CAPACITY INCREASE AND ENERGY EFFICIENCY IMPROVEMENT STUDIES IN A BIOGAS POWER GENERATION PLANT

Mehmet Keskin KILIC[1], Nurettin ABUT[2], Fatma CANKA KILIC[1*], Volkan COBAN[3], Durmus KAYA[3]

[1]Department of Electrical and Energy, Kocaeli Vocational School, Kocaeli University, Kullar Beldesi, Mahmutpaşa Cad. No:1, 41140 Basiskele/Kocaeli, Turkey;
[2]Department of Electrical Engineering, Faculty of Engineering, Kocaeli University, 41380 Umuttepe, Kocaeli, Turkey;
[3]Department of Energy Systems Engineering, Faculty of Technology, Kocaeli University, 41380 Umuttepe, Kocaeli, Turkey;
**Corresponding Author Address: Department of Electrical and Energy, Air Conditioning and Refrigeration Technology, Kocaeli Vocational School, Kocaeli University, Kullar Beldesi, Mahmutpasa Cad. No:1, 41140 Basiskele, Kocaeli, Turkey.*

*E-mail: fatmacanka@hotmail.com;

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ABSTRACT

Today, biogas, which is a type of renewable energy source, has been increasingly used in various fields around the world. Energy from biogas is an effective and non-externally dependent energy production model that best utilizes the economic and local resources, also the least harmful to the environment with its technologies. In addition, with biogas productions, the contribution to the energy productions can be made by realizing conversion of waste. As it is well known, waste is an inevitable result in the life cycle of the living and it needs to be evaluated successfully for the sustainable energy developments. In today's fast-paced technology, all natural and local wastes used for biogas production, which are not only considered as waste but as resources that awaiting for the conversion to energy. Therefore, it is necessary to convert waste to energy by using biogas technologies to have green energy. At the present time, while the numbers of industrial facilities are increasing rapidly, the improvement and development studies are also increasing accordingly, in the existing facilities. In this study, the improvement efforts that have resulted in success of a biogas plant in Kocaeli-Turkey have been examined in detail. Initially, the production capacity of the biogas plant was 305 kW, then it has been powered by an additional gas engine, which at the power of 415 kW and with this new addition, the plant production capacity has reach the level of 720 kW. The capacity and efficiency increase options that have been carried out during the process are presented in this work in technical and economical point of view.

Key words: Energy from waste, Biogas, Renewable energy, Energy efficiency

INTRODUCTION

Today, one of the most promising alternatives for the electricity generation is renewable energy sources. Due to the restructuring of the electricity sector worldwide and the increase in demand for electricity, the need for renewable energy generation has increased gradually. In addition, the need for renewable energy production has become even more important when looking at the need for power quality and system reliability and the current energy bottleneck [1].

The diversity of renewable energy sources has led to the development of many different energy production techniques. Different energy production methods in different areas revealed a decentralized production model.

In the report of International Conference on Electricity Distribution (CIRED), which published in Belgium in June 1999, the most common definition of energetically distributed production has been defined as it is electricity generation in the distributed network or on the customer side of the network [2]. In his work, Moskovitz emphasized the strategic importance of distributed energy production, about meeting the customer's energy demand, energy security and reliability requirements [3]. Regan, T., Sinnock, H. Davis, A. presented their work on the integration and control of renewable energy sources in the system in the National Renewable Energy Laboratory (USA) report [4]. Kim S. K., Jeon J. H., Cho C. H., Ahn J. B., and Kwon S. H, in their study, stated that the possible sources of energy must be interconnected among themselves. They also said that a hybrid system could be created to achieve better power quality through effective coordination and appropriate controls among their various subsystems against conventional sources of power generation for reliable sources [5]. In their work in 2009, Gözel T. and Hocaoğlu M. H stated that as one of the most important motivations for the integration of distributed resources, it is necessary to utilize renewable energy resources such as small hydro, solar, geothermal, biogas from natural resources scattered around the country [6].

The need for decentralized production has increased due to the restructuring of the electricity sector around the world and also the increase in demand for electricity. Ray P. K., Mohanty S. R., Kishor N., in their work in 2011, have also proposed decentralized production as one of the most promising alternatives for today's electricity generation. In addition, the need for decentralized production has become more important when looking at the need for power quality, system reliability and for the current energy shortage [1].In their work in 2013, Peter M. van de Ven, Nidhi Hegde, investigated the range of charge and discharge rate of battery groups used in energy storage in order to reduce energy costs versus energy demand [7].

