RESEARCH ARTICLE

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Ondokuz Mayıs University drinking water treatment plant carbon footprint: emission sources and strategies for sustainability

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Abstract

In this study, it was aimed to calculate the carbon footprint of the drinking water treatment facility within Samsun Ondokuz Mayıs University and to determine the greenhouse gas emission sources within the facility. The total daily CO_2 emission of the drinking water treatment plant is calculated as 85.05 kg CO_2e/d. The analyses show that off-site CO_2 emissions are higher than on-site CO_2 emission values. It has been determined that the primary source of off-site emissions arises from the electrical energy consumption used in the units, constituting approximately 86.4% of the total CO_2 emissions. The second important contribution parameter arises from the reaction of coagulants in mechanical mixing processes. This study emphasizes the importance of taking measures that support greener and sustainable production to reduce the current greenhouse gas emissions of the facility. In addition, calculating the carbon emissions of the drinking water treatment plant is important in informing the relevant institutions in the European Union's efforts to achieve the goal of zeroing carbon emissions by 2050.

Keywords: Carbon footprint, Greenhouse gases, Drinking water treatment plant, Sustainable water management, Climate change

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INTRODUCTION

Climate change is a worldwide problem today. One of the main causes of climate change is greenhouse gases, and their amounts have continued to increase since the industrial revolution (Clabeaux Et Al., 2020; Coşkun & Doğan, 2021). Although it is stated that the activities that contribute the most to greenhouse gas emissions are in private sectors (iron or steel production and cement clinker production, etc.), it is known that public facilities such as incineration plants and water treatment plants release significant amounts of greenhouse gases (Bani Shahabadi et al., 2009). Recently, it has been known that water treatment plants consume a huge amount of electricity and chemicals, causing significant amounts of CO_2 emissions (Rothausen & Conway, 2011). Although CH_4 and N_2O emissions from drinking water treatment plants are much less than those from wastewater treatment plants, annual greenhouse gas emissions cannot be ignored (Kyung et al., 2013). In the near future, treatment plants will likely be strictly regulated and controlled by protocols. Therefore, CO_2 emissions from water treatment plants must be reduced quickly and managed appropriately.

Carbon footprint calculation is required to reveal the hidden environmental impact of the drinking water treatment plant and take a more environmentally friendly approach to water consumption. Carbon footprint is used to define the amount of greenhouse gas emissions in terms of CO_2 equivalent caused directly and indirectly by an individual, product, industry, city, and region over a certain period (Karakaş, 2021; Yüksel, 2017). Although direct comparison of findings is somewhat complicated due to different system boundaries, water sources, treatment steps, functional units, and methods in drinking water treatment plants, overall, the use of electricity and chemicals are the main contributors to the carbon footprint in drinking water production (Bonton et al., 2012; Hofs et al., 2022). Nowadays, due to the increasing sensitivity to the environment, the calculation of carbon emissions as carbon footprints and the carbon zeroing policies of industries have begun to be used frequently. It is aimed to reduce negative impacts and emissions by making carbon footprint calculations in many sectors and areas. Carbon footprint calculations have gained importance in our country due to the green agreement process and circular economy studies. In this context, the "Regulation on the Monitoring of Greenhouse Gas Emissions" published by the Ministry of Environment, Urbanization and Climate Change in the Official Gazette No. 29003 in May 2014 came into force (Ministry of Environment, 2014). According to this regulation, industries and businesses that need to monitor greenhouse gases are required to submit their "Greenhouse gas monitoring and emission" plans to the Ministry of Environment, Urbanization and Climate Change. However, treatment facilities are excluded from the regulation and notification. However, treatment facilities have greenhouse gas emissions and need to develop policies to reduce them.

