in Adana province integrated solid waste facility was evaluated in terms of efficiency with the LandGEM model. In Figure 2, the electricity generation amounts in Adana province in the years 2011-2018 are given.

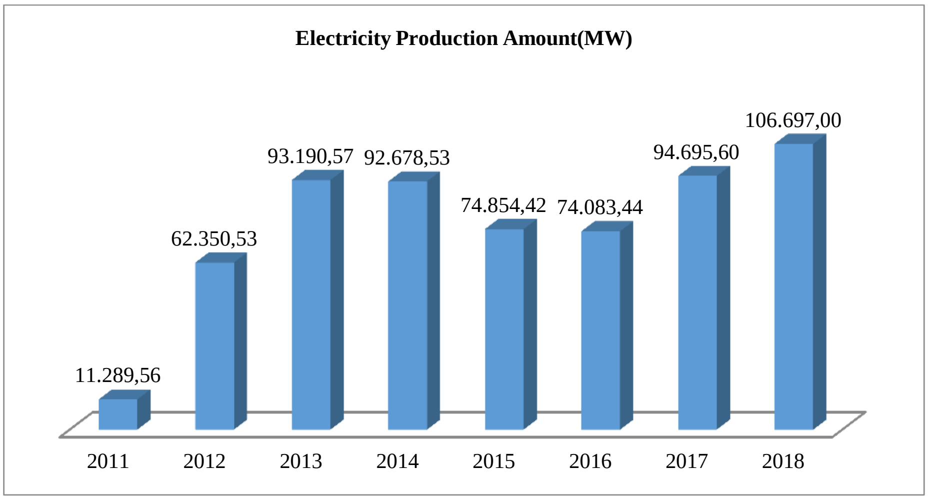

Figure 2. Electricity production by years [17]

The composition of the landfill gas is CH_4 = %50 (by volume), CO_2 = %50 (by volume). The formula used to find the energy equivalent of 1 $m^3$of landfill gas is given below:

$$CH_4 + 2O_2 \leftrightarrow CO_2 + 2H_2O \; \Delta H(298) = -802.7 \, kJ/mol \quad (5)$$

When 1 mol of CH_4 is burned at constant pressure, it releases 802.7 kJ/mol (192 kcal) of energy [25]. The density of methane is 0.657 kg/m^3 and since 0.5 m^3 of methane is in 1 m^3 of gas, the volume of methane will be 0.5 m^3. From here, the mass of methane gas can be calculated with the density formula.

$$d = m/V \quad (6)$$

0.657 kg/m^3 x 0.5 m^3 = 0.328 kg =328 g.

If 1 mol of CH_4 (16 g) is burned, it releases 192 kcal of energy;

When 328 g methane is burned, it releases X= 3936 kcal of energy

Since 1 kWs=860 kcal, the 3936 kcal energy released is equivalent to 4.57 kWh. In other words, the energy equivalent of 1 m3/h of landfill gas is 4.57 kWh. It is not possible to recover all of the landfill gas generated in solid waste landfills. For this reason, gas collection efficiencies for the storage area to be examined should be determined. In this study, the average landfill gas collection efficiency was determined as 70% according to the landfill area.

The gas engine and generator sets in the facility have a capacity of 1.4 MW. The electrical efficiency of the motors is about 42% (Jenbacher, 2020). Facility officials stated that this rate is around 35-45%. Based on this information, the rate was accepted as 40% in this study.

The electricity generation potential between 2020-2026 that can be obtained from landfill gas;

$$Eel\ (kWs) = mdg.LHVdg.R.nel \quad [26] \qquad (7)$$

In this equation;

m_{dg} = Total landfill gas flow (Nm^3/s)

LHV_{dg} = Energy equivalent of landfill gas (kWh/Nm^3)

R = Gas collection efficiency (%)

n_{el} = electrical efficiency of the gas engine (%)

Table 3. Estimated electricity production amounts for the next years

Years	Electricity Generation (kWh)	% increase rates
2020	2.320.065	-
2021	4.534.891	95.5
2022	6.735.147	48.5
2023	8.713.599	29.4
2024	10.687.192	22.6
2025	12.587.928	17.8
2026	14.420.666	14.6

The electricity production amounts for the past years were obtained from the Adana Province Environmental Status Report. The electrical energies calculated with the amount of landfill gas obtained from the LandGEM model are presented in Table 3 and presented graphically.