The studies within the scope of producing and consuming the energy on site which is emerging as an alternative method to the classical energy production, transmission and distribution line all over the world have been applied successfully, especially in recent years. These applied solutions have been discussed with this method which is seen as the closest and easiest approach to the new energy searches of the developing world. Thus, these solutions produced in the local sense have been evaluated in terms of converting the passive energy inputs in the small sense into active ones. As a result, this study aims to make a contribution to the increase of energy production in the whole country and draw attention to take necessary the precaution carried out by means of distributed energy production. Turkey has made important decisions in the direction of designing and implementing cheap, reliable, continuous and sustainable programs and energy policies. Many domestic renewable energy sources, which constitute alternative solutions in order to overcome many energy-related problems in Turkey, are waiting to be evaluated properly. These sources are hydraulics, geothermal, wind, solar, biomass and bio-fuels. It is expected that Turkey will play an important role in solving the energy problems of the country through correct and conscious application and operation methods.In parallel with the general direction in the world, it is hoped that the proportion of the distributed energy production system in Turkey will come to significant levels in the near future. It is also envisaged that this approach will deeply affect the distribution system planning and operating philosophies. In this study, an example study has been conducted in order to ensure that local energy sources in passive conditions are brought to energy production using appropriate technologies. A biogas plant that has 305 kW production capacity in Kocaeli, Turkey has been extended to the capacity amount 720 kW with 415 kW of additional gas engine. The change in energy generation process according to the capacity increase was examined and the results were presented in this study. It has been seen that the overall energy efficiency will increase with the addition of the energy storage systems to the production model. Also, it is aimed to keep the common efficiency at the top level with a proper energy management program related to the system.

MATERIAL AND METHODS

Distributed Energy Production

As of February 2017, Turkey has reached the total installed power of 78,788.6 MW. The sources of power and the proportion of these sources to the total installed power in Turkey are given in Table 1 down below [8].

Table 1. Installed power distribution in Turkey as of February 2017 [8].

Source	Installed Power (MW)	Installed Power as a %
Natural gas and LNG	22,095.2	28.0%
Imported Coal	7,473.9	15.5%
Stone Coal, Lignite and Asphaltite	9,869.9	22.5%
Fuel Oil, Naphtha and Diesel Oil	368.7	0.5%
Sun	898.9	1.1%
Wind	5,882.3	7.5%
Hydraulic Stream	7,147.9	9.1%
Hydraulic Dam	19,633.1	24.9%
Multifuel	4,021.1	5.1%
Geothermal	835.9	1.1%
Renewable, waste and other	561.7	0.7%

Local energy production affects the normal working and transient working conditions of the electricity networks positively, with the increase in the energy distribution systems. In some cases, localized energy sources can lead to voltage sags or amplitudes, resulting in increased losses and overloading of transmission lines. Therefore, when the integration of local energy production resources with the existing energy system is considered, the effects on the system need to be evaluated correctly.

The utilization rate and output powers of local energy production sources cause the rate of change of voltage level in the distribution system to increase. The small, strongly distributed power generation sources that are connected to the grid near the consumers provide energy losses and reduced voltage drops, increasing the power quality and reliability of the system.

The purpose of distributed production is to provide an active source of electrical energy. According to this definition, it is not necessary to verify distributed production reactive power. Distributed production is a production unit that can accommodate different technology groups and can be used in low and medium voltage, connected directly or indirectly to the operation distribution of the network.

Today, traditional energy production, transmission and distribution system structures are now in a process of change. That is to say, instead of large-scale power plants, smaller-scale plants that will produce local solutions have begun to take place. These techniques are applied in many areas, especially in energy supply functions, to provide appropriate average values. Along with the advances in information technology, however, significant improvements have been made in increasing digital control and load efficiencies. In this way,

a) The saving of local or imported energy resources is realized in the use of primary energy,

b) As a result of the energy production cycle occurring at the point of consumption, it is ensured to minimize the losses of transmission and distribution of the electric energy,

c) When compared to central power plants, it provides the advantage of shorter construction and commissioning time, at this point, it is possible to respond quickly to the electricity energy requirement,

d) Considering the small power plants, especially those of fossil energy source based; the amount of solid, liquid and gaseous matter that thrown into the surroundings is much less than that of the central power plants and therefore, it is easy to control of the waste,

e) Energetic economy, minimizing losses, increasing control and reliability, as well as ensuring the feeding of the general network system, if necessary, in the advantages of generating electricity in a distributed power generation system instead of a small number of central power generation systems [9].

Biogas Energy and Turkey

Biogas, which is a type of renewable energy source, is increasing its usage field and efficiency. Contributing to the overall energy need will be achieved by transforming the inevitable wastes into energy in the most efficient way in the life cycle. Now we have to think of these wastes not only as remnant but as matters that are waiting to turn into energy.

