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# Energy Recovery Analysis of A Biomass Type of Installed Waste Water Treatment Plant

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## Abstract

Energy production can also be obtained from plant, animal or sometimes human material, referred to be the biomass technology. The biomass raw material can be obtained from purposely grown energy crops, waste from food crops, wood or forest residues, horticulture, animal farming, food processing, or human waste from sewage plants. In this study, energy recovery analysis of an installed waste water treatment plant was conducted. The physical and chemical analyses of energy recovery that can be obtained from waste water treatment plant were clarified. In this regards, parameters including daily wastewater inlet water flow rate, wastewater inlet water 24 hourly average temperature, wastewater inlet water 24 hourly pH average, wastewater inlet water 24 hourly conductivity average, gas generator daily gas consumption, diesel generator daily energy generation, daily energy consumption from the city line, gas generator energy generation, total energy consumption of the water treatment plant, and daily gas generation of the treatment plant were identified. The plant has the duty of providing water treatment, so it is certain that noteworthy energy consumption in the plant can occur is an expected situation. However, the point that how much of the energy can be regained by the biomass technology provided by the burning processes conducted on the human waste is important. Namely, it is reported in this study that 78.29% of the total energy consumed by the plant was regained by these processes occurred in the treatment facility. On the other hand, this amount of recovered energy was reported to correspond a total of 14.200 GWh in this installed plant of Turkey. Apart from the amount of the recovered energy, the discharge of the amount of the methane gas which is responsible of the biomass energy generation was also analyzed according to the considered physical and chemical parameters. For instance, the analyses have shown that the increase of the waste water temperature causes decrease on the amount of the methane gas generation. On the other hand, the conductivity and the degree of acidity increase resulted the increase of the amount of the methane gas production.

**Keywords:** Biomass, Energy recovery, Gas generator, Waste water treatment

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## Biokütle Tipi Kurulu Atık Su Arıtma Tesisinin Enerji Geri Kazanım Analizi


## Öz

Enerji üretimi, biyokütle teknolojisi olarak adlandırılan bitki, hayvan veya bazen insan materyalinden de elde edilebilir. Biyokütle hammaddesi, bilinçli olarak yetiştirilen enerji bitkilerinden, gıda mahsullerinin atıklarından, ağaç veya orman artıklarından, bahçecilikten, hayvancılıktan, gıda işlemeden veya kanalizasyon tesislerinden kaynaklanan insan atıklarından elde edilebilir. Bu çalışmada, kurulu bir atık su arıtma tesisinin enerji geri kazanım analizi yapılmıştır. Yani, çalışmada, atık su arıtma tesisinden elde edilebilecek enerji geri kazanımının fiziksel ve kimyasal analizleri netleştirilmiştir. Bu kapsamda, günlük atık su giriş suyu debisi, atık su giriş suyu 24 saatlik ortalama sıcaklığı, atık su giriş suyu 24 saatlik pH ortalaması, atık su giriş suyu 24 saatlik iletkenlik ortalaması, gaz jeneratörü günlük gaz tüketimi, dizel jeneratörü günlük enerji üretimi, şehir hattından gerçekleştirilen günlük enerji tüketimi, gaz jeneratörü enerji üretimi, su arıtma tesisinin toplam enerji tüketimi ve arıtma tesisinin günlük gaz üretimi gibi parametreler tespit edilmiştir. Tesisin su arıtımını sağlama görevi vardır, bu nedenle tesiste, kayda değer bir enerji tüketiminin oluşabileceği beklenen bir durumdur. Ancak, insan atığı üzerinde gerçekleştirilen yakma işlemlerinin sağladığı biokütle teknolojisi ile enerjinin ne kadarının geri kazanılabileceği hususu önemlidir. Yani, bu çalışmada tesisin tükettiği toplam enerjinin %78,29'unun arıtma tesisinde meydana gelen bu işlemlerle geri kazanıldığı rapor edilmiştir. Öte yandan, Türkiye'nin bu kurulu santralinde geri kazanılan bu enerji miktarının toplam 14.200 GWh'ye karşılık geldiği bildirildi. Geri kazanılan enerji miktarının yanı sıra, biokütle enerji üretiminden sorumlu olan metan gazı miktarının deşarjı da dikkate alınan fiziksel ve kimyasal parametrelere göre analiz edilmiştir. Örneğin, yapılan analizler, atık su sıcaklığının artmasının metan gazı oluşum miktarının azalmasına neden olduğunu göstermiştir. Öte yandan, iletkenlik ve asitlik derecesinin artması ise metan gazı üretim miktarının artmasına neden olmuştur.


**Anahtar Kelimeler:** Biokütle, Enerji geri kazanımı, Gaz jeneratörü, Atık su arıtma

## 1. INTRODUCTION

Energy is the main driving force in developments of technology and the economy. However, energy choices of the countries certainly have influences on the climate change, politics, growth of the economy, and even on the determination of international alliances and commitments [1-5]. Energy generation using the fossil fuels is still the most preferred global way of power obtaining method. Accordingly, the energy generation using fossil fuels increases day by day in parallel to the energy consumption increase [6]. Besides, the greenhouse gas emissions occurred as the product of fossil fuels unfortunately drive the climate change [7-8]. Although biomass technology is similar to fossil fuel energy production methods and causes some pollution in nature; the main thing here is that the organic wastes that are produced naturally and will be wasted without utilization, are evaluated as fuel and contribute to the worldwide total energy production.

It is certain that traditional fossil fuel energy sources have unfortunately the decreasing availability trend. This situation as well as the climate concerns have created enhanced attention in the emerging of the renewable energy sources [9]. In this context, the biomass technology which can be regarded as one form of renewable technologies has the tendency of improvement. Turkey’s biomass technology is expected to reach 2 GW of installations by 2023 year, based on the renewable vision plans of the country [10]. Additionally, energy recovery obtained from biogas utilization is a renewable and economically valid substitute for energy generation. Since, the energy obtained from the recovery procedure substitute the fossil fuel usage. In this regards,

Figure 1 exhibits the capacity of the installed biomass energy facilities, including the waste heat, of Turkey, considering the year range between 2011 and 2022.

