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Providing the Ratio of Micro Hydroelectric Generation of the Municipal Wastewater Treatment Plant to Turkey's Total Electricity Consumption

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Abstract

In this study, it was aimed to determine to provide the ratio of municipal wastewater treatment plant (WWTP) micro-hydropower generation to Turkey's total electricity consumption. Primarily, population and treated wastewater flow predictions of Turkey were made between 2020 and 2023 years. The power predictions that micro-hydroelectric power plants could generate were made by using 2 meters drop height and predicted flow data. Then, for the same years, Turkey's total electricity consumption prediction was made. For forecasting data for the coming years, a forecast sheet application was used. Finally, the total predicted electrical energies that could be generated with micro-hydroelectric at municipal WWTPs were compared with Turkey's predicted electricity consumption from 2020 to 2023 years. Thus, the ratio of these two parameters to each other was determined. The population was predicted as 87873632 people and the total amount of treated wastewater (TWW) was predicted as 5117528600 m^3 for the year 2023. Total annual electricity generation that could be generated from micro-hydroelectric power plants was predicted as 2231 GW/year for 2023 year, while the total electrical power consumption value was predicted as 312547 GW/year. It was predicted that the supplying ratio of micro-hydropower generation in municipal WWTPs to total electricity consumption would be 0.00714% on average between 2020-2023 years.

1. Introduction

Climate change and its social, environmental, and economic consequences are interrelated problems facing humanity. The effects and costs are great. The main reason behind global warming is energy consumption based on fossil fuels by people for different purposes. In order to obtain secondary energy, fossil fuels such as coal and oil are usually burned. In the past when consumption was less, power plants operated locally and fed a certain area. With the advancement of technology, energy need has increased as a result of the establishment of industrial facilities and local productions have become unable to meet this [1]. Renewable energy sources such as solar, hydroelectric, wind, geothermal and biomass energy are offered as alternative energy sources to meet the increasing demand [2]. Throughout history, water has played an important role not only as a source of life but also as an energy source. In addition, the fact that it was considered a major energy-related resource in recent years carries water to a special point [3]. We are more likely to be more dependent on energy in the future. In the energy hierarchy, electrical energy is at the top. However, traditional sources of electricity generation are limited. One of the most useful sources of electricity generation today is the hydroelectric power plant established in municipal sewage WWTP. Wastewater in municipal sewage WWTPs is generated by housing, public and commercial buildings [4].

Hydroelectric is a renewable, non-polluting energy source that is relatively less harmful to the environment than other sources. Municipal sewage wastewater has hydroelectric potential. Generating electrical energy by using this potential energy of wastewater in municipal sewage WWTPs can be considered an alternative energy source. This energy is defined as a micro-hydroelectric power plant. The micro hydroelectric system has become one of the popular renewable energy sources in developing

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countries. These plants are environmentally friendly as they do not produce greenhouse gas emissions [5]. Renewable energy sources are the most important points to consider when designing the social and economic system on a global scale. At this point, hydropower plants in municipal sewage WWTPs can also be considered a renewable energy source [6]. Micro-hydroelectric technology used in municipal sewage WWTPs is a clean and sustainable energy source. Since it is not fossil-based, it may also contribute to carbon emission reduction [2]. Today, in addition to large hydroelectric power plants, small hydroelectric power plants with a maximum output capacity of 10 MW are also utilized. The aim of these plants is to convert the potential energy of water into electrical energy with the help of a turbine and a generator. The power generated from the plants is proportional to the flow and drop height of the water. Since the flow rate and amount of water depending on the amount of rainfall received in the water basin according to the seasons, the water flow rate may vary non-linearly [7]. Small-scale hydroelectric investment is a renewable energy source that is clean, sustainable and emission-free, and its usage is increasing day by day all over the world. Small-scale hydroelectric power can be classified as small, mini, micro or pico depending on the output power and type. Micro-hydropower typically corresponds to power generation below 100 kW, while pico-hydropower generally corresponds to an installed power of less than 5 kW.