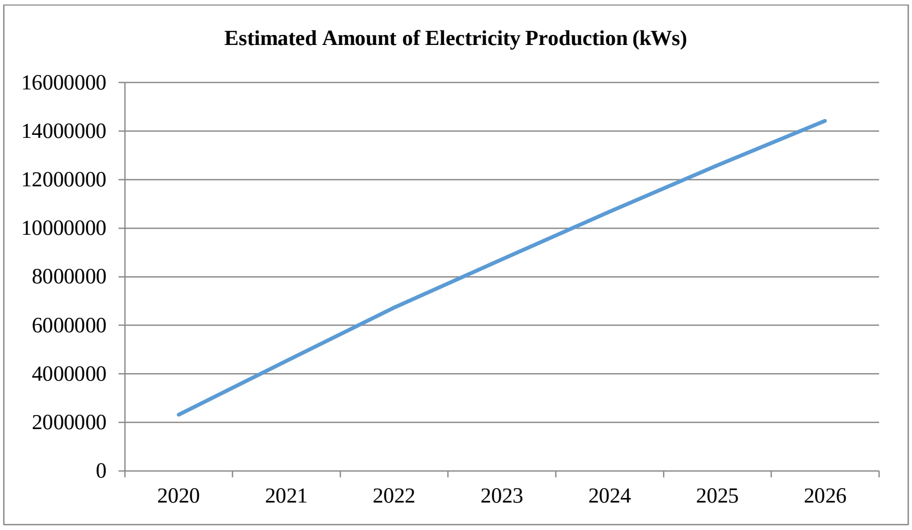

Figure 3. Graphical display of estimated electricity generation amounts for the next years

When the calculation for the next years is made, the highest value of electricity production was calculated as 14420666 kWh in 2026, the closing year of the plant. It has been calculated that there will be an increase of 521.5% in the amount of electricity generation from 2020 to 2026. It has been concluded that there will be an increase in the amount of waste and landfill gas released due to population growth. It has been determined that there will be an increase in the amount of electrical energy to be obtained with the increase of landfill gas every year.

CONCLUSIONS AND RECOMMENDATIONS

The deterioration of the ecological balance and the use of energy resources with limited lifetimes increase the importance of using renewable energy resources over time. The rapid increase in the world population, the wide variety of consumer goods, and the change in habits cause serious waste problems. In order to reach a final solution to this problem, the use of new technology should be expanded in our country and even throughout the world. For the model of solid waste management that should be preferred, it should not be thrown away from people's eyes and thrown into an empty area, but it should be seen as a resource in terms of economy and removed by using environmentally compatible disposal options [27]. Since CH_4 gas, which constitutes approximately 55% of the biogas released in landfills, is an important energy source, its contribution to global warming is 25 times higher than CO_2. The decomposition and gas formation from the fields can continue even 50 years after the fields are closed [28].

The emission of methane gas that will occur over time at the sanitary landfill in Adana to the atmosphere will be prevented by using it in energy production with Adana Sofulu Dumpling Biogas Power Plant. For this reason, obtaining energy from solid wastes should not be seen only as a bioenergy application. A mathematical modeling study was carried out in order to determine the electrical energy and methane potential that may arise from approximately 7.810.662 tons of solid waste dumped in the sanitary landfill of Adana province. It has been determined that 14.420.666 kWh of electrical energy can be obtained in 2026, the closing year of the facility. From 2020 to 2026, there has been an increase of 521.5% in the amount of electricity production. As a result of the calculations, it has been determined that a total of 185.065.000.000 m^3/year of methane gas and 370.150.000.000 m3/year of landfill gas will be generated in the field until 2026. In another study conducted for the province of Sivas in our country; Findings were obtained by using LandGEM Version 3.02 on how much energy can be obtained annually from landfill gas. As a result, the highest amount of energy to be produced in 2030, the closing year, was calculated as 2947 kWh [11]. However, the amount of solid waste, population, and climatic conditions show serious differences compared to Adana. Even if the energy calculation is made with the same method, the fact that the total amount of waste calculated especially for Sivas province is 946.920 tons and for Adana 7.810.662 tons clearly reveals this difference. The biodegradable organic matter content of the wastes generated in Adana is high. In future studies, it is important to perform site-specific experiments in the selection of parameters in the models to be established. Whenever possible, pump tests should be carried out in the field. Thus, the gas production potential of the field will be determined and healthier and more realistic results will be achieved for the coming years. Obtaining electricity from landfill gas is the second economic technology among renewable technologies after hydroelectric power plants. Energy production from landfill gas is positive in terms of its impact on the environment and is a reliable energy source due to its high capacity [10]. The risk is very low as a tried and developed technology is used. In general, landfill gas power plants are located a few kilometers outside the cities. Therefore, grid connections are short, which reduces costs and energy losses [17].

Today, since the energy resources of our country are not sufficient, it has to import a large part of the energy it needs [29]. In order to close the energy gap and eliminate the solid waste problem, it is of great economic importance to generate electrical energy from the waste that remains and needs to be stored after the waste is recycled in Adana and other big cities. It should be considered that a certain part of the generated heat and electricity will be used for the internal energy needs of the facility and the other part will be sold within the scope of the renewable energy law. In this way, it is ensured that the wastes released from the landfills are evaluated without harming the environment in any way, and they can be recycled into the country's economy with energy production with environmentally friendly technologies.

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