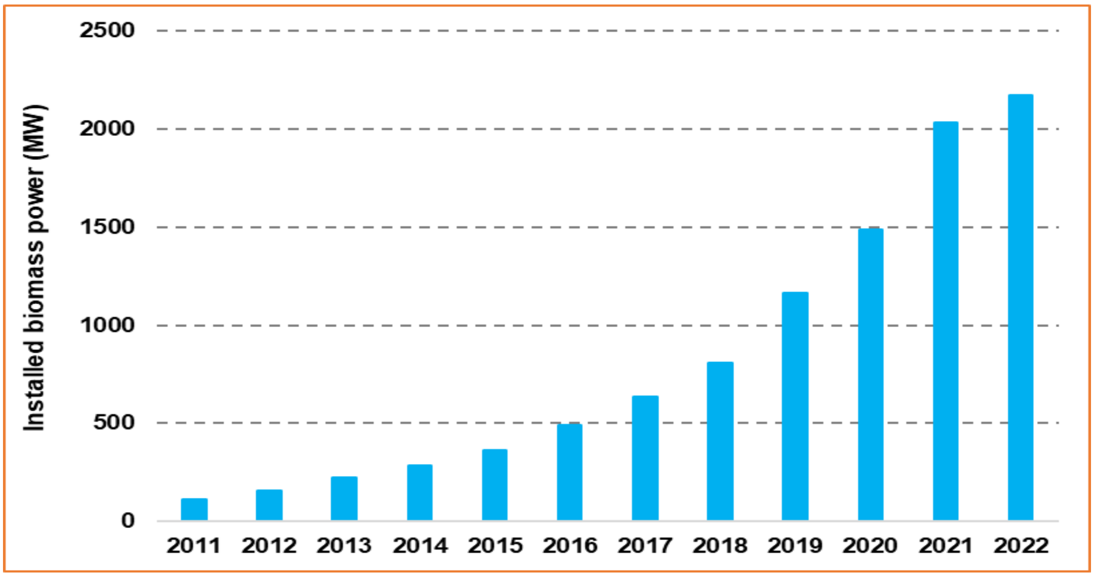



**Figure 1.** Installed biomass power of Turkey [11]

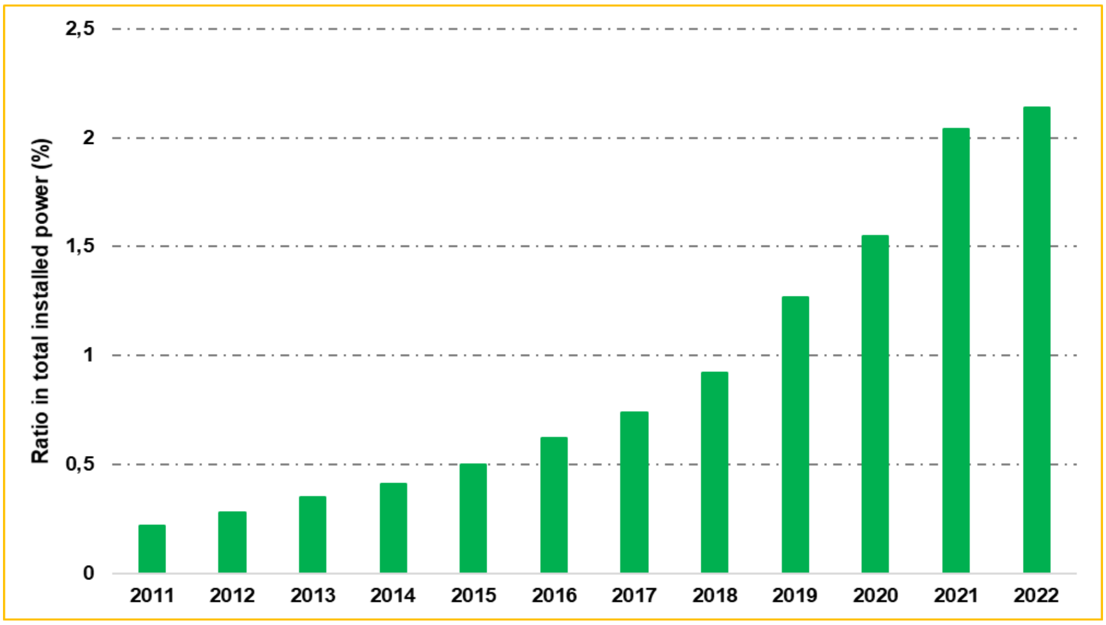



**Figure 2.** Ratio of biomass power installations to total installed power of Turkey [11]

As clear from Figure 1 that the total installed biomass power of Turkey has increased from 115 MW to 2,172 MW, considering the year range from 2011 to 2022. Besides, the percentage of this increase measured with respect to the total installed power of Turkey, has been reported to be increased from 0.22% to 2.14% in the same year range, as demonstrated in Figure 2. In this context, it is seen that Turkey attaches great importance to biomass energy production, especially in recent years. Moreover, it is seen that the importance given to this technology by Turkey will accelerate considerably in the near future.

**Figure 3.** View of a sample wastewater treatment plant

One of the methods of obtaining biomass energy is running gas turbines in the waste water treatment plants. In fact, the major purpose of treatment of the waste water is to remove as much of the suspended solids as possible before the remaining water, which is called as effluent, is discharged back to the environment. Methane gas generation occurs from those suspended solids. In Figure 3, a view of a sample waste water treatment plant is demonstrated.

While determining the characterization of the wastewater, its physical, chemical and biological compositions are used. Parameters such as color, odor, temperature, and electrical conductivity can be given as examples of the physical properties. Besides, the volatile organic compounds, oil-grease, pesticides, the degree of acidity are the examples of chemical parameters. In this regards, the influence of the discharged waste water to the soil in terms of the degree of the acidity has been inspected in the literature [12]. Besides, electrical conductivity measurements are performed in literature to observe the quality of the processes in waste water treatment [13].

The waste water treatment is so significant today. For instance, the seas, oceans, and rivers turning into garbage because of the release of micro plastics and other wastes to the water sources, pollution of the environment, newborn and children deaths arising from lack of clean and safe water, increasing climate migrations arising from drinking water shortage and drought are modern problems of our World. On the other hand, clean water is so important especially in our lives as well as production facilities. Accordingly, some of these troublesome problems can be solved by qualified treatment of wastewater. In other words, a powerful tool exists to bypass the water crisis, i.e., the treatment of the waste water [14].

The question is; what is waste water and its treatment? The logic of treatment of the waste water is identical to the treatment of the normal waste. Waste water is initially the clean water that has been utilized especially by humans and then it is turned to waste. However, later it becomes to contain many substances including food waste, bacteria, chemicals, and even much more than these. E.g., waste water is formed everywhere in the houses, from the dishwashers to the sinks, or to the washing machines. Accordingly, the main goal in wastewater treatment is to remove unwanted chemical or biological dissolved substances from water as much as possible [14].