A study was carried out by Abbas et al. (2019) on the energy savings and power output that would occur if a hydro turbine was used in a WWTP in Wisconsin. The waste flow rate of the wastewater treatment plant under consideration was 190 million gallons (836927 m^3) per day. There was a height of 3 meters between the wastewater treatment plant and the discharge point. A computational fluid dynamics software had been applied to evaluate the performance of the system. The value of the savings was estimated to be 1564 MWh/year. The hydroelectric potential of the WWTPs in Switzerland had been evaluated in the study carried out by Bousquet et al. (2017). Hydroelectric generation estimates were made separately for 19 WWTPs with different head heights. 55 m^3/s in total from nineteen WWTPs. An algorithm had been developed for the economic evaluation of each plan. As a result of the study, it was estimated that annual potential energy generation of 9.3 GWh/year could be realized for nineteen project areas in the country. Chae et al. (2015) conducted a study on the applicability of small-scale municipal WWTPs with different flow levels in a micro-hydro system with flow variable turbines in South Korea. As a result of the study, they concluded that the type of turbine that gives the highest performance is the semi-tiger turbine. However, in South Korea, wastewater-based hydroelectric turbine efficiency was not considered feasible due to low efficiency. As a result of this study, micro-hydropower plants from WWTP had been proposed as a clean energy source due to their simple installation, economic contribution and minimum environmental impact. Power et al. (2014) developed a method for estimating potential forces and payback periods for hydroelectric power recovery studies in more than 100 WWTPs in Ireland and the UK. A sensitivity analysis was performed based on changes in flow, turbine selection, electricity pricing and financial incentives. A method had been developed to optimize a design that could accommodate flow change without hindering turbine efficiency. In addition, the effect of future flow rate changes on the design was investigated. Concerning turbine selection, it was concluded that the Kaplan brand turbine had the highest potential power output. Furthermore, electricity pricing had been found to have a major impact on the economic viability of hydroelectric energy recovery. In the study conducted by Kose et al. (2013) a hybrid system consisting of wind and hydroelectric power plants was analyzed to meet the energy demand of the Konya water treatment plant. In addition to 250 kW HEPP (Hydroelectric Power Plants) and 250 kW WPP (Wind Power Plant), two 250 kW or one 500 kW wind turbine were added to the HEPP in order to meet the electrical energy requirements of the Konya water treatment plant. In this case, the energy demand of the power plant could be met with HEPP for 10 months per year. It had concluded that a WPP was required to provide uninterrupted energy. Bhandari et al. (2017) conducted a study on how the micro hydroelectric power plant can meet high electricity demands. They conducted a study on the advantages and disadvantages of generating micro-hydroelectric power from WWTP. They concluded that they could generate at 11.32 kWh of electricity with a 0.57 m^3/s flow rate and 1.8-meter drop height. In the study made by Albany et al. (2011) an integrated 15 kW turbine/generator system had been designed and evaluated to obtain energy from the flow in WWTPs. The prototype system was designed to supply 15 kW of electrical power to the power grid when fed with 12 million gallons (52858 m^3) per day. A case study on a hydroelectric system had been conducted by Kusakana (2019) in Zeekoegat WWTP, South Africa. The WWTP's electricity load demand, water resources and potential energy that could be recovered using the proposed hydroelectric power plant were evaluated to determine the projected cost savings over a proposed 20-year operating period. According to the economic analysis obtained in the study, the breakeven point was 6.35 years. For the foreseen 20 years, it had been concluded that 45.63% of the total electricity to be consumed could be met by WWTP hydro. In the study by

Never (2016), the dependency between India's wastewater and energy availability was analyzed. It was analyzed under which conditions and which vehicles were useful in wastewater systems. In addition, land and water scarcity caused changes in planning depending on local conditions.

The aim of this study was to reveal the hydroelectric potential of municipal sewage WWTPs in Turkey. For this aim, the amount of TWW that belongs to past years was taken from Turkey Statistical Institute (TUIK). In the Microsoft excel environment, forecast sheet application was used to predict the flow rates for the coming years. According to the obtained flow values, total micro-hydroelectric energy values which could be generated from municipal sewage WWTPs were obtained according to 2 meters head height. Also, by using previous years data, next years electricity consumption values of Turkey were predicted. Finally, micro-hydropower generation values obtained from municipal sewer WWTPs and Turkey's next years predicted electricity consumption values were compared. In this context, it was thought that the electrical energy to be obtained from the TWW, which was released directly to the discharge environment after treatment, would be a guide in terms of how much of the total electricity consumption, which was constantly increasing, could be met.