In Turkey, there are 82 active biogas plants with an installed capacity of 467.37 MW, an annual electricity production of 1,873 GWh and a total installed power of 0.55%. It is expected that these power plants will increase rapidly in the next 10 years and catch the level of wind energy as installed power [10].

Biogas production is provided by taking advantage of wastes, vegetal wastes and wastes generated during the processing of vegetable products, domestic and organic wastes generated during the processing of animal wastes and animal products. In addition, energy production is also a matter of combustion or storage.
In burning method; incoming wastes are subjected to process treatment after being dumped into the deep pit pools of the unit, especially industrial and hospital wastes. It is inevitable that chemical wastes which are very different in industrial wastes and which may be dangerous and it can cause disease by spreading organisms, so must be handled carefully. The size of the contamination and decay that they will give to the environment also needs to be taken into consideration. For domestic wastes, storage techniques are usually handled in open pool areas.
Some basic infrastructure work needs to be done before pouring garbage into open pool areas. The surface channels are required for the liquids that leak from the garbage on the bottom surface and it must be evacuated before the pool filling level begins to increase (due to the accumulation of wastes). If the garbage collection area is open to the atmosphere, this also be necessary for leaks that may be caused by rain and snow effects. In order to evacuate the leaking gas, it is also necessary to install discharge chimneys to certain points of the garbage pool. Thus, any methane explosion is prevented in the landfill area. But, the methane here is mostly given to the atmosphere and polluted the environment. If such proposed energy production model is added to the system, the waste that is taken from the environment and it is transformed into energy and not harm the environment [11]. A biogas production process is shown below in Figure 1 [12].

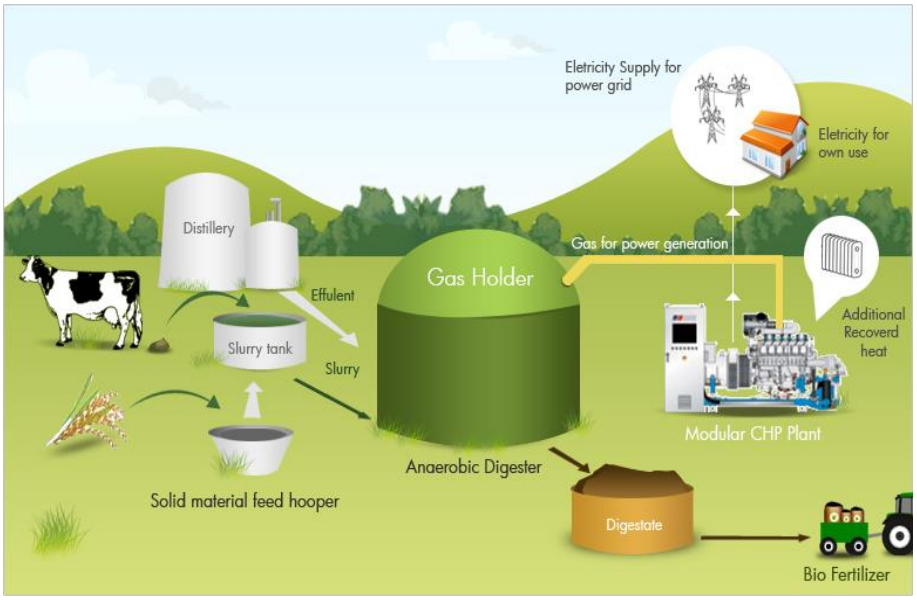


Figure 1. A biogas production process [12].

Using closed storage areas contributes to faster and more continuous energy production. The gas outlets of the wastes taken to the closed storage areas cannot escape to the atmosphere and collected by the gas discharge pipes. The waste mixer impellers working for a certain period and accelerate the gas discharge by venting the garbage. When the gas output decreases to the minimum according to the results, the new wastes are removed from the warehouse and commissioned for the same process so that the continuity of the production mechanism can be ensured. 1 m^3 of biogas can provide approximately 5 kWh of energy. Besides the obtained electricity, there is also heat energy output. This heat is used to heat the houses and the animal stables near the plant. In addition, the output product is also evaluated as solid and liquid fertilizer. This process shown in Figure 2 below [13]. In addition, the biogas potentials calculated on the basis of the numbers of cattle, sheep and poultry given by the Turkish Statistical Institute (TUIK) animal production statistics for 2016 published in Issue 24655 on 7 February 2017 are given in Table 2 [14].