The carbon footprint of drinking water involves a complex web of factors, including water collection, treatment, distribution, and waste management. Each of these stages can directly or indirectly contribute to greenhouse gas emissions. Studies on the carbon emissions of drinking water treatment plants are few, other than life cycle assessment, and there is a serious gap in the literature (Hofs et al., 2022; Vince et al., 2008). These studies compare the carbon footprints of drinking water facilities using conventional and advanced treatment (Bonton et al., 2012; Kyung et al., 2013). Recently, it has become important to reduce CO_2 emissions by providing basic information about important carbon emission sources and their emission amounts with a life cycle assessment approach or mathematical models (Bani Shahabadi et al., 2010; Larsen, 2015; Yan et al., 2014). The correct mathematical model can be selected by deciding on the facility optimization and treatment units. In this context, first of all, the treatment units of the facility must be determined in detail, and then the emission sources inside and outside the facility must be determined. The uniqueness of this study is that although the carbon emissions of wastewater treatment facilities (Güller & Balcı, 2018; Karakaş, 2021) have been calculated in our country, the carbon emissions of drinking water treatment facilities have not been calculated. This study is the first study conducted in our country and aims to set an example for other studies.

In this study, it was aimed to calculate the carbon footprint of the drinking water treatment facility located at Ondokuz Mayıs University (OMU), which is taking firm steps towards becoming a green university. For this purpose, a mathematical model developed by the South Korean government is planned to be used to determine on-site and off-site CO_2 emissions of drinking water (Korea Water Resources Corporation, 2017). It is aimed to provide basic information about CO_2 emission sources by detecting on-site and off-site emissions occurring in the drinking water treatment plant and to provide suggestions for reducing CO_2 emissions efficiently.

MATERIALS AND METHODS

Study area

OMU Kurupelit Campus has an area of 8 thousand 800 decares and has 58 thousand students, 2 thousand 348 academic staff, and 3937 employees, and clean water is delivered to the faculties from the drinking water treatment facility within the university. OMU drinking water treatment plant was established approximately thirty-five years ago to provide clean water to the campus. It has undergone many renovations and revisions over time. Raw water to the facility comes from the Karakavuk pond, located 8.5 km away, and the facility purifies the flow rate of 122 m^3/h daily. Physicochemical measurement results of raw water values coming to the facility are given in Table 1.

Calculation and determination of system limits

In this study, the mathematical model developed by the South Korean government was used to calculate the carbon emissions of the classical drinking water treatment plant (Korea Water Resources Corporation, 2017). It was aimed to estimate the on-site and off-site CO_2 emissions generated in the drinking water treatment plant. In-site CO_2 emissions are defined as emissions resulting from mechanical mixing processes (rapid and slow mixing) and chemical reactions such as the addition of alum ($Al_2(SO_4)_3.18H_2O$). Off-site CO_2 emissions include electricity consumption for treatment units. CH_4 and N_2O emissions were not considered in the model because they are rarely produced in drinking water treatment plants. Additionally, since the amount of sludge generated in the facility is low, no energy is consumed for sludge disposal, and it is discharged to the receiving environment. The production and transportation of chemicals coming to the facility are not included in the system boundaries. The boundaries and emission paths of the OMU drinking water treatment plant system are shown in Figure 1. The operating conditions and parameters of the drinking water treatment plant were used to inform the model that calculates CO_2 emissions. The operating conditions and parameters of the drinking water treatment plant used for input data for the model are given in Table 2.

Table 1. Physicochemical measurement results of raw water coming to the facility.