Furthermore, the content of all wastes released to the nature is not limited with the disposals of the waste water of the houses, but also includes production wastes coming from the industries as well as the businesses. And, these business and industrial wastes are always meet with clean water and unfortunately pollute it. Because of these reasons, treatment of the waste water becomes more important and evident. Consequently, the scope of waste water treatment should be analyzed in terms of the composition to include biological waste water treatment, chemical waste water treatment, medical waste water treatment, industrial waste water treatment, and most importantly hazardous waste water treatment [14].

Mainly, three different types of waste water are available. Those include sewage waste water that originates from sinks, showers, and toilets; industrial waste water which is resulted from commercial, production and overall industrial activities; and finally, municipal waste water created by the municipalities composed of different ratios of rain water, sewage water and industrial water. Accordingly, a proper treatment of the waste water should prevent pollution of the water as well as should maintain a safe and clean water. The nature is sufficiently successful to balance small number of water pollutants. But, it needs a good technology to meet the dangerous and big impurities that especially increase by activities of the humans. And, the process of the treatment of the waste water accomplishes this, and it reduces pollutants as much as possible and it discharges remaining water back to the nature which would probably be useful. In the case of it not to be useful, the nature, in its own balance can take care of the rest [14].

Laboratory experiments were performed in the literature to investigate the most substantial ions concentration behavior in a sequencing batch reactor (SBR) as well as the electrical conductivity and pH profiles were studied and developed. It is mentioned in the study that those are the main requirements to be considered as parameters of water treatment plants [15]. Besides, the influence of temperature on waste water treatment is also analyzed in literature studies. Accordingly, it was aimed in the study of Alisawi to configure the optimal temperature for waste water treatment [16].

Although in the literature as shown above, a variety of studies are found mentioning the physical and chemical parameters of the solutions, as well as studies that are found related with the waste water treatment; this study as a novelty presents the influence of the physical and chemical parameters on the methane gas generation. On account of this, in the present study, the analysis of the recovered power generated in the waste water treatment facility, as a result of the combustion of the obtained methane gas in the gas turbine, was also taken into account.

## 2. MATERIALS AND METHODS

The equivalent calculation of carbon dioxide emissions based on the substrate oxidation of the carbon and nitrogen is defined by the chemical reaction, shown in Equation (1):

$$\text{C-substrate+N-substrate+O}_2 \rightarrow \text{CO}_2\text{+C}_5\text{H}_7\text{NO}_2\text{+H}_2\text{O} \quad (1)$$

On the other hand, Equation (1) demonstrates that C-substrate elimination yielding in the production of $CO_2$ and the partial segregation of biomass on carbon ($C_5H_7NO_2$) [17]. Thus, initial global warming mitigation benefit presented by the treatment of the wastewater is obtained in this way. Thus, free carbon, which can be harmful to nature if found in abundant amounts, is converted into other forms. Besides, the methane ($CH_4$) and stabilized biomass are produced by the digestion of the biomass, under the reaction:

$$Active\ biomass+C\text{-}substrate \rightarrow CH_4+CO_2+stabilized\ biomass+H_20 \quad (2)$$

Here the product obtained as the cumulative of $CH_4$ + $CO_2$ is the beneficial component used in power generation from treatment plant. Namely, the generated biogas ($CH_4$ + $CO_2$) is either flared or refined to be used in power production units. Following this operation, the stabilized biomass may be sent to landfills in the available situation or it may also be already in the incinerated form. Equation (2) indicates the second global warming mitigation benefit based on the wastewater treatment, i.e., the burning of the biogas causes the recovery of the energy. But, the benefit of the global warming mitigation is over the energy recovery phenomenon, because direct release of $CH_4$ to the nature has much worse influence compared to the global warming caused by the $CO_2$ [18]. Before final release of $CO_2$ to the air, theoretically, production of methane is only an intermediate step. The chemical reaction exhibited on Equation (2) later continues with the chemical reaction shown in Equation (3);

$$CH_4+2O_2 \rightarrow CO_2+2H_20 \quad (3)$$

In Table 1, the data analysis of the installed waste water treatment plant has been provided. A total of 445 days were used in the energy recovery analysis of the waste water treatment plant. The determined parameters including daily total waste water inlet water volume flow rate ($Q_{ww}$), waste water inlet water daily average temperature ($T$), waste water inlet water daily average degree of acidity ($pH$), waste water inlet water daily average electrical conductivity ($\sigma$), the daily total volume of the consumed gas in the gas generator ($Q_{gc}$), diesel generator daily total energy generation ($E_d$), daily total energy consumption from the city line ($E_{cl}$), gas generator daily total energy generation ($E_g$), daily total energy consumption ($E_c$), and daily total volume of the generated gas by the waste water treatment plant ($Q_{gg}$) were used in terms of the daily averages.

**Table 1.** Data analysis of the installed waste water treatment plant, located in Turkey

| **Examined data** | **Corresponding value** |
|---|---|
| Minimum ($Q_{ww}$ - $dam^3$) | 126.476 |
| Maximum ($Q_{ww}$ - $dam^3$) | 244.876 |
| Average ($Q_{ww}$ - $dam^3$) | 198.811 |
| Total ($Q_{ww}$ - $hm^3$) | 88.471 |
| Minimum ($Q_{gg}$ - $dam^3$) | 6.711 |
| Maximum ($Q_{gg}$ - $dam^3$) | 19.284 |
| Average ($Q_{gg}$ - $dam^3$) | 13.683 |
| Total ($Q_{gg}$ - $hm^3$) | 6.089 |
| Minimum ($Q_{gc}$ - $dam^3$) | 0 |
| Maximum ($Q_{gc}$ - $dam^3$) | 18.832 |
| Average ($Q_{gc}$ - $dam^3$) | 11.767 |
| Total ($Q_{gc}$ - $hm^3$) | 5.236 |
| Minimum (T - $^0$C) | 12.400 |
| Maximum (T - $^0$C) | 26.820 |
| Average (T - $^0$C) | 21.061 |
| Minimum (σ - µS/cm) | 540.000 |
| Maximum (σ - µS/cm) | 1,741.000 |
| Average (σ - µS/cm) | 1,315.250 |
| Minimum (pH) | 6.410 |
| Maximum (pH) | 8.570 |
| Average (pH) | 7.493 |
| Minimum ($E_c$ - MWh) | 28.440 |
| Maximum ($E_c$ - MWh) | 50.620 |
| Average ($E_c$ - MWh) | 40.758 |
| Total ($E_c$ - GWh) | 18.137 |
| Minimum ($E_g$ - MWh) | 0.000 |
| Maximum ($E_g$ - MWh) | 48.780 |
| Average ($E_g$ - MWh) | 31.911 |
| Total ($E_g$ - GWh) | 14.200 |
| Minimum ($E_d$ - MWh) | 0.000 |
| Maximum ($E_d$ - MWh) | 3.850 |
| Average ($E_d$ - MWh) | 0.066 |
| Total ($E_d$ - GWh) | 0.029 |
| Minimum ($E_{cl}$ - MWh) | 0.030 |
| Maximum ($E_{cl}$ - MWh) | 37.391 |
| Average ($E_{cl}$ - MWh) | 8.782 |
| Total ($E_{cl}$ - GWh) | 3.908 |