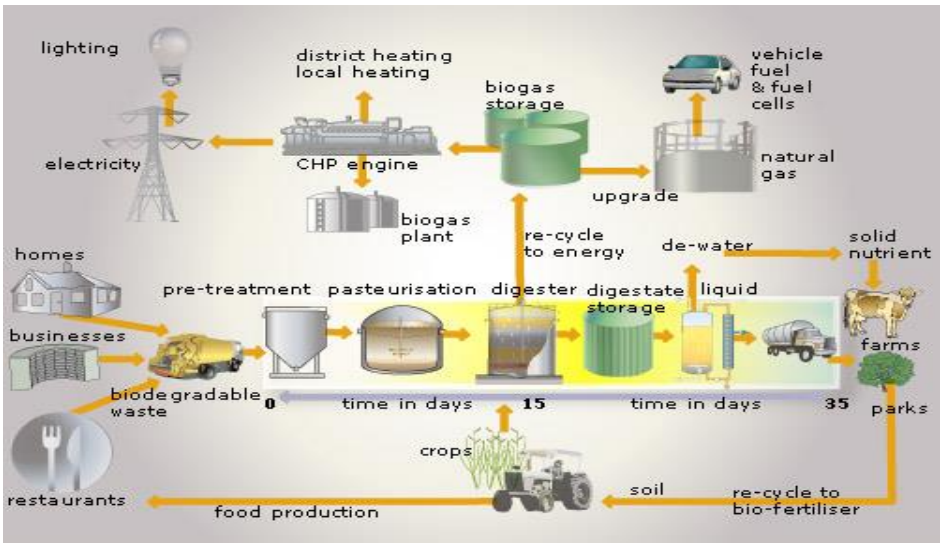


Figure 2. Entry and exit products of a biogas process [13].

Table 2. Biogas potentials that calculated based on 2009 animal production statistics of TUIK [14].

Animal	Bovine Animal	Small Cattle	Poultry
Number of animals	14,222,000	41,329,000	332,194,000
Unit wet fertilizer amount (Ton/year)	9.95	0.82	0.03
Total amount of fertilizer per year (Million ton/year)	107.57	22.03	7.02
Dry fertilizer ratio (%)	12.7	25.00	25.00
Total amount of dried fertilizer (Million Ton/year)	13.66	5.50	1.75
Availability (%)	65.00	13.00	99.00
Total amount of available dry fertilizer (Million Ton/year)	8.87	0.71	1.73
Amount of biogas for 1 ton dry fertilizer (m^3/year)	200.00	200.00	200.00
Total biogas amount (billion-m^3/year)	1.77	0.14	0.34

In this case study, the energy conversion process of waste coming to a biogas plant is examined and the result obtained from the process is presented for the energy world and the related people.

The system, which has 305 kW installed power, produces energy through a working cycle. Livestock and cattle wastes coming from the plant are transferred to a reactor with a storage volume of 2400 m^3 after being poured from a chopper in the reservoir volume of 100 m^3. If the reactor occupancy rate is around 90%, incoming products are directed to Reactor 2. The product input is approximately 5 m^3/h per hour. The reactor temperatures are between 37 °C and 40 °C. The gas formed here is sent to the gas engine with a pressure of 2.40 mbar. If the pressure of the gas drops below 1 mbar, the gas engine is switched off. In addition, the equilibrium pipes between the reactors stabilize the gas pressures. When the gas pressure is above 5 mbar or the gas engine malfunctions, the gas is thrown into the atmosphere by the flare to reduce the gas pressure. This process continues until the gas pressure drops below 5 mbar. At the plant around

10% to 15% of the produced energy is used for internal use and the rest is transferred to the main network of SEDAŞ via 0.4/34.5 kV and 800 kVA transformers. Figure 3 shows the change in the production Turkish Liras with respect to the US Dollar in November 2015. Figure 4 shows the change in energy production in November 2015 and Figure 5 shows the comparison of internal consumption-energy production in January 2016. In addition, Figure 6 presents the change in electricity generation as an estimated hour in January 2016. Figure 7 The comparison of electricity generation in November 2015 to the values of in January 2016.

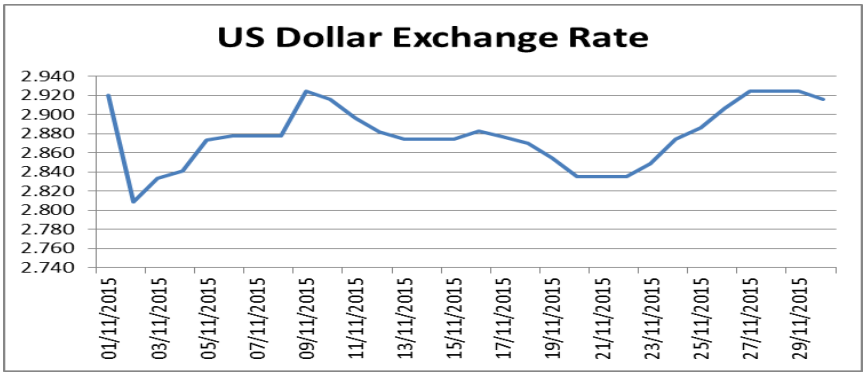


Figure 3. The exchange rate of Turkish liras versus US Dollars in the production in November 2015.