Parameters	Raw water
pH	8.00
Turbidity (NTU)	64.3
Conductivity (µs/cm)	136.6
Hardness (mg/L)	21
Total suspended solid (mg/L)	80.6
Salinity (‰)	0.1
Temperature (°C)	14
Nitrate nitrogen (NH_3-N)	10.91
Chlorine (Cl^-)	0
Sulfate ($SO4^{-2}$) (mg/L)	100
Manganese (Mn^{+2}) (µg/L)	55
Iron (Fe^{+2}) (µg/L)	680
Aluminum (Al^{+3}) (mg/L)	15
Dissolved oxygen (mg/L)	10.46
Total organic carbon (TOC) (mg/L)	2.91

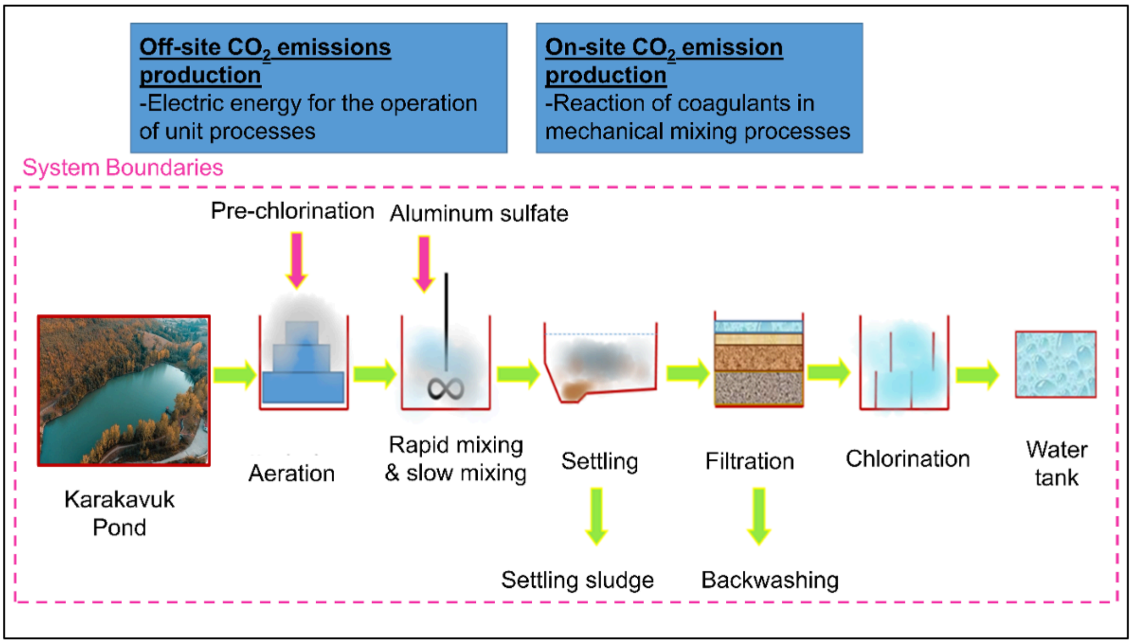

Figure 1. System boundaries and emission sources of OMU drinking water treatment plant.

Table 2. Physicochemical OMU drinking water treatment plant operating conditions and parameters.

Operating Conditions	Symbol	Parameter
Flow	Q_{flow}	2928 m^3/d
input blur	$Turb._{inlet}$	64.3 NTU
Output blur	$Turb._{outlet}$	0.49 NTU
Heat	T	14 °C
water density	P_{water}	998.2 kg/m^3
Operating Parameters		
Chemicals		
Added aluminum sulphate flow rate	Q_{chem}	0.5 m^3/d
Added sodium hypochlorite flow rate	Q_{NaClO}	0.2 m^3/d
Pumping pressure	Pr_{chem}	2 kPa
Operating time	t	24 sa/d
Aluminum sulfate density	P_{alum}	2670 kg/m^3
Sodium hypochlorite density	P_{NaClO}	1110 kg/m^3
Rapid mixing		
Electricity consumption	$E_{rapid\ mixing}$	36 kWh
Slow mixing		
Electricity consumption	$E_{slow\ mixing}$	18 kWh
Backwasing		
Electricity consumption (for 3 motors)	$E_{backwashing}$	36 kWh
Other consumptions		
Building lighting and dosing pumps	E_{others}	9 kWh