The next part of the study consists of four sections. In the second section, hydroelectric theory and its calculation were explained and population and TWW estimates were made. In the third section, the predicted flow rate until the year 2023 was calculated according to the predicted amount of electricity that can be generated according to 2 meters of drop height. Then, Turkey's total electricity consumption value was compared with these total generations. The fourth section was the conclusion part, and the results obtained in the study were compared.

2. Materials and Methods

2.1. Hydroelectric Theory

The potential energy of water with a certain height is called hydroelectric energy. This energy is first converted to mechanical energy and then to electrical energy by the rotation of the generator motor connected to the turbine wheel. Thus, hydroelectric power plants convert the power of the flowing water into electricity. The flow or drop rate of water is directly related to the amount of energy that the flowing water will have. When this relationship is taken into consideration, it is concluded that a high amount of energy can be obtained by decreasing the water from a very high point [17]. In hydroelectric technology, there are two basic parameters, namely the height of the head and the flow rate enough to generate electricity [2]. Accordingly, in order to determine the potential of the power of the water flowing into the sewer, it is necessary to determine both the flow rate of the water and the head height of the water. The flow rate is the amount of water flowing from a point at a given time. Flow units are liters per second or cubic meters per second. The head refers to the vertical height.

Accordingly, the potential power calculation that can be obtained from a micro-hydroelectric power plant is as follows. The potential energy of water at a given height can be calculated by Eq. (1) and Eq. (2) [17]:

$$P_E(joule) = m \times g \times h \quad (1)$$

where m is the weight of water (kg), g is the gravitational acceleration (9.81 m/s^2), and h is the height of the drop (m).

$$P_E(Wh) = Q * 1000\left(\frac{kg}{m^3}\right) \times g \times h \times R \quad (2)$$

$$P_E(kWh) = Q * 1\left(\frac{kg}{m^3}\right) \times g \times h \times R \quad (3)$$

where PE is the power (kWh), Q is the flow rate (m^3/s), g is the gravity coefficient (9.81 m/s^2), h is the drop (m), and R is the efficiency coefficient [18].

2.2. Forecast Sheet Application

The "Forecast Sheet" is a forecasting tool that quickly and easily predicts based on historical data grouped by time. The ability to recognize seasonality in historical data and take it into account is something that traditional linear projections do not. Also, the speed at which you can forecast using this tool is also unique [19].

2.3. Curve Fitting

The data generated in experimental studies are usually punctual. A continuous function cannot be obtained. In this case the data is (x_1, y_1), ……, (x_n, y_n) are given as pairs of points. Determining another function closest to the function at given values for each point of a function is defined as the "curve fitting" problem [20]. It is aimed to find a suitable curve equation that will best represent the relationship between two variables.

2.4. Matlab

MATLAB is expressed as the 4th generation programming language. Developed by MathWorks. It offers many possibilities such as matrix operation, drawing and scientific programming. It also contains many tools. Examples of these are signal processing, optimization, statistics, signal and image processing toolboxes [21]. R2015a version was used in this study. It was used to obtain the polynomial equations of population by years, TWW related to population and total electricity generation related to population value. The curve fitting method was used as a method.

2.5. Prediction Studies

In this chapter, predictions of Turkey's population and TWW were made. Predictions were made until 2023. Turkey's population values between the years 2000-2018 are given in Table 1. These data were taken from TUIK [22]. Population predictions between 2019 and 2023 years were made by using the forecast sheet application in Microsoft excel [23].

Table 1. Current and Predicted Population Values (Turkey).