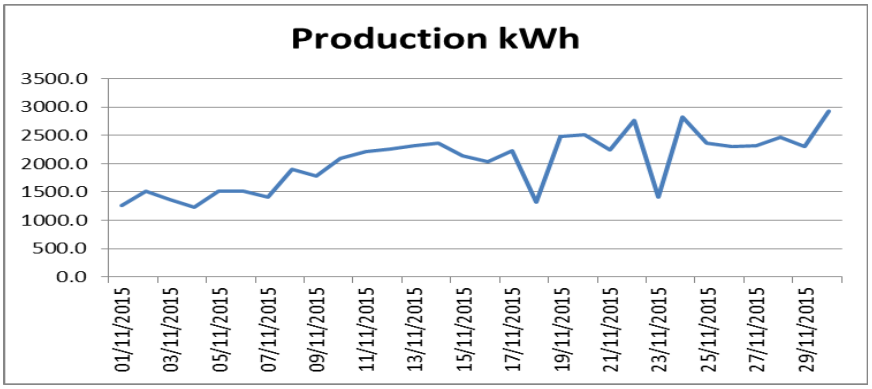


Figure 4. The energy production (kW) in November 2015.

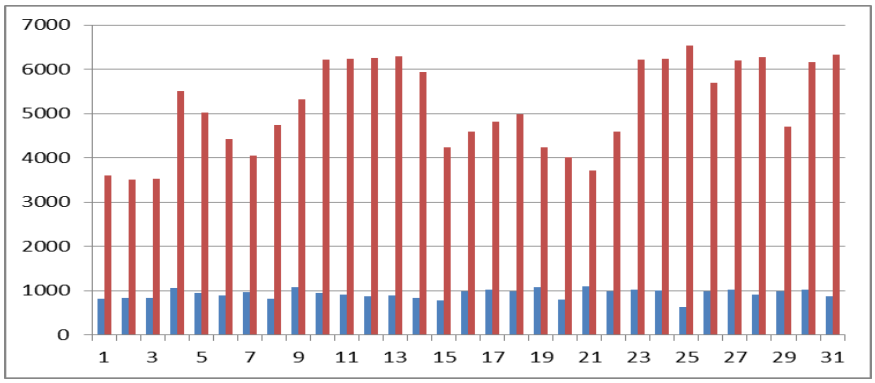


Figure 5. The Comparison of Internal Consumption- Energy Production in January 2016.

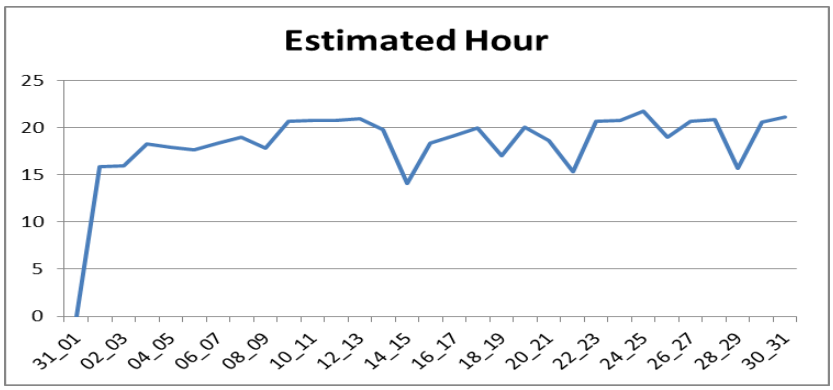


Figure 6. The change in electricity generation as an estimated hour in January 2016.

