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Feasibility Study of Using Renewable Energies in the Water and Wastewater Industry (Case Study: Tehran Water and Wastewater Company)

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ABSTRACT

Climate change refers to any significant and long-term alterations in global or regional weather conditions. The impact of climate change on the industrial plans is enormous, while the water supply sector has been challenged to examine how it could continuously operate in the current situation. Optimization of energy consumption and reduction of Greenhouse Gases (GHG) emissions are some of the priorities of water companies. The objective of the study is to propose a novel evaluation approach to the feasibility of using renewable energies (solar, wind, and biomass) in the water and wastewater industry. Tehran Water and Wastewater Company consists of six regional districts and forecasting of its energy consumption, power costs, and carbon tax rates for the next ten years was done by using the regression model. The results indicated that increase in water supply and electricity consumption was evidenced by the increase in Tehran's annual population. GHG emissions were calculated in two scenarios, the first of which is based on the total supply of required electricity from conventional power plants and the second is on the generation of approximately one-third by renewable energies. In addition to the higher emissions of carbon dioxide (CO_2) from diesel and oil power plants than the natural gas-fueled plants, by increasing the carbon tax to more than 30 USD per tonne of CO_2, it is expected that the emissions will be reduced by 30 % in all fossil-fueled power plant types. Results showed that a small amount of tax was not effective in reducing GHG emissions.

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1. INTRODUCTION

Renewable energy sources that meet domestic energy needs are capable of delivering zero or near-zero emissions of air pollutants and GHG. The development of a renewable energy system enables it to solve the most important tasks of today such as improving the reliability of energy consumption and organic fuel economy, solving local energy and water supply problems, enhancing the living and working conditions of local people, and ensuring sustainable development. Remote areas in the desert and mountainous areas may require countries' commitments to international agreements on environmental protection [1]. Developing and implementing a renewable energy project in rural areas can create job opportunities and thus, minimize migration to urban areas [2]. Decentralized Renewable Energy Harvesting is one of the options to meet rural and small energy needs in a reliable, cost-effective, and environmentally sustainable manner [3, 4]. Renewable energy technologies are considered as clean and sustainable sources of energy for current and future economic and social needs. The optimal use of these resources could minimize environmental impacts and secondary waste [5]. Today, one of the most critical environmental problems globally that needs drastic action is the necessity of optimizing the production of energy using different types of renewable sources and, at the same time, reducing GHG emission. Widespread and persistent use of fossil fuels has turned carbon dioxide (CO_2) into the largest contributor of GHG emissions [6, 7]. Many economists [8] have long used carbon pricing as an efficient tool to reduce CO_2 emissions. A growing number of jurisdictions around the world are using this tool as an Emissions Trading System (ETS). Carbon pricing is an important policy tool for achieving cost-effective decarburization. The European Union has adopted the ETS as a key pillar of its policy mix to achieve short-term and long-term goals of GHG emissions [9].

In recent decades, increasing water usage for industrial, agricultural, and domestic needs and strictly enforcing water quality regulation have significantly increased water purification and transmission. Besides, a high volume of water usage in the agricultural sector is due to the intensified cultivation and expansion of irrigated farms to fulfill the increasing demand for food and biomass fuel supplies. These activities generally require a large amount of energy and lead to increased energy consumption in the water sector in many parts of the world, which finally influenced the GHG emissions [10, 11, 12, and 13]. In countries with very high freshwater harvesting, most of the total available water is used for irrigation, and the energy used in abstraction and transmission is often significant. Estimates for India indicate that GHG emissions to raise irrigation water could account for 6 % of the country's total emissions. In the US, agriculture is the largest consumer of electricity and water [13]. Due to the decreasing measures required to deal with climate change, the

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water sector has been challenged to examine how it currently operates. Energy efficiency optimization and GHG emission limitations are those that are a priority for water companies [14]. In Iran, one of the environmental issues is the rapid release of carbon. Since 1980, carbon emissions in Iran have increased by almost 450 %, from 33.1 million tons in 1980 to 146.8 million tons in 2008 [15]. Controlling growth and possibly reducing GHG emissions are important for not only the countries themselves but also the international community in pursuit of climate change strategies. According to 2008 statistics, Iran is ranked eighth in the world in GHG emissions. Further, a worrying factor is the growth rate of GHG emissions in the country, which has increased by 45 % in a decade with an increase in CO_2 emissions per capita from 4.78 ml in 1997 to 6.92 ml in 2007. This demonstrates the importance of Iran taking serious steps to control GHG emissions [16].