In this table, considering the analyzed 445 days of water treatment data; minimum, maximum, and average values of $Q_{ww}$, $Q_{gg}$, $Q_{gc}$, $T$, $\sigma$, $pH$, $E_c$, $E_g$, $E_d$, and $E_{cl}$ parameters have been shown. Besides, the analysis of 445-day data on parameters such as temperature ($T$), electrical conductivity ($\sigma$) and degree of acidity ($pH$), which takes into account the physical and chemical properties of the treatment water, is shown in the table with only these three statistical parameters. On the other hand, for the other parameters, in addition to these three statistical results, total values of the related parameter considering 445 days have been shown. Namely, the total values in these parameters give us information about the performance and capacity of the water treatment plant in this date range.

## 3. RESULTS AND DISCUSSIONS

Figure 4 provides the analysis of the daily wastewater inlet water flow rate distribution of the water treatment plant ($Q_{ww}$), regarding these 445 days. So, the analysis has revealed that a total of 88.5 $hm^3$ of waste water entered the treatment plant of the city considering this period of time. Based on the principle of methane generation from the waste water, some portion of the waste water had been utilized to form gas generation inside the plant. The formed gas inside the plant is known as the energy potential that is recovered; so the recovered energy was later used to run the gas turbines, namely, in order to generate electricity.

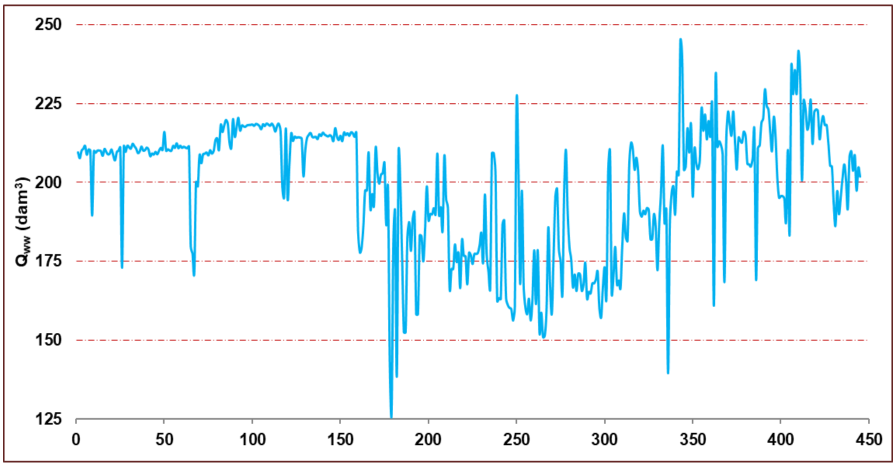



**Figure 4.** Daily wastewater inlet water flow rate ($Q_{ww}$) distribution analysis

It is certain that the plant unfortunately consumes electricity in order to obtain waste water. However, of course waste water treatment is an important issue in order to protect the environment from considerable pollutions. And, the main point of the treatment plant is to recover some of the consumed energy inside the plant from the utilization of the burning of the generated methane gas, that is obtained as a product of waste water treatment process. In this regards, Figure 5 demonstrates the volume of generated methane gas ($Q_{gg}$) as well as the total consumption in the gas generator ($Q_{gc}$), during the utilization of the waste water inlet. The magnitudes of both parameters are presented in terms of distribution functions depending on the considered days. Namely, considering this period of time, a total of 6.09 hm$^3$ of gas generation ($Q_{gg}$) has occurred. The gas generation distribution function has been exhibited with orange color in the figure. On the other hand, the corresponding consumption of the gas inside the gas generator ($Q_{gc}$) was reported to be 5.24 hm$^3$. The gas consumption distribution function has been demonstrated in the figure, with dark blue color. In this context, it is concluded that the situation of burning all gas in the waste water treatment plant has not been successful. However, it is still comprehended that the efficiency of the burning process in the gas generator was still high. Namely, about 86% of the total generated methane gas was used in the gas generator for the re-gaining energy process.

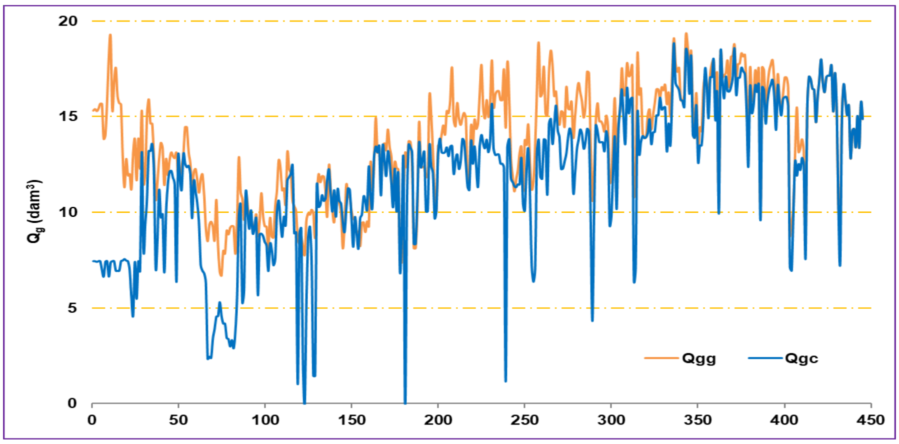



**Figure 5.** Gas generation ($Q_{gg}$) and consumption ($Q_{gc}$) status of the treatment plant

On the other hand, the physical and chemical properties of the waste water inlet are shown in Figures 6, 7, and 8. These properties were obtained by calculating the daily averages of the hourly measured data. That is, each numerical value on the x-axis points to a daily average value of the relevant parameter, demonstrated on y-axis, corresponding to that day among 445 days. In this context, while Figure 6 and Figure 7 show the average temperature ($T$) distribution of the studied period and conductivity ($\sigma$) as the physical properties, whereas Figure 8 presents the chemical situation, i.e., the acidity ($pH$) of the wastewater with respect to the days. The temperature distribution in this interval of period, namely considering 445 days, was reported to be in the range of $12.40\ ^{o}\mathrm{C} \leq T \leq 26.82\ ^{o}\mathrm{C}$, as provided in Figure 6. Besides, the average temperature in this analyzed period is also conducted to be 21.06 $^{o}$C. The meaning of this average value of temperature can be summarized as; the temperature of 21.06 $^{o}$C, which can be the answer to the question of what is the temperature of the waste water during the considered and analyzed 445 days.