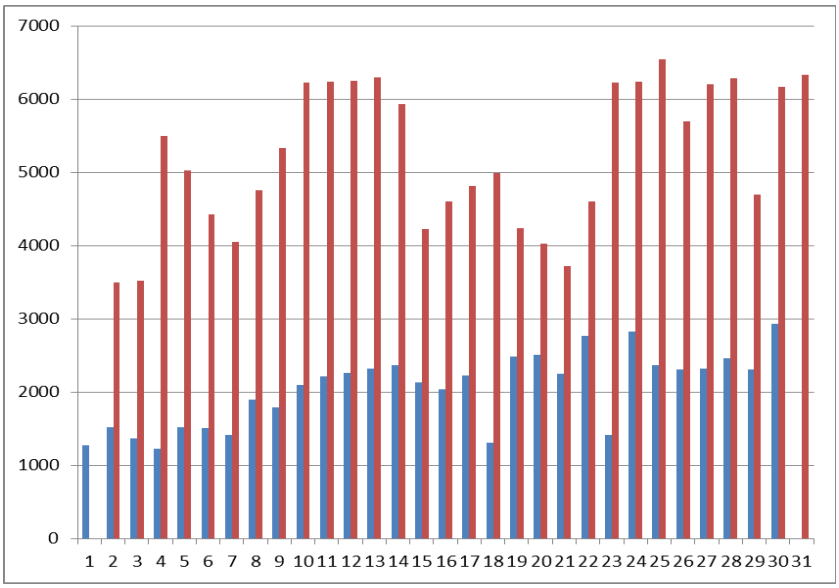


Figure 7. Comparison of electricity generation in November 2015 to the values of in January 2016.

RESULTS

New Situation with the addition of 415 kW System to the Plant

The total energy production amounts have increased with the 415-kW production system addition to the installed power plant. The schematic representation of the energy production process is given in Figure 8 down below. By this means, the raw materials that have come to the fore are prevented from being piled up. Moreover, these are considered as the back-ups of each other. When a gas engine is deactivated in the event of any malfunction or maintenance, the other gas engine will operate and secure the continuity of energy production. This is a general situation that supports the reliability of the biogas plant's energy production system.

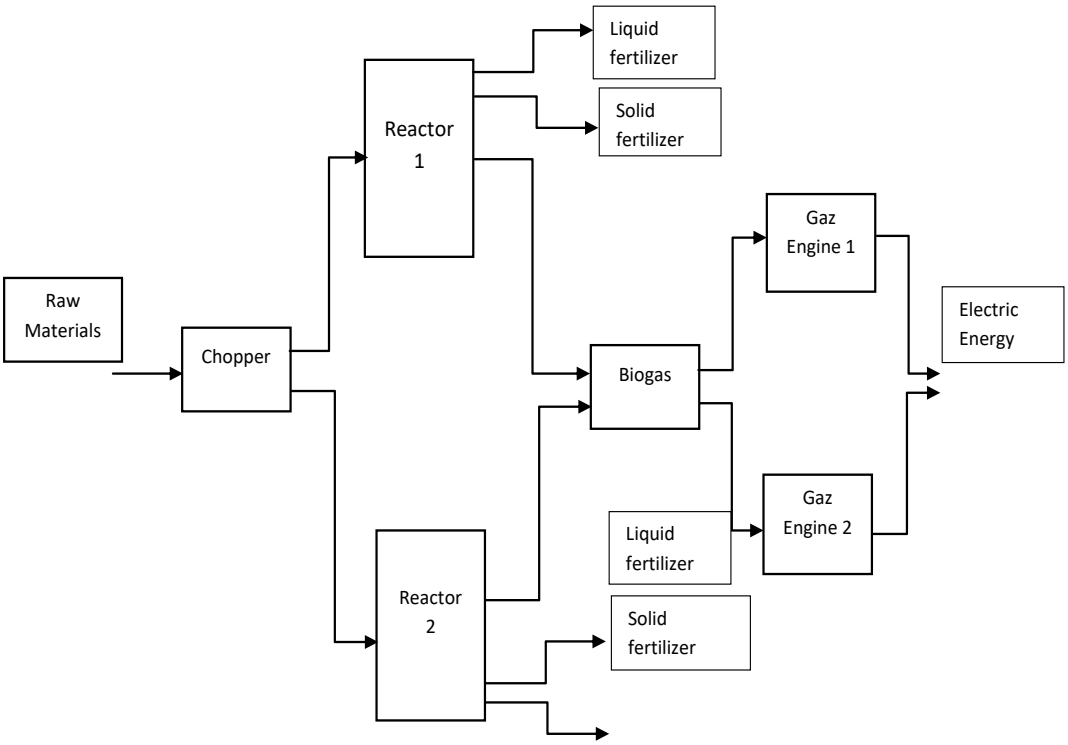
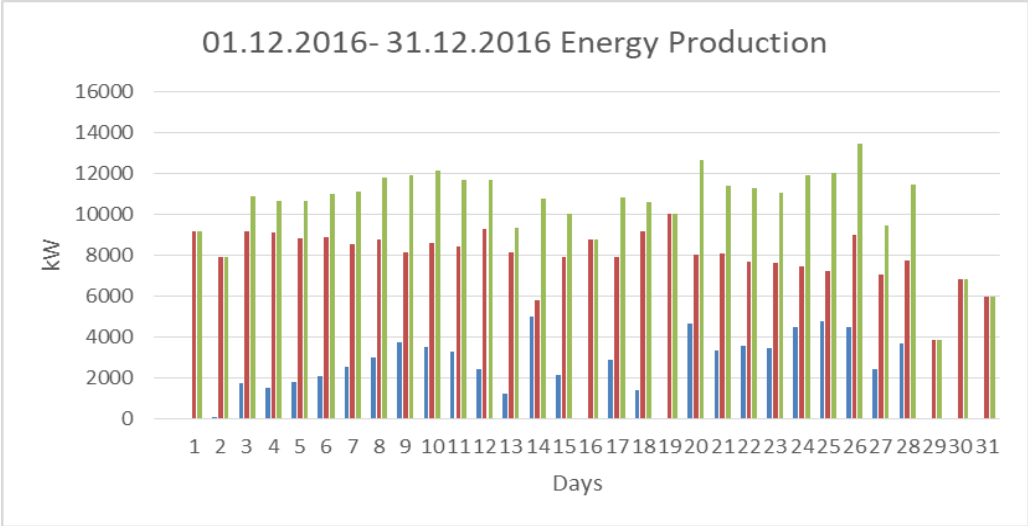