Raghuvanshi et al. [17] concluded that CO_2 emission as a combustion product of coal (fossil fuels) was responsible for over 60 % of the greenhouse effect. Yan et al. [18] also concluded that nearly 40 % of all CO_2 emissions in China came from the electricity sector. The reason is that China relies heavily on thermal power generation to meet its energy needs. Zhang et al. [19] also found that electricity production efficiency played an important role in reducing CO_2 emissions. Zhang et al. [19] concluded that coal products were the main fuel types of thermal energy generation, accounting for over 90 % of CO_2 from electricity generation.

Guo et al. [20] reviewed the available green energy and biomass energy that could be applied to wastewater treatment plants. Using renewable energy sources in these plants such as solar, wind, and biomass energy in different technologies has been summarized in their study. Moreover, several successful experiences of related companies have been obtained in this way. Also, advanced energy-efficient technologies for wastewater treatment were discussed and some control and management systems were proposed in that research.

Solar energy, which is considered the most abundant renewable energy source, can be introduced to water and wastewater companies. The application of solar thermal energy to this industries mainly includes three aspects: (a) the solar heat is collected through a heat collector to increase the reaction temperature and improve the treatment efficiency [21]; (b) the solar thermal is used to dewater the sludge or reduce the water content of some special wastewater in industrial wastewater treatment [22], and (c) the solar heat can be used for evaporation and desalination of special wastewater in industrial wastewater treatment.

Some researchers have suggested that photovoltaic power generation that provides electricity for sewage biological treatment could reduce the energy consumption of sewage treatment plants [23]. The power generated from a photovoltaic power station can satisfy the needs of a water treatment plant, which is in line with the "self-sufficiency" mode [24]. The electricity consumption takes up more than 30 % of production costs; therefore, cost reduction and efficient treatment are required intensively [25]. Han et al. applied solar power to drive the oxidation ditch without the battery, and the solar power system automatically started and stopped depending on the change in light intensity [26].

In previous researches, the issues of electricity consumption and the type of fuel consumed in the water and sewage industry have not been addressed. Thus, the purpose of the present study is to predict the GHG emissions over the next ten years and the effect of the carbon tax on the amount of GHG emitted by Tehran Water and Wastewater Company. It is also worth highlighting that the novelty of the proposed research is about the use of the predictive model to calculate the amount of electricity consumed and the carbon tax needed resulting from the usage of fossil fuels and renewable energy by Tehran Water and Wastewater Company.

2. MODELING APPROACH

2.1. Study area

Tehran is located at the center of Tehran province with an area of about 1.5 km2 and the respective latitude and longitude of 35°41′39″ N and 51°25′17″ E. The province is bordered by Mazandaran province to the north, Qom province to the south, Markazi province to the southwest, Alborz province to the west, and Semnan province to the east. According to the 1395 census (2016), the population of this province was 13,267,637, of which 12,452,230 lived in urban areas and 814,698 in rural areas [27]. Iran is one of the richest countries in the world in terms of various energy resources since it enjoys extensive resources of fossil fuels, such as petroleum and natural gas, and possessing high potentials of renewable energies, such as solar. Tehran is located on the sunbelt of the world with an insulation level of more than 5 kWh/m^2. Therefore, the country has good potential for using solar energy. The calculations show that the amount of practical solar radiation hours exceeds 2800 hours per year [28]. Therefore, due to the remarkable surface areas in different branches in Tehran, the application of this significant potential by the water and wastewater company can be a beneficial approach to generating some proportions of the electrical energy required by the country. Tehran is also the capital of Iran. The water and sewer companies of the six districts of Tehran including District 1, District 2, District 3, District 4, District 5, and District 6 within the districts of Tehran.

2.2. Forecasting model

This study applied predictive modeling has been used based on mathematical and computational methods to predict principal factors in energy consumption of the Tehran Water and Wastewater Company. Hence, a mathematical approach was used in the form of an equation-based model that described the pertained phenomenon considering all important characteristics of the company and its application. General Linear Methods (GLMs) include different techniques used in prediction issues. The most popular methods are Linear Regressor (LR), Lasso Regressor (Lasso), Ridge Regressor (Ridge), and Elastic Net Regressor (ElasticNet).