Years	Population	Years	Population	Predicted Population
2000	64729501	2012	75627384	-
2001	65603160	2013	76667864	-
2002	66401851	2014	77695904	-
2003	67187251	2015	78741053	-
2004	68010215	2016	79814871	-
2005	68860539	2017	80810525	-
2006	69729967	2018	82003882	-
2007	70586256	2019		83177528
2008	71517100	2020		84351554
2009	72561312	2021		85525580
2010	73722988	2022		86699606
2011	74724269	2023		87873632

When Table 1 is examined, the population growth rate would increase by 1.431% in the year 2019 compared to the previous year, 1.411% in 2020, 1.392 in 2021, 1.373% in 2022, 1.354% in 2023. Also, the total predicted population would be 87.873.632 in 2023. When the predicted data in Table 1 is applied to the curve fitting algorithm written in Matlab [24] environment, Eq. (4) is obtained.

$$Population = 1.009 \times 10^6 \times (year) - 1.953 * 10^9 \quad (4)$$

R-square: 1

The total amount of TWW by municipal sewage WWTPs in Turkey between 2001 and 2016 years are shown in Table 2. In addition, the flow prediction between 2017-2023 years was made. These data were taken from TUIK [22]. Microsoft excel forecast sheet application was used for prediction. When this table was analyzed, it was predicted that the rate of increase at the amount of TWW would increase by 4.682% in 2017 and 3.700% in 2023 compared to the previous year, and the total amount of TWW would be 5117528600 m^3 in 2023.

Table 2. Current and Predicted Amount of TWW (Turkey).

Years	Current and Predicted Flow Rate (thousand m^3/year)	Years	Current and Predicted Flow Rate (thousand m^3/year)
2001	1193975	2016	3842350.0
2002	1312379	2017	4022246.4
2003	1586550	2018	4204793.4
2004	1901040	2019	4387340.5
2006	2140494	2020	4569887.5
2008	2251581	2021	4752434.5
2010	2719151	2022	4934981.5
2012	3256980	2023	5117528.6
2014	3483787		

The predicted data in Table 2 was applied to the curve fitting algorithm written in Matlab environment. The resulting equation was shown in Figure 1. Figure 1 is a graphical representation of the data obtained in Table 2. The values to be obtained by the equation in Figure 1 are very close to the values in Table 2. Coefficients were with 95% confidence bounds.

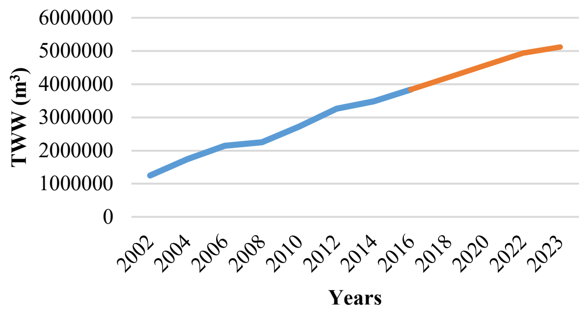

Figure 1. Turkey's Current and Predicted Flow Rate Amounts

When Table 1 and Table 2 are compared, the population growth rate from 2001 to the year 2019 was 26.79%, while the rate of increase in TWW by municipal sewage WWTPs is 267.46%. The rate of increase at the amount of TWW is ten times the population growth rate. Similarly, while the predicted population growth rate from 2019 to the year 2023 is 5.65%, the predicted amount of TWW by municipal sewage WWTPs increases by 16.64%. Using the annual flow rates obtained in Table 2, if the desired flow rate per second is calculated, Table 3 is obtained. While calculating the flow rate obtained per second, annual flow rate is obtained by dividing into 365 days, 24 hours, 60 minutes and finally 60 seconds respectively.

Table 3. Predicted Amount of TWW (Turkey)

Years	Predicted Amount of Wastewater (m^3/year)	Predicted Amount of Wastewater (m^3/sec.)
2020	4569887500	144.90
2021	4752434500	150.70
2022	4934981500	156.49
2023	5117528600	162.28

The relationship between population growth and the amount of TWW was analyzed. All data for both parameters were used for this purpose. When the related parameters were written to the above-mentioned Matlab algorithm, the polynomial of the 3rd order is as in Eq. (5). Here, P is the population. The coefficients in the obtained equation were with 95% confidence bounds.

$$TWW(year) = -1.301 * 10^{-6} * P^2 + 372.9 * P - 1.762 * 10^{10} \quad (5)$$

R-square: 0.9968

3. Results and Discussion

3.1. Micro-hydropower Generation in Case of Drop Height is 2 Meters

In the studies in literature, the drop height varies between 1.8-3 meters, and in this study, calculations were made according to the drop height of 2 meters.