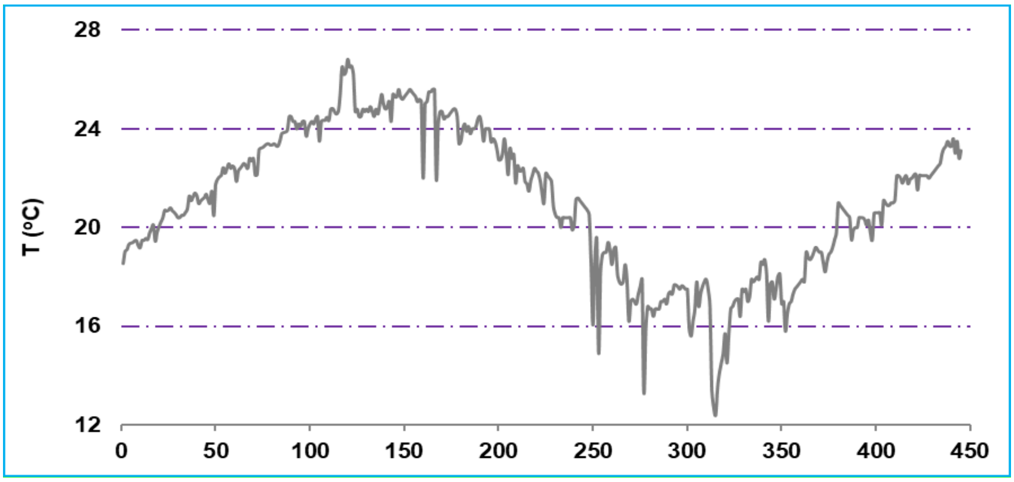



**Figure 6.** Daily wastewater inlet water 24 hourly average temperatures ($T$)

Electrical conductivity deals with the measurements performed on finding the amount of the dissolved chemical, minerals, or other substances found in the water. The facilities of waste water treatment trust the measurements of electrical conductivity in controlling which treatment process would be the most accomplished in removing impurities and the contaminants. To remove the contaminants in an accomplished way from the waste water, the measurements on the electrical conductivity of the waste water are performed. Electrical conductivity is indispensable for industries as well as the applications in order to improve water quality. For the measurements of the waste water electrical conductivity, an electrical conductivity sensor is utilized [19].

Electrical conductivity on the other hand refers to the capability of waste water in conducting the electrical current in a solution over a certain distance. It is generally measured in Siemens (S) per distance. As the ion concentrations inside the water increases, the water becomes more powerful in conducting the electricity. The ion concentration mainly occurs from inorganic materials including carbonate compounds, sulfides, and chlorides as well as the dissolved solids. The level of the conductance is also related with the potential of the ion to bind with the water. The conductivity of pure water is less. This is the case, since pure water doesn't include any impurities. If some ions are presented inside the water, water becomes conductive. Namely, if contaminants or pollutants are found inside the water, the electrical conductivity of the water will be altered. For instance, if the water contains ions such as chloride, sodium, magnesium, calcium, the water's electrical conductivity will be high. This is due to the increase of the dissolved ionic compounds in the water resulting also the increase of the electrical conductivity. Shortly, those dissolved substances, i.e., the ions result the transportation of the electrical current inside the solution [19]. Besides, the presence of the amount of ions inside the water solution is also a measure of the degree of the acidity in the positive or negative direction. I.e., the concentrations of $H^+$ and $OH^-$ ions determine whether the solution is acidic or alkaline. The scale of the acidity between 0 and 14 determines the degree of the acidity of a solution. In this scale, as the number approaches to 0 indicates the increase of the acidity, whereas, as the number approaches to 14 indicates the increase of the alkalinity [20].

A similar calculation method as in the case of temperature was implemented for the conductivity of wastewater in this time period. Namely, the wastewater conductivity analysis shown in Figure 7 reveals that the conductivity ($\sigma$) of the waste water during this period of days was observed to be in the range of $540.00\ \mu S/cm \leq \sigma \leq 1{,}741.00 \mu S/cm$. On the other hand, the average of the conductivity ($\sigma$) value during this period was calculated to be $\sigma = 1{,}315.25\ \mu S/cm$. This conductivity value corresponds to an electric resistance of 760 ohms per each centimeter. In other words, under a certain voltage difference, when some amount of voltage is applied to this wastewater, it is seen that the current will meet with a certain amount of resistance. This resistance is due to the bio wastes dissolved in the wastewater.