Linear regression provides the simplest and most widely used statistical model for predictive modeling. It is a linear model approach between response variables with one or more descriptive variables. In this case, it is assumed that one or more descriptive variables whose value is independent of the other variables or under the researcher’s control can be effective in predicting the response variable whose value is not dependent on the descriptive variables under the researcher's control. The purpose of regression analysis is to identify the linear model of this relationship. The dependent variable rather than the response variable and the independent variable rather than the descriptive variable are used. The form of the simple linear regression model is as follows [29]:

$$Y \approx \beta_0 + \beta_1 X \quad (1)$$

The parameters of this linear model include intercept (β_0) and slope of line (β_1). They are known as the model coefficients or parameters. Moreover, in training data, $\hat{\beta}_0$ and $\hat{\beta}_1$ are used to predict the model coefficients.

$$\hat{y} = \hat{\beta}_0 + \hat{\beta}_1 x \tag{2}$$

In Eq. (2), $\hat{y}$ shows a prediction of Y based on $X=x$. This symbol is used to indicate the estimated value of an unknown parameter or coefficient. It might be applied to signify the forecast value of the response. Since β_0 and β_1 are unknown, the estimation of coefficients by the data should be performed, as shown in Eq. (3).

$$(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n) \tag{3}$$

For making a linear model, available data will be used as in the following relation:

$$\hat{y}_i = \hat{\beta}_0 + \hat{\beta}_1 x_i \text{ for } i = 1 \ldots n \tag{4}$$

The above equation is used to make forecasting for Y based on the i[th] value of X and $e_i = y_i - \hat{y}_i$ represents the ith residual, which is forecasted by this linear model. Then, the residual sum of squares (RSS) can be defined as Eq. (5):

$$RSS = e_1^2 + e_2^2 + \ldots + e_n^2 \tag{5}$$

The least-squares method chooses $\hat{\beta}_0$ and $\hat{\beta}_1$ for minimizing the RSS. Therefore, Eq. (6) and Eq. (7) minimizers will be obtained [30].

$$\hat{\beta}_1 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})\text{-}(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{6}$$

$$\hat{\beta}_0 = \bar{y} - \hat{\beta}_1 \bar{x} \tag{7}$$

where $\bar{y} \equiv \frac{1}{n}\sum_{i=1}^{n} y_i$ and $\bar{x} \equiv \frac{1}{n}\sum_{i=1}^{n} x_i$ are the sample means. Eqs. (6, 7) represent least-squares coefficient estimates for general linear regression.

Furthermore, the slope of the line, generally linear regression, shows how sensitive the dependent variable is to the independent variable. That is, the value of the dependent variable changes by increasing one unit to the value of the independent variable. The width of the source represents the value of the dependent variable which is calculated as zero for the value of the independent variable. Alternatively, the constant value or the width of the source can be considered as the mean of the dependent variable for the independent variable [30].

In the present study, the independent variables are renewable energy potentials (solar, wind, and biomass), population rate, water consumption rate, current electricity consumption, and GHG emission values by using conventional power generators and current electricity prices. On the other hand, dependent variables including electricity consumption, renewables proportion, carbon tax, and electricity cost are predicted. Objective functions are aimed at forecasting energy consumption (in two scenarios), greenhouse gas emissions rate, and electricity cost.

3. RESULTS AND DISCUSSION

3.1. Forecasting energy consumption

Electricity consumption data of the six districts of Tehran Water and Wastewater Company from 2016 to 2019 were collected. Then, the prediction of electricity consumption for the year 2030 was made. Figure 1 shows the electricity consumption in Districts 1 to 6 of Tehran Water and Wastewater Company from 2016 to 2030 based on a million kWh. According to this chart, the total electricity consumption of the six districts of Tehran Water and Wastewater Company is increasing. The minimum and maximum values were calculated for District 5 (by 49.6 million kWh) and District 2 (by 123.8 million kWh), respectively, while different upward trends of Districts 2 and 5 were quite clear in this graph, directly depending on the rate of population rise for these reasons. Besides, Figure 2 indicates the graph of Tehran's total electricity consumption prediction up to 2030. This chart shows the sum of the lowest and highest amounts of the mentioned six districts of Tehran's electricity consumption predicted by 2030.

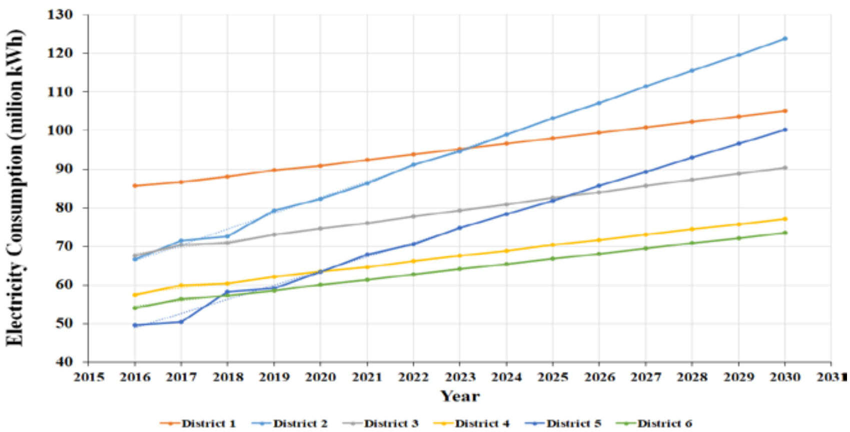

Figure 1. Current and expected values of electricity consumption in different districts of the Tehran Water and Wastewater Company.