Eq. (3) was used to calculate the amount of energy that could be generated according to the amount of wastewater treated. Here R yield coefficient is accepted as 0.80 in this study. Accordingly, using the flow values in Table 3, the energy value calculations obtained for the year 2020 at a height of 2-meter head are obtained as at Table 4:

Table 4. Power generation calculations obtained for the year 2020 at height of 2 meters head

Power Generation	Hourly (kW)	Daily (kW)	Yearly (kW)	Yearly (GW)
	2274.35	54584.41	19923309.5	19.92

Like this calculation, if the predicted electricity generation values of the other years were calculated, the power values in Table 4 are obtained. Table 5 shows the predicted hourly flow that could be obtained from municipal sewage WWTPs between 2020-2023 years, annual power available for one hour and annual power values obtained in one year. Predicted wastewater amounts to be treated in Table 3 were used to calculate the generation values of these years. As could be seen in Table 5, the amount of electricity to be generated increased every year. However, it is predicted that these increase rates would decrease as a percentage compared to the previous year. While the value increased by 4.02% in 2021 compared to 2020, it is predicted that these percentage values would increase by 3.86% and 3.67% in the following years.

Table 5. Predicted flow rate and power values for the coming years at a height of 2 meters

Years	Predicted Flow Rate (m^3/sec)	Generated Electricity (kWh)	Generated Electricity (GW/year)
2020	144.90	2274.35	19.92
2021	150.70	2365.39	20.72
2022	156.49	2456.27	21.52
2023	162.28	2547.15	22.31

If the similar study between the population and TWW amount was made between amount of predicted wastewater to be treated and predicted electric power to be generated in 2020-2023 years, the polynomial equation obtained was as at Eq. (6). GE means generated electricity. Coefficients were with 95% confidence bounds.

$$GE\ (GW/year) = 2.182 \times 10^{-8} \times TWW - 0.09253 \quad (6)$$

R-square: 1

Accordingly, if the Eq. (5) and Eq. (6) were combined based on wastewater to be treated between the population and the generated energy, Eq. (7) is obtained.

$$GE\ (GW/year) = 2.182 \times 10^{-8} \times (-1.301 \times 10^{-6} \times P^2 + 372.9 \times P - 1.762 \times 10^{10}) - 0.09253 \quad (7)$$

Using the Eq. (7) obtained, the predicted generation of electricity based on the wastewater to be treated depending on the population of the following years could be obtained.

3.2. Supplying Ratio of Municipal WWTP Micro-hydroelectric Generation to Turkey's Total Electricity Consumption

At this stage, a study was conducted to determine the supplying ratio of municipal WWTP micro-hydroelectric that generated from municipal sewage WWTPs to Turkey's total electricity consumption (TEC) at 2020-2023 years. Predicted electricity generation values obtained from municipal sewage WWTPs, which was one of the two data required for this comparison, are obtained in Table 5. Predicted electricity consumption values between the years 2020-2023 have been obtained with the excel forecast sheet application. Figure 2 shows the values obtained by this embodiment.

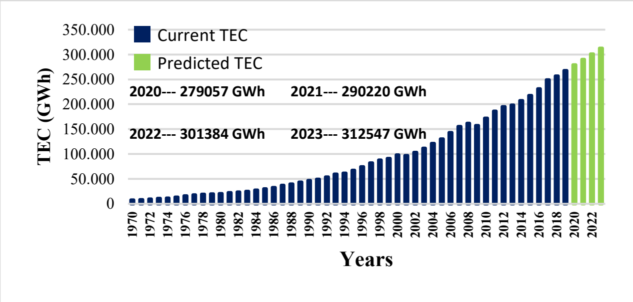

Figure 2. Turkey's Current and Predicted TEC

When Figure 2 is examined, it is seen that TEC continuously increases. However, when analyzed in more detail, the consumption rate shows a decrease compared to the previous year. For example, while the consumption of electricity consumed in the 2020-year increase by 4.17% compared to the previous year, the year 2019, increase rate was predicted to be 4.00%, 3.85% and 3.70% in the following years, respectively. To determine whether the municipal WWTP micro-hydroelectric generation of Turkey meets TEC to what extent, the data of Figure 2 and Table 5 are used. The supply ratios obtained are as in Figure 3.