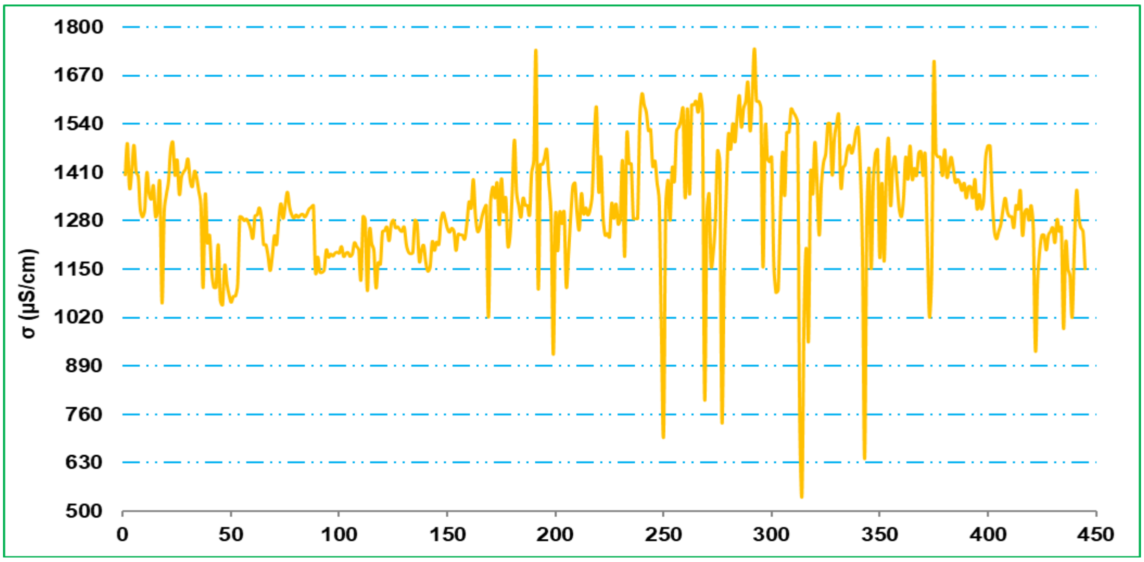



**Figure 7.** Daily wastewater inlet water 24 hourly conductivity ($\sigma$) averages

Apart from the physical analysis of the waste water including the average temperature ($T$) and the average conductivity ($\sigma$), the chemical analysis of the water has been also presented including the acidity amount of the waste water. Accordingly, the ionic analysis of the waste water, shown in Figure 8 reveals that the pH values of the waste water during this period was observed to be in the range of $6.41 \leq pH \leq 8.57$. On the other hand, the average of the acidity value, during this period was calculated to correspond, $pH = 7.49$. Although in some days, the waste water was observed to be acidic, however in general, it was determined that the wastewater was in the form of alkaline. This is also observed from the figure involving the pH to be generally over 7.00.

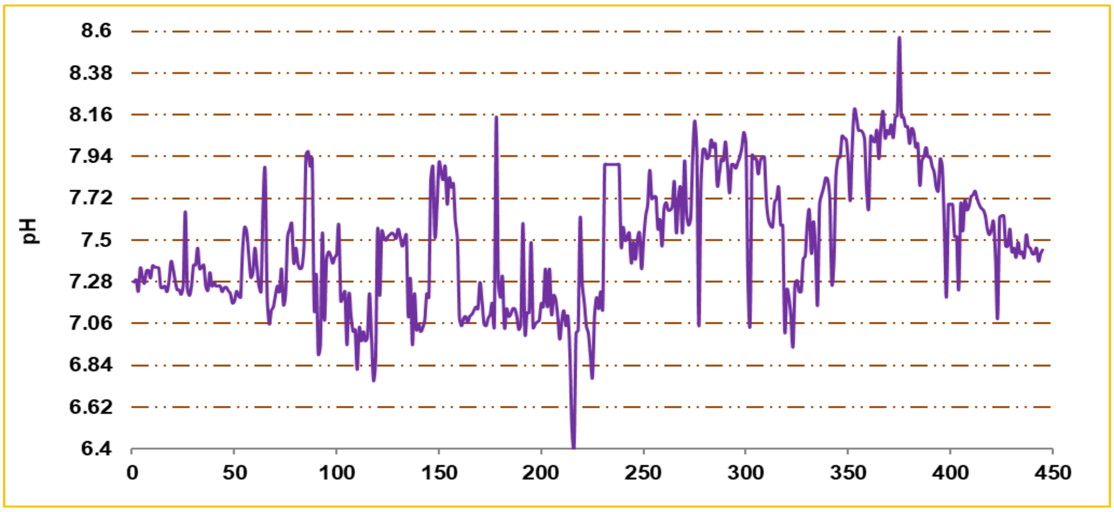
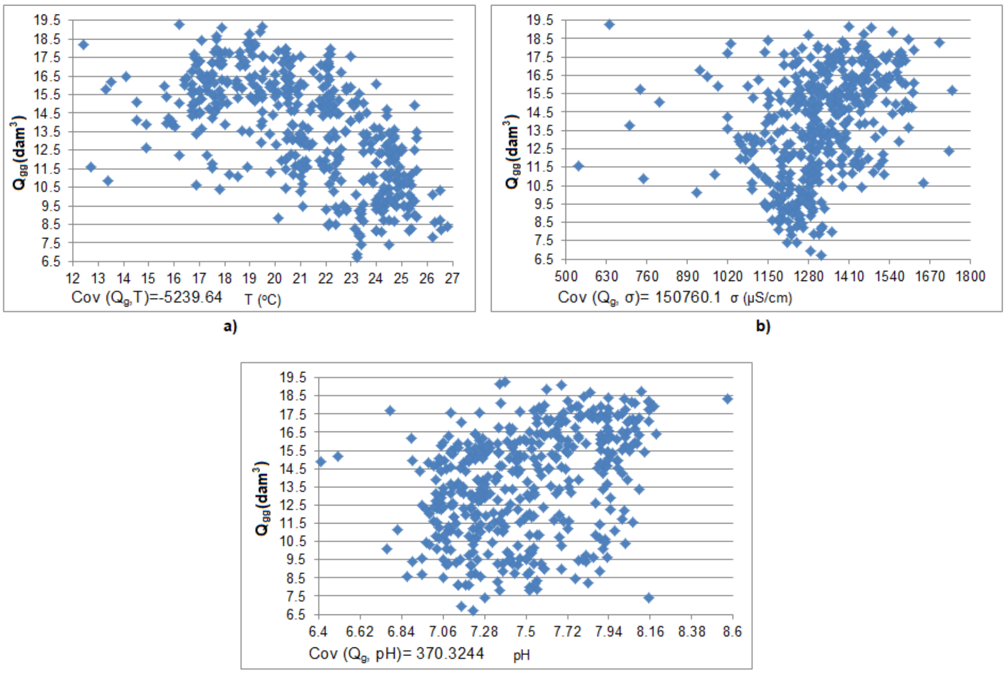