According to Figure 1, the slope of all graphs is positive. The coefficient of determination for all of the six districts is approximately 100 % except District 2 (which is 97 %). Therefore, it can be concluded that about 100 % of the changes in the dependent variable are explained by the independent variable. In these figures, the independent and dependent variables are time and amount of electricity consumption in Districts 1 to 6 of Tehran Water and Wastewater Company, respectively.

The electricity consumption rise can be described by the increase in Tehran's annual population and, consequently, it would cause a significant increase in the potable water supply of all districts of Tehran.

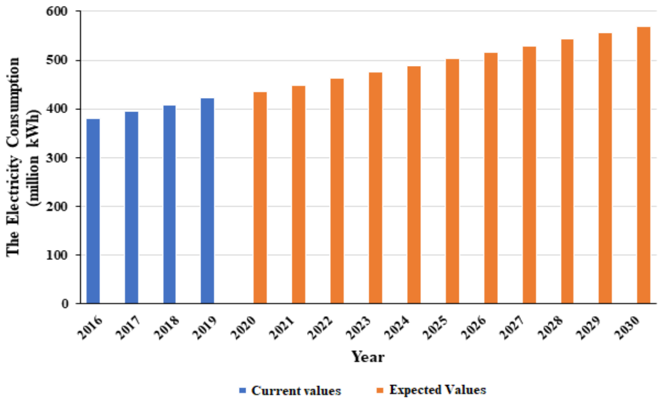

Figure 2. Current and expected total electricity consumption values of Tehran Water and Wastewater Company.

3.2. Predicting energy consumption by using renewable energy

Table 1 shows the emission levels of GHGs and pollutants in power plants in grams per kWh. According to this table, the amount of pollutants emitted from diesel-fired power plants is higher than oil and natural gas-fired power plants. Also, although natural gas-fueled power plants have lower emissions than other types, the amounts of CH_4 and CO_2 emissions are still considerably high. It is important to highlight that the main objective of this study is to substitute the use of fossil fuel with renewable energies for electricity generation. Thus, it has been assumed that fossil fuel consumption was reduced by 30 % and replaced with renewable energies. As a result, GHG emissions would be declined. There are 72 water storages at different locations of Tehran under operation that provide an approximate volume of 2,065,000 m^3, and generating electricity from solar energy is possible by installing photovoltaic systems on their rooftops. Figure 3 shows a sample water storage tank covered by solar photovoltaic panels by a Spanish company [31]. Figure 4 shows the amount of electricity consumed by Tehran Water and Wastewater Company by 2030 (with 30 % renewable energy).

Table 1. Greenhouse gases emissions from power plants (gr/kWh) [32].

Type of power plant fuels	SO_2	N_2O	CH_4	CO_2
Natural gas	4×10^{-6}	0.4	17.99	201.8
Diesel	926×10^{-3}	2.2	35.97	266.5
Fuel oil (mazut)	508×10^{-3}	2.2	35.97	278.42

Figure 3. A water storage tank covered by solar photovoltaic panels [31].

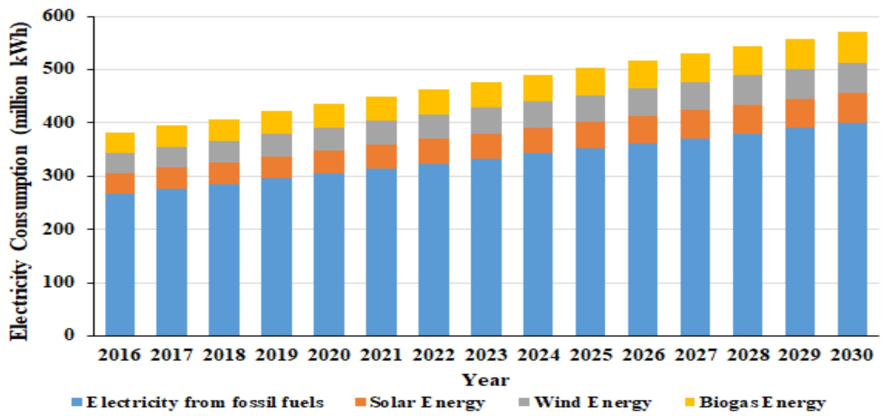

Figure 4. Electricity consumption prediction of Tehran Water and Wastewater Company by 2030 (Considering 30 % renewable energy).