On-site CO_2 emissions

On-site CO_2 emissions are mainly due to alkalinity production during chemical reactions in the mechanical mixing process of coagulants (aluminum sulfate) and buffer anions (CO_3^{2-} and HCO_3^-). Equation 1 shows the formation of CO_2 emissions due to the reaction of aluminum sulfate with calcium bicarbonate.

$$Al_2(SO_4)_3.18H_2O + 3Ca(HCO_3) \rightarrow 2Al(OH)_3 \downarrow + 3CaSO_4 + 6CO_2 + 18H_2O \qquad (1)$$

To calculate on-site CO_2 emissions, the utilization of aluminum sulfate as a coagulant was considered, incorporating a CO_2 emission factor (EF_{chem}) based on stoichiometric mass balance. For aluminum sulfate, this factor is taken as 0.395 g CO_2e/g. Aluminum sulfate concentration was calculated by multiplying by the total flow rate to determine the total mass of aluminum sulfate used during the process. Daily CO_2 emissions from chemical reactions within the facility were calculated with Equation 2 (Kyung et al., 2013).

$$p_{co_2,chemical}=(C_{chem}\, x Q_{flow}\ x\ 10^3 Lm^{-3}\ x\ 10^{-6} kgmg^{-1})x\ EF_{chem} \qquad (2)$$

where is on-site CO_2 emission by chemical reaction (kg CO_2e/d), C_{chem} is concentration of coagulant (mg/L), Q_{flow} is flow rate (m^3/d), and EF_{chem} is CO_2 emission factor of coagulant (gCO_2e/g).

Off-site CO_2 emissions

CO_2 emissions related to electricity consumption

Off-site CO_2 emissions converted from electricity consumption used to operate the units in the drinking water treatment plant were calculated as given in Equation 3. Total emissions of the units were calculated using 0.7424 kgCO_2e/kWh (TEIAS, 2023) as the CO_2 emission factor (EF_{elec}) for electricity consumption. In the calculations, chemical feed includes rapid and slow mixing and backwashing. Rapid mixing, slow mixing, and backwashing electrical consumption data were obtained from the drinking water treatment plant. Electricity consumption for sludge transport is not included in the calculations. Because the sludge of the drinking water treatment plant is discharged into the stream right below the facility. Calculations were made for electricity consumption and CO_2 emissions, assuming the efficiency of the pump, motor, and gear was 85%. Electricity consumption data of each unit was obtained from the drinking water treatment plant.

$$p_{co_2,electricity} = \sum[(E_{chemical\ supply} + E_{rapid\ mixing} + E_{slow\ mixing} + E_{backwashing} + E_{others})\ x\ EF_{elec}] \quad (3)$$

where is off-site CO_2 emission by electricity consumption (kg CO_2e/d), $E_{chemical\ supply}$ is energy consumption for chemical supply (kWh/d) $E_{rapid\ mixing}$ is energy consumption for rapid mixing (kWh/d), $E_{slow\ mixing}$ is energy consumption for slow mixing (kWh/d), $E_{backwashing}$ is energy consumption for backwashing (kWh/d) and EF_{Elect} is CO_2 emission factor for electricity generation (kgCO_2e/kWh).

Electricity consumption for chemical supply

Various chemicals are used to meet water quality standards during the operation of a drinking water treatment plant. Aluminum sulfate (Alum) coagulant was added during the rapid mixing process for effective floc formation. Sodium hypochlorite was added for disinfection. Off-site emissions during the production and transportation of chemicals used in drinking water treatment plants are calculated in Equation 4 (Kyung et al., 2013).

$$E_{chemical\ supply} = \sum\ (Pr_{chem}\ x\ Q_{chem}\ x\ t_{chem}\ x\ Eff_p^{-1}\ x\ 86400^{-1}) \quad (4)$$

Where $E_{chemical\ supply}$ is energy consumption for chemical supply (kWh/d), Pr_{chem} is chemical supply pump pressure (kPa), Q_{chem} is feed rate of chemical (m^3/d), t_{chem} is process operating time (hr/d), and Eff_p is efficiency of operating pump.