Figure 8. Schematic representation of the energy production process.

The total change in 1st and 2nd gas engine production values taken as an example from the biogas plant in December 2016 is given in Figure 9.



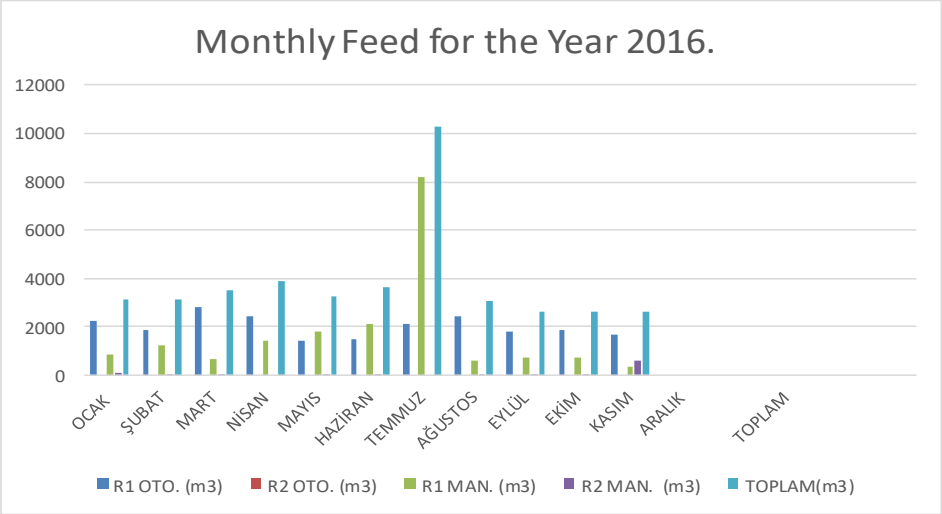
Gas engine 1, *Gas engine 2*, *Total Production (kW)*

Figure 9. Total change in 1st and 2nd gas engine production values.

Automatic or manual feeding of the reactors in 2016 is given in Table 3 and graphically in Figure 10.

Table 3. Automatic or manual feeding of reactors in 2016.

2016 YEAR	R1 Automatic (m^3)	R2 Automatic (m^3)	R1 Manuel (m^3)	R2 Manuel (m^3)	TOTAL (m^3)
January	2222.7	0	837.6	85.8	3146.1
February	1855.9	0	1254.1	54	3164
March	2847	0	655.3	38.3	3540.6
April	2440.3	0	1428.2	0	3868.5
May	1461	0	1795.5	28.2	3284.7
June	1480.7	0	2111.4	53.8	3645.9
July	2117.7	0	8179.6	0	10297.3
August	2423.6	0	588.3	36.2	3048.1
September	1835.9	0	759.4	64.1	2659.4
October	1866.7	0	708.3	46.9	2621.9
November	1667	0	367.5	588.5	2623
December	1723.4	0	492.5	476.3	2692.2
Total	23941.9	0	19177.7	1472.1	44591.7



January, February, March, April, May, June, July, August, September, October, November, December, Total

Figure 10. Automatic or manual feeding of reactors in 2016.

The selected product quantities for the plant on December 19, 2016 are given in Table 4 and on December 17-23, 2016 biogas quantities are given in Table 5.

Table 4. Product quantities in the plant on December 19, 2016.

	Product	Poultry	Ton (kg)	km (%)	Ph
19.12.2016	Chicken	1+3	15360	22.9	
	Chicken	1	17070	26.48	
	Chicken	5	15100	28.52	
	Chicken	-	16200	24.9	
	Chicken	-	15400	26.27	
	Bovine Animal	Bovine Animal	16120		
	Bovine Animal	Cheese whey	14920		
	R1			6.69	7.8
	R2			6.17	8.02

Table 5. Biogas quantities in between the dates 17-23, December 2016.