Figure 5 shows the amount of CO_2 as the main GHG emitted from different types of fossils fuel power plants of Tehran Water and Wastewater Company by 2030 in thousand tons per kWh (with 30 % renewable energy). Two scenarios were designed to calculate GHG emissions. In the first scenario, the total electricity of the Water and Wastewater Company will be supplied by fossil fuel power plants by 2030 and, in the second scenario, 30 % of fossil energy will be replaced by renewable energy sources (solar, biomass, and wind power). This figure also compares the amount of GHG (CO_2) emitted in the two scenarios presented. As shows, CO_2 emission from oil fuel power plants is much higher than other types, and after the reduction of 30 % of fossil fuels, the CO_2 emissions from natural gas power plants have the lowest CO_2 emissions through all of the considered fossil power plants. Furthermore, it depicts the amount of GHG (CH_4) emitted from fossil-fueled power plants in Tehran Province to generate the required electricity of the Water and Wastewater Company by 2030 (with 30 % renewable energy). Moreover, Figure 5 indicates the amount of methane emission in both presented scenarios.

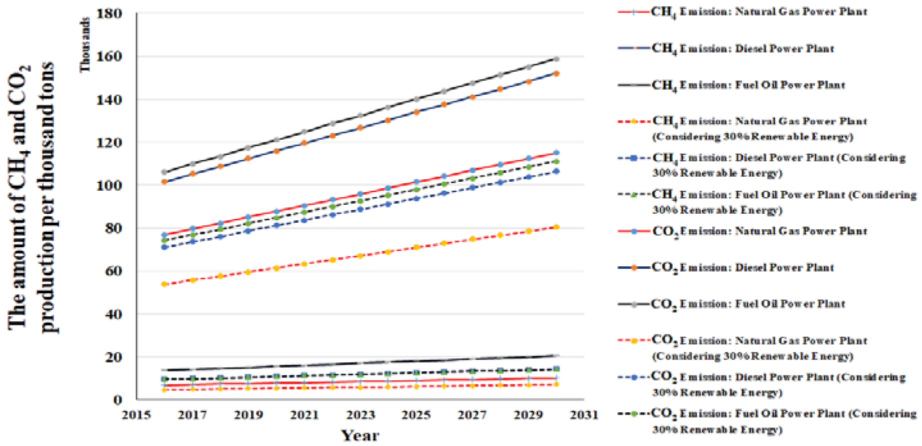

Figure 5. Comparing the amount of GHGs (CH_4 and CO_2) emitted in the two scenarios presented.

Results also show that the emitted CO_2 from natural gas, diesel, and fuel oil-based power plants in 2030 is about 115,000, 152,000, and 158,000 tones, respectively, without using renewable energies. By generating one-third of the electricity demand in the case study from renewable energy sources, CO_2 emission will be reduced up to 30 % annually in the considered period. It is approximately the same for all fossil-fueled power plant types.

Figure 6 shows the amount of another principal GHG, N_2O, emitted from Tehran's Water and Wastewater equivalent fossil-fueled power plants by 2030 (with 30 % renewable energy). In addition, this figure compares the amount of N_2O emitted in the two presented scenarios. According to the presented figure, N_2O emission from the fuel oil power plants is higher than that of plants that use natural gas. Moreover, it shows the amount of emitted sulfur dioxide by Tehran Province Water and Wastewater Company equivalent fossil-fueled power plants by 2030 (with 30 % renewable energy). As Figure 6 shows, the amount of sulfur dioxide from diesel fuel plants is higher than that in other plants. Moreover, this figure demonstrates the difference in the amount of sulfur dioxide emitted between the use of renewable energy and the non-use of renewable energy.

By comparing the results of the proposed scenarios, it is perceptible that pollutant emissions from diesel-fueled power plants are higher than those from other types of plants (SO_2 emission of diesel-fueled power plants is approximately two times more than fuel oil plant, while other pollutants value are almost the same). Moreover, the significant CO_2 and methane emissions of the natural gas-fueled power plants are not comparable with renewable power plants. Thus, by replacing 30 % of fossil fuels with renewable energies, natural gas plants have the lowest GHG emissions among other plants. Additionally, the mentioned results are significantly comparable to previous studies reviewed in the introduction section [17-19]. It should be emphasized that the substitution of conventional power plants with renewable energy generators in the mentioned company causes a considerable reduction in GHG emission through time, as shown in Figures 5 and 6.