**Figure 8.** Daily wastewater inlet water 24 hourly pH averages

Besides, in Figure 9, the covariance analyses of three physical and chemical properties of the treatment plant have been performed. In this context, in Figure 9a, the covariance analysis of the daily total volume of the generated gas ($Q_{gg}$) with respect to the temperature ($T$) has been shown. The negative value result of the covariance has indicated that the generated biogas volume ($Q_{gg}$) is negatively influenced by the increase of the waste temperature ($T$). Namely, the increase of the waste temperature ($T$) has resulted the decrease of the daily total volume of the generated gas ($Q_{gg}$). In other words, it is certain that the volume will be adversely affected by the increase in air temperature ($T$). Because the increase in air temperature means an increase in the treatment water and the solid solution in it, finally causing the decrease of the volume of the generated gas ($Q_{gg}$). This situation can already be understood from the figure, as the trend in the y-axis values ($Q_{gg}$) goes down in the -y direction with the increase in temperature ($T$). Besides, unlike temperature ($T$), the daily total volume of the generated gas ($Q_{gg}$) is positively influenced by the increases of waste water daily average electrical conductivity ($\sigma$) as well as the daily average degree of acidity ($pH$). The positive results of the covariance values for both parameters have given such information. In this regards, the covariance outputs of the daily total volume of the generated gas ($Q_{gg}$) obtained with respect to the $\sigma$ and $pH$, have been respectively indicated in Figures 9b and 9c, for this purpose. This situation can already be interpreted from these figures, as the trends in the y-axis values ($Q_{gg}$) go up in the +y direction with the increase in electrical conductivity ($\sigma$) and the degree of acidity ($pH$). From a physical point of view, the situation can be interpreted as follows: When the solution deviates from the neutrality; i.e., when the pH value deviates from 7.0; in the solution, more ions are formed, which leads to an increase in the conductivity ($\sigma$). Because more ions mean actually more conductivity ($\sigma$). On the other hand, when the amount of the ions increases; the solution will become more energetic, and this means that more potential energy in the solution can be converted into other forms in greater amounts, according to the 1$^{st}$ law of thermodynamics. But, this is inversely proportional to the temperature ($T$). As a matter of fact, an increase in temperature ($T$) causes solid expansion and less resistance occurs in the expanding material due to the cross-sectional expansion. Decreased resistance manifests itself as the increased conductivity ($\sigma$), because resistance and conductivity ($\sigma$) are inversely proportional, and this situation is already summarized in Figure 9b.



c)

**Figure 9.** The covariance analysis of the physical and chemical properties of the wastewater, **a)** the covariance of daily gas generation ($Q_{gg}$) of the treatment plant shown according to the temperature ($T$), **b)** the covariance of daily gas generation ($Q_{gg}$) of the treatment plant shown according to the conductivity ($\sigma$), **c)** the covariance of daily gas generation ($Q_{gg}$) of the treatment plant shown according to the pH

Figure 10 presents that the bio-gas production obtained in the waste water treatment plant, helps the recovery of some portion of the energy consumed in the treatment plant. This is due to the burning of the methane gas that is generated using the waste water of the water treatment plant. Biogas can be regarded as a renewable energy source, since it is formed naturally due to the waste water. In this treatment plant, the bio gas will already be produced in all circumstances and will be released freely to the nature without producing any energy; but, in this case, it makes a high contribution to the energy production by being burned. The obtained biogas from the waste water treatment plant is burned as a fuel in the gas generators. Besides, in case the electrical energy of the facility cannot be fully met from biogas or from the grid, diesel generators are activated, as can be seen in Figure 10. The figure exhibits the distributions of the daily power generations obtained from diesel ($E_d$) or gas ($E_g$) turbines as well as the energy consumption from the city line ($E_{cl}$). Since the generated power from either gas ($E_g$) or diesel ($E_d$) turbine manifests itself later as the consumption in the plant, the summation of power generations from diesel and gas turbines as well as the consumption from the city line ($E_{cl}$) constitute the daily total energy consumption ($E_c$) within the plant. Accordingly, the distribution curve belonging to the daily total energy consumption ($E_c$) of the plant is always above the other three curves presented in Figure 10, and it is indicated by blue color in the figure. The analysis of 445 days has indicated that the maximum value of the total daily energy consumption ($E_c$) in this plant reached 50.620 MWh. Besides, when the energy generation and the consumption of the treatment plant is considered, it is analyzed that a value of 40.758 MWh as the average value of the total daily energy consumption ($E_c$) was determined. On the other hand, during 445 days, the total requirement of electrical energy for this plant was reported to be 18.137 GWh, to obtain the facility operation for the waste water treatment plant. Whole data analysis regarding the energy generation and the consumption in this plant has revealed that 78.29% of the 18.137 GWh energy, corresponding to 14.200 GWh has been recovered by the biogas generation. I.e., this portion of the energy was not consumed from the city line ($E_{cl}$) or it was not consumed from the energy generations obtained from the diesel generators ($E_d$). As similar to the low energy consumption from the city grid ($E_{cl}$), using the diesel generators ($E_d$) as little as possible will reduce the fossil fuel consumption and this will lead to national energy and money gain. By evaluating the bio fuel, which is ready and was going to be wasted; in this way, both the emissions of methane gas to the nature will be prevented and energy would be produced.

When these three physical and chemical parameters influencing the methane gas generation are considered, the absolute values of the covariance results of these parameters according to the gas generation were analyzed in order to speak about or compare the impact degree of them. Accordingly, the order of the absolute magnitudes of the covariance results can be formed as; $|\mathrm{Cov}(Q_{gg}, \sigma)| > |\mathrm{Cov}(Q_{gg}, T)| > |\mathrm{Cov}(Q_{gg}, pH)|$. The physical explanation for this situation is; as a result of the analysis, it is understood that the increase effect of the electrical conductivity of the wastewater on the methane gas output is more than the decrease influence of the temperature of the wastewater on the methane gas output, and the latter is more than the increase effect of the acidity level of the wastewater on the methane gas output. Accordingly, it is concluded that the methane gas generation or the energy output obtained from the gas turbine, using the generated methane gas is at most dependent to the electrical conductivity in direct proportionality, followed by the temperature in indirect proportionality; and, it is concluded that the energy output is least influenced by the degree of the acidity, in direct proportionality.

In the study of Alisawi (2020), it was concluded that a temperature ranges of 15 $^oC$ to 25 $^oC$ is suitable for the growth and production of the bacteria that is forming the methane gas. This range is consistent with the maximum methane gas production obtained in the current study, considering temperature range of $15\ ^oC \leq T \leq 22\ ^oC$. As demonstrated in Figure 9a, highest amount of the methane gas is generated by the bacteria, at this interval of temperature. Although the further excess increase of the temperature causes a significant reduction in the obtained methane gas generation, this mentioned range can be regarded as the optimum generation of methane gas resulted by the optimum growth and development of the bacteria.