Date:	Total (m^3)	Hourly Average (m^3)
17.12.2016	6830	284.58
18.12.2016	4889	203.71
19.12.2016	4081	170.04
20.12.2016	5510	229.58
21.12.2016	6683	278.46
22.12.2016	4674	194.75
23.12.2016	5365	223.54
26.01.2017	3736	155.67

Energy Storage

When looking at the national network of Turkey, it is seen that the demand for energy is different in every hour of the day. In Turkey, the consumed energy distribution in terms of MW is given for the day on 27.03.2017 in Turkey, which can be seen as follows in Figure 11 [15].

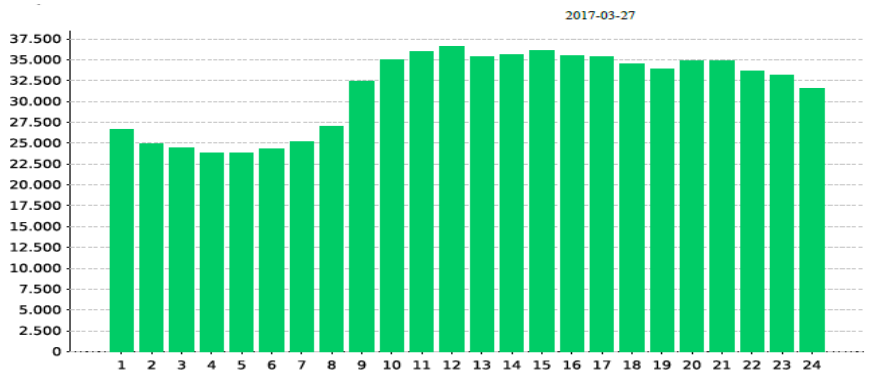


Figure 11. The consumed power distribution that observed in 27.03.2017 (in MW hours) in Turkey [15].

There may sometimes be difficulties in supplying raw materials in a biogas plant that produces energy locally. This causes a decline in energy production. Sometimes the efficiency that can be taken from the raw material decrease due to the excess raw material that is waiting in the depot area. A reserve power unit is required to reduce these limiting effects of energy supply. In addition, modern storage techniques can be realized as a backup to handle the excess energy between the hours 22.00 pm and 06.00 am as because energy consumption is rather low between these hours. This stored energy can be transferred to the network when necessary or it can be used for the internal needs. In case of

island mode operation, the excess energy will also be stored and ready for use in this way. This situation is also related to the determination of the target power level for the storage of the energy. Taking these applications into consideration, appropriate solutions can be found and applied to the system. An energy storage model to be used and adapted to the plant is given below in Figure 12.

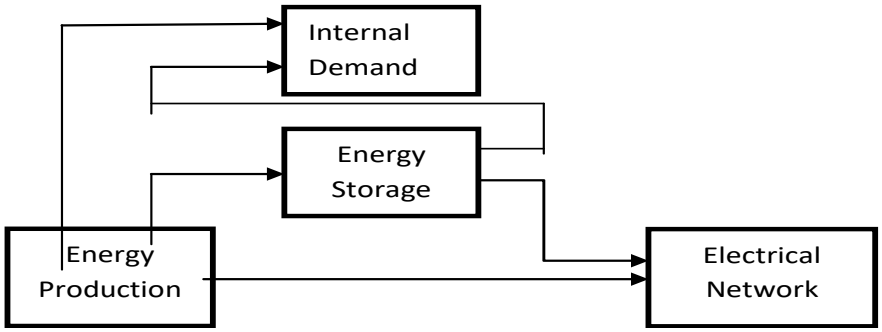


Figure 12. Attaching the energy storage system to the plant.

CONCLUSIONS

While Turkey may have 2000 biogas plants considering the animal waste capacity, there are about 80 biogas plants, currently [13]. The facility that we have studied is one of them. The capacity increase of the plant has assured the increase in the energy production. Thus, both animal wastes are evaluated and electricity is produced with the biogas production. The electricity that generated in the plant is used to meet for the in-plant need, which has the rate from 10% to 15%, the rest is transferred to the national network. With the energy storage method to be added to the system, the electrical efficiency of the plant will rise. In addition, problems and delays encountered during product entry and process, and fluctuations in energy production will be subsidized by the stored energy. Poly-hybrid solutions can be produced with other renewable energy sources such as wind turbines and solar panels to be added to the existing system. With an energy management model that will coordinate all of these, it is possible to further increase in the efficiency.

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