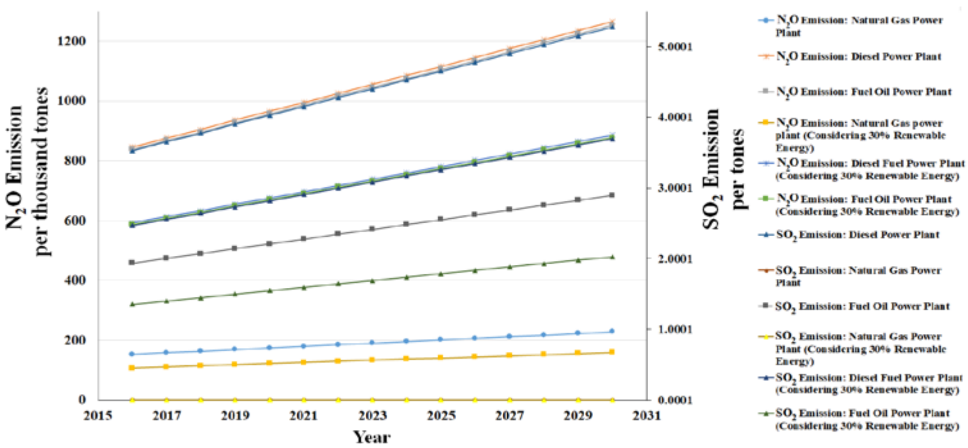

Figure 6. Comparing the amount of GHGs (N_2O and SO_2) emitted in the two scenarios presented.

CO_2 emissions due to the fossil fuel consumption of Iran in 2016 were approximately 642,560,030 tons, an increase of about 2.22 % annually, while the global proportion of Iran's CO_2 emission was almost 1.8 % [33]. Due to the lack of recorded carbon tax for Iran, taxes were compared with other countries based on the share of GHG emissions in each state from different regions of the world and the position of Iran in global CO_2 emission. Based on the published data, Iran has almost 1.8 % of the world's CO_2 emission. Therefore, the Iranian tax should be equal to Australia because of the approximately equal share of these countries in the field of CO_2 emission. The tax rate for each tone of CO_2 is USD 10 [34]. Figure 7 shows the predicted carbon tax rate in million USD.

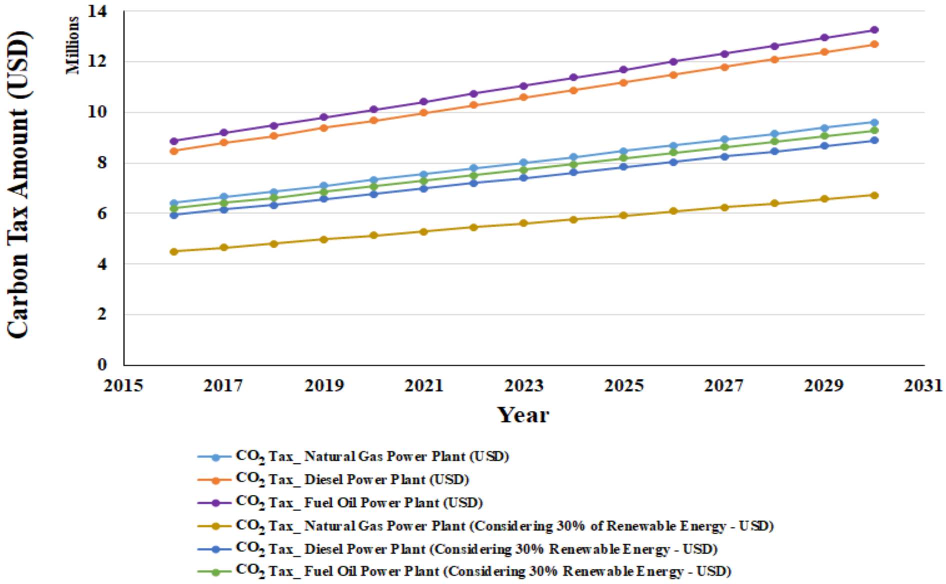

Figure 7. The carbon tax rate in USD from 2016 to 2030.

Mardones and Flores [35] concluded that a tax of up to 10 USD per ton of CO_2 did not significantly change the use of fuel in industrial sources in Chile. However, if the tax is between 10 and 30 USD per ton of CO_2, then GHG emissions will decline rapidly due to the social and economic impacts. Furthermore, by increasing this tax to more than 30 USD per ton of CO_2, it is expected that the emissions will be reduced. Therefore, it should be noted that a small amount of tax (almost one-third of the planned value) does not have a significant effect on reducing GHG emissions.