RESULTS AND DISCUSSION

On-site CO_2 emissions calculations

On-site CO_2 emissions occurred only due to alkalinity formation during chemical reactions in the mechanical mixing process of aluminum sulfate and buffer anions (CO_3^{2-} and HCO_3^-). The CO_2 emission factor for aluminum sulfate used in the drinking water treatment plant is 0.395 gCO_2e/g (Ecoinvent, 2019). Accordingly, when all the data were put into equation 2, the amount of CO_2e within the facility was 11.56 kgCO_2/d. Chemical selection in drinking water treatment plants is a factor that significantly affects the carbon footprint, especially for the coagulation unit. Generally, Fe coagulants have lower CO_2 emissions than Al coagulants. Emissions from producing Fe coagulants range from 29 to 395 kgCO_2e per ton, while Al coagulants range from 148 to 537 kgCO_2e per ton (INCOPA, 2014). This difference is due to factors such as the type of raw materials used (natural mineral or by-product), the processing method in the production process, and where the raw material is produced (Pellikainen et al., 2023).

Table 3. On-site CO_2 emissions due to chemical use.

Chemical	Dossage rate	Flow (m^3/d)	Emission factor[a] (kgCO_2e/kg)	CO_2e emission (kgCO_2e/d)
Aluminum sulfate	10	2928	0.95	11.56

[a]Ecoinvent 2019

Off-site CO_2 emissions calculations

CO_2 emission calculation based on off-site electricity consumption

Calculating CO_2 emissions from off-site electricity consumption requires a separate calculation for each unit, calculating chemical supply and then calculating total emissions. In this context, first, the CO_2 emissions of the chemical supply were calculated. The main energy consumption in chemical feed comes from the operation of injection pumps, and the total energy consumed by chemical feed is significantly affected by pumping pressure, feed rates of chemicals, operating time, and pump efficiency. Calculations were made for electricity consumption and CO_2 emissions, assuming the efficiency of the pump, motor, and gear was 85%. Accordingly, when the calculations related to the total chemical supply were made according to Equation 4, the electricity consumption was found to be $4.57x10^{-4}$ kWh. Rapid mixing, slow mixing, backwashing, and other off-site electricity consumption data are given in Table 4. As shown in Equation 3, by multiplying the total electricity consumption with the CO_2 emission factor for electricity consumption, 0.7424 kgCO_2e/kWh, the amount of CO_2e due to the total electricity consumption was calculated as 73.49 kgCO_2.

Table 4. Off-site CO_2 emissions due to electricity consumption.

Process	Electricity consumption	Emission factor[a] ($kgCO_2e/kWh$)	CO_2e emission ($kgCO_2e/d$)	Percentage (%)
Chemical supply	$4.57x10^{-4}$	0.7424	$3.40\ x10^{-4}$	0.0004
Rapid mixing	36	0.7424	26.72	35.88
Slow mixing	18	0.7424	13.37	18.19
Backwashing	36	0.7424	26.72	35.88
Other consumption	9	0.7424	6.68	9.08

[a]T.C. Energy and Natural Resources Ministry, 2023

CO_2e emissions during drinking water treatment plant operation were calculated as in-site and off-site emissions, and each category's contribution percentage and CO_2e emissions are given in Table 5 and Figure 2.

Table 5. Total on-site and off-site CO_2e emissions of the drinking water treatment plant and percentage distribution of each category.