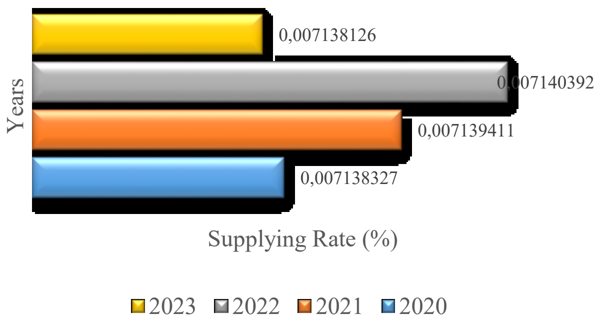

Figure 3. Supplying Ratio of Municipal WWTP Micro-hydroelectric Generation to Turkey's TEC

As can be seen from Figure 3, similar supply-to-demand ratio emerges in four years. These values are around 0.00714%. The reason for the close supply-demand ratios is that between 2020-2023 years, both municipal WWTP electricity generation and total electricity consumption increased at close rates.

When the studies mentioned in the literature review section above were examined, generally the appropriate turbine selection for electricity generation from WWTP, the amount of generation that could be obtained, and similar studies could have been made. In addition, in this study, the contribution rate of the hydroelectric that could be obtained from WWTPs to the total electricity generation of the country had been investigated. In addition, in the studies in the literature, either for a single WWTP or separate generations of different WWTPs were evaluated. In this study, the total hydroelectric calculation that could be obtained by considering the total amount of TWW in Turkey was performed. In addition, in this study, the ratio of the generated hydroelectricity to the electricity consumption of the country was calculated. Compared to the study conducted by Bousquet, Samora, Manso, Rossi, Heller & Schleiss (2017), it was predicted 9.3 GWh/year hydroelectric generation for 55 m^3 total flow rate from nineteen WWTP, whereas in this study, 22.31 GWh/year generation was predicted for 162.28 m^3 flow rate for 2023 year. While the flow rate was 295 times, the amount of hydroelectric produced was 240 times in Turkey. The slight difference in generation was thought to be due to the drop height and the use of different models of turbines. In the study conducted by Bhandari & Rahate (2017), the flow rate was taken as 0.57 m^3/s and the drop height as 1.8 meters, and 11.32 kWh was obtained. In this study, 2547.15 kWh electricity generation was predicted for the year 2023 with 162.28 m^3 flow rate. While the flow rate was 285 times, the amount of hydroelectric generated was 225 times in Turkey. The small difference in the generation amount was thought to be due to the use of different model turbines and the selection of parameters used in the calculations.

4. Conclusions

This paper aimed to determine the supplying ratio of municipal WWTP micro-hydroelectric that generated from municipal sewage WWTPs to Turkey's TEC. The head height was assumed to be 2 meters. The prediction years were between 2020-2023 years. According to the predictions made for this purpose, the population growth rate would increase by 1.431% in 2019 compared to the previous year, 1.411% in the year 2020, 1.392 in the year 2021, 1.373% in the year 2022, 1.354% in the year 2023, and the total population would be 87873632 in the year 2023. The rate of increase in the amount of TWW was predicted to increase by 4.682% in 2017 and 3.700% in the year 2023 compared to the previous year, and the total amount of TWW was predicted to be 5117528600 m^3 in the year 2023. Furthermore, both municipal WWTP micro-hydroelectric power generation and the total electric consumption predicts were made for Turkey. According to the prediction studies, a total of 2231 GW/year electricity generation was predicted in 2023 year, while the TEC was predicted to be 312547 GW/year. For the following years, the supplying ratios were similar for four years. These values are around 0.00714%. The reason for the close supplying ratio was that both the predicted electricity generation predicts from the municipal WWTP and the TEC predicts have increased over the years. As a result, energy from WWTPs supports future-oriented renewable energy generation plans. In this respect, it should be taken into consideration in energy policies in the sustainable development of countries.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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