Figure 8 illustrates the consumed electricity cost in the six districts of Tehran Water and Wastewater Company in million USD, and Figure 9 presents the cost of electricity consumption in the two proposed scenarios. Based on the results obtained, by replacing 30 % of the fossil fuel used by Tehran Water and Wastewater Company with renewable energies, 5,987,086.482 USD would be saved during the years 2016 to 2030. Therefore, the use of renewable energy in the water and wastewater industry could enhance the domestic economy as well as reduce GHG emissions.

It should be stressed that carbon tax has had a significant effect on reducing energy consumption in modern countries. The main outcomes of these rules are the substantial progress of energy management, energy efficiency, and the distribution of renewable energies. This issue has been emphasized in various scientific publications and on energy statistic websites [33, 34]. Therefore, legislating carbon tax on polluting industries of Iran (such as Water and Wastewater Companies) will create a greater tendency to establish energy conservation methods, particularly using such renewable energies as the green electricity generators.

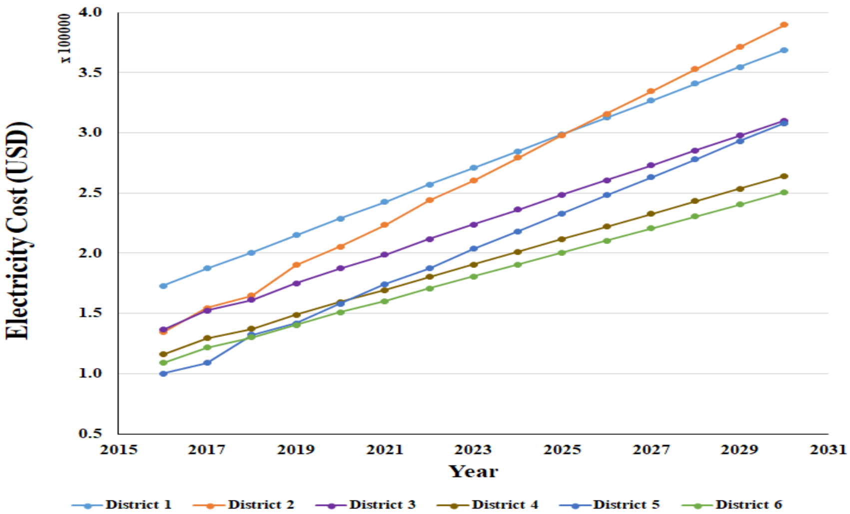

Figure 8. The electricity cost in six districts of the Water and Wastewater Organization.

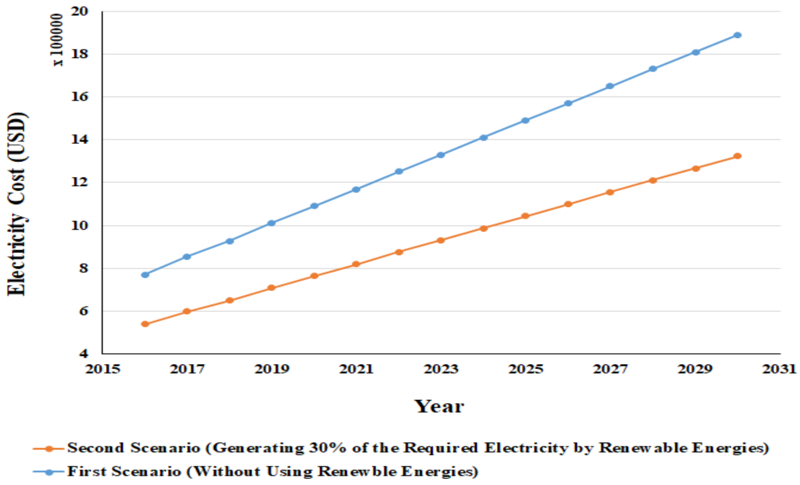

Figure 9. The electricity cost of the two proposed scenarios.

Figure 10 shows the electricity cost of the proposed scenarios considering the effect of the carbon tax, while Figure 11 indicates the difference between the two graphs on fossil energy use without renewable energy and fossil energy use with 30 % renewable energy (cost in millions of USD).

It should also be pointed out that the economic benefits of using a proportion of the alternative energies in the mentioned case study will increase over time, based on Figure 11.

Besides, Districts 2 and 5 have the highest priorities for energy consumption management in the case study due to the predicted rates of demand for water supply and, consequently, infrastructure development in these two districts of the company. Therefore, the substitution of conventional electricity generation with renewable energy generators should be started from these two districts to control the power costs of the company efficiently.