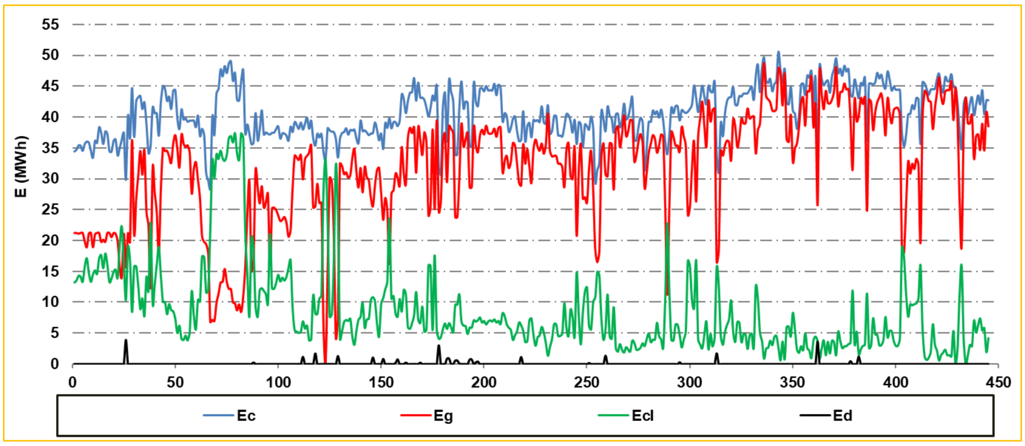


**Figure 10.** Energy data of wastewater treatment plant ($E$)

## 4. CONCLUSIONS

The transition to renewable energy sources has gained importance due to the increase in the World population and the depletion of energy resources. Biomass energy, which is one of these resources, stands out with both the diversity of production technologies and its high potential. Biomass energy becomes an effective and useful resource when processed with the right methods. Biomass is renewable and non-fossilized organic matter derived from plants and animals. It contains atoms containing oxygen, nitrogen, hydrogen and carbon, as well as low proportions of heavy and alkali metals. In this sense, all plant and animal origin substances containing carbohydrate components in fact constitute some amounts of biomass. Recently, about 10% of the World's energy comes from the biomass energy. Plant-based alternative sources used instead of exhaustible energy sources get their power from solar energy. On the other hand, the biomass becomes an inexhaustible resource as plants will continue to photosynthesize as long as the sun exists. The energy that can be renewed in less than 100 years and can be obtained from all plants and animals, forest products, wastes of cities and food industry is called biomass energy. Besides, energy can be obtained from biomass in solid, liquid, or the gas form. Different fuel types such as biogas, bioethanol, biodiesel can be given as examples of biofuels. Biogas, which is a sub-type of biofuel, is carbon dioxide and methane gas formed by organic wastes as a result of anaerobic fermentation in an oxygen-free environment. Bovine, ovine and poultry manure, municipal solid waste, agricultural waste, beet pulp, peanut shell and tea waste are used in biogas production. This technology helps restore waste to the soil, while also obtaining energy from the waste materials. The electrical energy is obtained by burning biogas in gas engines. Biogas stands out as an environmentally friendly fuel. Methane gas obtained from this source emits less carbon dioxide than petroleum-based fuels, that are used today.

In this study, the physical and chemical properties of the waste water as well as the energy generation and consumption capacity of an installed waste water treatment plant of Turkey have been performed. Namely, it has been demonstrated that the generation of the bio-gas obtained in an installed waste water treatment plant causes the recovery of some of the energy consumed in the same plant. The recovery of the energy has been obtained by the generated biogas of the plant, which is gained by the waste water and later it is used in the gas generators. In this regards, a total of 88.471 $hm^3$ water that was required to be water treated has entered the treatment plant, in a total of 445 days. So, from this amount of water quantity, considering 445 days, a cumulative of 6.09 $hm^3$ of biogas generation ($Q_{gg}$) has actualized. Among the total of 6.09 $hm^3$ of the gas, 5.24 $hm^3$ of the cumulative was burned in the gas generator ($Q_{gc}$), for the recovery of some portion of energy, consumed during water treatment processes in the waste water treatment plant. Due to these burning of the generated gas; accordingly, as it is shown in the energy balance of the plant, the maximum value of the total daily energy consumption ($E_c$) in the plant, considering the analyzed 445 days; reaches 50.620 MWh. Besides, the average value of the total daily energy consumption ($E_c$) in the plant during the same period of time is concluded to be 40.758 MWh. In addition, when 445 days of operation time is taken into account; a total of 18.137 GWh of electrical energy was required in order to operate the waste water treatment plant and to obtain refinement of the dirty waste water in this period of time. The analysis of the data has shown that 78.29% of the energy has been recovered by the generated biogas, obtained from burning of the methane, and accordingly, it was not consumed from the city grid line.

On the other hand, the covariance analysis was also carried out in this study to show the influence of the physical and chemical properties of wastewater on the amount of the energy produced. In this regards, the covariance analyses of three physical and chemical properties of the treatment plant demonstrated that the increase of the waste temperature ($T$) has a negative influence on the total volume of the generated gas ($Q_{gg}$). On the other hand, it is demonstrated that the total volume of the generated gas ($Q_{gg}$) is positively influenced by the increase of the electrical conductivity ($\sigma$) as well as the increase of the degree of acidity (*pH*).

Accordingly, in the current study, the influence of the physical and chemical parameters on methane gas generation, thus their impacts on the energy recovery obtained from the waste water treatment plant are also considered. As a result of the performed analyses, it is concluded that while the increase of the waste water temperature causes decrease of methane gas generation, whereas, the increases of electrical conductivity and the degree of acidity of waste water cause increase of the methane gas generation. In this context, while waste water temperature increase reduces the power generation from the facility; increase of the electrical conductivity and the increase of the degree of the acidity of the waste water cause increase of the energy production from the waste water treatment plant. Also, the comparison of the correlations of these parameters on gas formation has been shown. Accordingly, it is come up to a conclusion that the increase effect of the electrical conductivity of the wastewater on the methane gas output is more than the decrease influence of the temperature of the wastewater on the methane gas output. And finally, the decrease influence of the temperature of the wastewater on the methane gas output is more than the increase effect of the acidity level of the wastewater on the methane gas output. It is also come up to a conclusion that this correlation relationship given for methane gas production is also valid for the energy output obtained from the facility.

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## NOMENCLATURE:

$Q_{ww}$ : Daily total volume flow rate of waste water
$Q_g$ : Volume of the methane gas either generated in the plant or consumed by gas generator
$Q_{gg}$ : Daily total volume of the generated gas by the waste water treatment plant
$Q_{gc}$ : Daily total volume of the consumed gas in the gas generator
T : Waste water daily average temperature given in Celsius degree
pH : The measurement unit to determine daily average degree of acidity of a solution
σ : Daily average electrical conductivity
E : Daily total energy abbreviation that includes $E_c$, $E_g$, $E_d$, and $E_{cl}$
$E_c$ : Daily total energy consumption
$E_g$ : Gas generator daily total energy generation
$E_d$ : Diesel generator daily total energy generation
$E_{cl}$ : Daily total energy consumption from the city line