Emission type	Category	Emission ($kgCO_2e/d$)	Percentage (%)
In-site CO_2 emissions	Chemical reaction	11.56	13.6
Off-site CO_2 emissions	Electricty consumption	73.49	86.4
Total CO_2 emissions		85.05	100

The results show that the most significant CO_2 emissions come from electricity consumed at the facility. The electrical energy used in the units releases 73.49 $kgCO_2e/d$ of CO_2 outside the facility, constituting 86.4% of the total value. In emissions related to electricity consumption, the highest CO_2 release occurred in rapid mixing and backwashing to treat raw water with a flow rate of 2928 m^3/d. During the rapid mixing and filtration unit backwashing process, 26.72 $kgCO_2e/d$ emissions related to electricity consumption occurred for each unit. This is thought to be due to the mechanical mixing of impellers with high rotation speed to maintain the appropriate speed gradient for the rapid mixing process, while for the backwash process, it is due to the electrical energy used by the backwash pump and air blowers. CO_2 release from electricity consumption in the slow mixing process is 13.37 $kgCO_2/d$. Finally, CO_2 emissions due to off-site electricity consumption arise from electricity consumption in the chemical supply process. The contribution to CO_2 emissions at this stage is 3.40 x 10^{-4} $kgCO_2/d$ and is negligible. This is because the pumps feeding the chemicals are operated at very low pressure compared to other processes and consume less electrical energy.

Upon investigation of on-site CO_2 emissions, it was found that the CO_2 emission attributed to the chemical reaction during this stage amounted to 11.56 $kgCO_2/d$. When aluminum sulfate is used as a coagulant, on-site CO_2 emissions from chemical reactions constitute a small portion (13.6%) of the total on-site and off-site CO_2 emissions. It has been determined that CO_2 production in the aqueous phase based on stoichiometric mass balance is directly related to the consumption of buffer anions. Different coagulant substances (powdered activated carbon, iron sulfate, etc.) can be tried to reduce the CO_2 emissions resulting from the chemical reaction (Zamfiroiu & Masu, 2007). In this way, it is thought that CO_2 emissions can be reduced with advantages such as less sludge production and less use of chemicals. Although on-site CO_2 emissions are very small, CO_2 emissions can be significantly reduced by low alkalinity consumption and appropriate coagulation dosages to reduce on-site emissions in drinking water treatment plants (Pellikainen et al., 2023).

When the literature is examined, there are few studies on the carbon footprint calculation of drinking water treatment plants (Yateh et al., 2024). There are studies mostly aimed at calculating the carbon footprint of wastewater treatment plants. Nevertheless, there are studies in the literature to reduce the carbon emissions of drinking water treatment facilities. One of them, Kyung et al. (2013), is their study. This study compared the carbon emissions of classical and advanced drinking water treatment plants. Carbon emissions were found to be higher in the advanced drinking water treatment plant because the membrane and ozonation unit are additional processes. Similar to the presented study, off-site carbon emissions were found to be higher in both drinking water treatment plants. However, the carbon footprint of the classical wastewater treatment plant was higher than that of the presented study. One of the most important reasons is that the flow rate to the facility is very high. Beeftink et al. (2021)estimated carbon emissions for drinking water treatment plants using the softening method and found that chemical consumption increased electrical energy consumption. Maziotis et al. (2023) calculated in another study that the total drinking water emissions associated with electricity consumption across the USA were 26.5×10^9 $kgCO_2e$. They found that water and wastewater electricity generation contributes 2% of total greenhouse gas emissions each year.