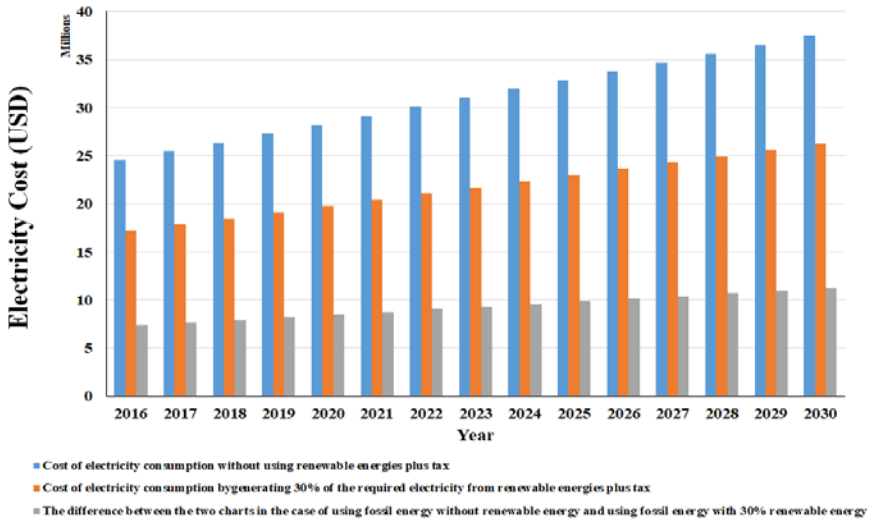

Figure 10. The electricity cost of the proposed scenarios considering the effect of the carbon tax.

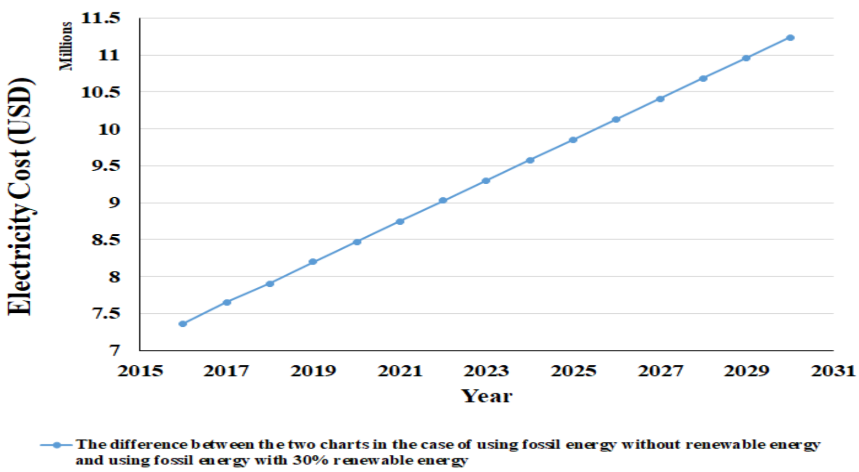

Figure 11. The difference between the two graphs on fossil energy use without renewable energy and fossil energy use with 30 % renewable energy (cost in millions of USD).

4. CONCLUSIONS

A comprehensive approach was mentioned in this study due to the current crisis in the field of high energy consumption to supply potable water and also sewage collection in urban applications. A significant potential to produce electricity from renewable energy sources is available in Tehran. For this reason, using some principal types of alternative energies such as solar, wind, and biomass can be specifically beneficial for the mentioned case study in this research. Urban water supply energy management is constrained by the attributes and realities of each city. In the presented research, the effective factors of energy consumption in Tehran Water and Wastewater Company were demonstrated. Moreover, a novel approach was proposed to predict the effect of renewable energy utilization in this sector on air pollution reduction.

Regarding the results, electricity consumption in the six districts of Tehran Water and Wastewater Company is a relatively straightforward trend, up to 2030. Therefore, the implementation of renewable energy and advanced technology was proposed for GHG mitigation potential in the power sectors. The presented approach offered sustainable potential of renewable energy technologies including solar, wind, and biomass power plants with carbon tax strategies. CO_2 emission will be decreased by about 30 % by replacing the conventional power plants with renewable energy plants based on the Tehran Water and Wastewater Company electricity demand.

Based on global warming issues, carbon tax which is one of the effective tools that a government imposes on any company that burns fossil fuels should be considered. For this reason, most debates are centered on oil, diesel, and natural gas-based power plants. The results showed that if carbon tax legislation contains tax imposition between 10 and 30 USD per ton of CO_2, an immediate reduction of greenhouse gas emissions will be predictable. Besides, by increasing carbon tax more than 30 USD per ton of CO_2, a significant decrease in air pollution of power generators will be expectable. Eventually, considering a fair amount of carbon tax is suggested to reduce GHG emissions due to energy consumption in water and wastewater companies.

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