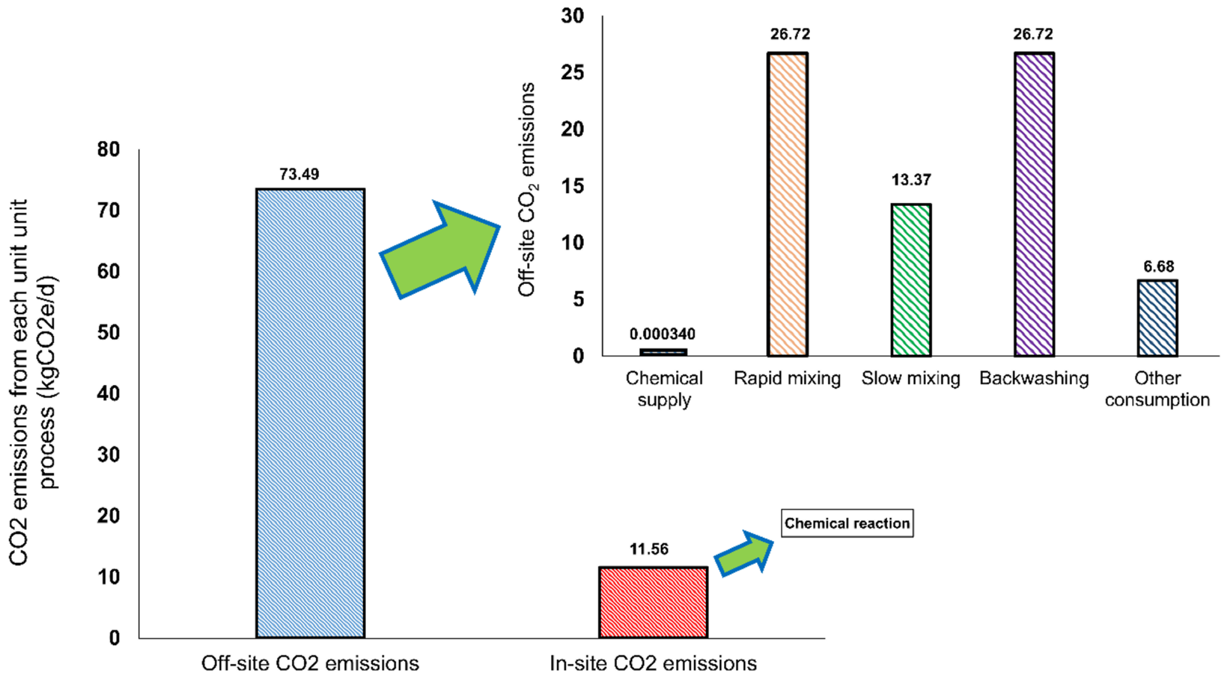

Figure 2. The CO_2 emissions from each unit process of the drinking water treatment plant

CONCLUSION

This study calculated the carbon footprint of the drinking water treatment facility within Samsun Ondokuz Mayıs University, which supplies clean water to the campus. In this context, the drinking water treatment plant's on-site and off-site CO_2 emissions were calculated. Accordingly, the total CO_2e emission of the drinking water treatment plant is 85.05 kg CO_2e per day, and the annual amount is estimated to be approximately 31.04 tons CO_2e. In the study, it was determined that the facility's primary source of CO_2 emissions occurred during electrical consumption. To reduce carbon emissions caused by electricity consumption, air blowers, pumps, etc., consume less electricity, and it is recommended to use equipment. Switching to electricity production from renewable sources (wind, solar, biomass, etc.) will help reduce carbon emissions. Within the scope of the European Union Green Deal, Turkey aims to reduce greenhouse gas emissions by 55% in 2030 and become carbon neutral in 2050. In this context, preventing and reducing greenhouse gas emissions from drinking water and wastewater treatment facilities is important. Treatment plants must pursue new green and sustainable water treatment technologies with high pollutant removal efficiency and low CO_2 emissions. Considering greenhouse gas emission issues in the water treatment sector is important for understanding the relationship between water quality and greenhouse gases. This study is thought to be a good example of preventing greenhouse gas emissions in public regulations regarding authorities' treatment facilities.

COMPLIANCE WITH ETHICAL STANDARDS

Peer-review

Externally peer-reviewed.

Conflict of interest

The author has declared no conflict of interest.

Author contribution

Sevde Üstün Odabaşı: conceptualization; investigation; methodology; data curation funding acquisition; writing-review & editing.

Ethics committee approval

Ethics committee approval is not required.

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Data availability

Data available on request from the authors.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

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