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Research Paper

Estimated Carbon Footprint for the Construction and Operational Phases of a Wastewater Treatment Plant

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Abstract: In this paper, the carbon footprint of the construction and operational phases of a WWTP in Giresun was evaluated in accordance with TSE EN ISO 14064 Guidelines for Calculation of Greenhouse Gases, within the framework of GHG Protocol standards and CCaLC2 software. The carbon footprint of the plant during the construction phase was calculated as 1077.55 tCO_2e for 2022 and 1110.52 tCO_2e for 2023. The estimated carbon footprint for operational phase was determined to be 800.64 tCO_2e. The primary contribution to greenhouse gas emissions stems from fuel consumption and wastewater treatment for construction and operational phases, respectively. The calculated carbon footprint value was relatively low compared to other WWTPs reported in the literature, primarily due to the lack of real-time operational data. However, the research incorporating both design data and operational data from the plant will further elucidate the findings of this study and enable the examination of carbon footprints under various operating conditions.
Keywords: *carbon footprint, greenhouse gas, emission, energy, wastewater.*

Introduction

Water is a fundamental element of life and is indispensable for the sustainability of ecosystems and human health. Increasing population, industrialization, agricultural and urbanization processes intensify pressure on water resources, leading to water scarcity and pollution problems. Wastewater, which refers to polluted water because of domestic, industrial and agricultural activities, can cause serious environmental problems if discharged directly to receiving environments. In this context, wastewater treatment plants (WWTPs) play a critical role in protecting water resources, securing human health and sustainability of ecosystems. Furthermore, with the escalating climate crisis, energy saving and energy efficiency have become more prominent. WWTPs are recognized as significant energy consumer and sources of greenhouse gas (GHG) emissions (Campos *et al.*, 2016; Chai *et al.*, 2015; Goliopoulos *et al.*, 2022; Robescu & Presură, 2017). Energy consumption in WWTPs is influenced by factors such as location, size, extent of the sewerage network, treatment configuration, aeration type, equipment energy efficiency and overall WWTP efficiency. Aeration, a primary energy-consuming component, accounts for 25-60% of total energy consumption (Goliopoulos *et al.*, 2022). The energy consumption of WWTPs is estimated to be about 4% of the electricity consumption of the water industry, depending on the country. (Goliopoulos et al., 2022; Gupta et al., 2024). According to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report, the global GHG emissions from the waste/wastewater sector constituted 3.9% of 59 $GtCO_2e$ total emissions in 2019 (IPCC, 2022). GHG emissions from WWTPs can originate from direct sources, such as the sewage collection system, treatment processes, and disposal, and indirect sources, such as electricity consumption, transportation of various chemicals and sludge, consumption of chemicals, disposal of residues (Goliopoulos *et al.*, 2022) (Karakas et al., 2024). WWTPs directly produce various GHGs, such as carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), as a result of treatment and directly contribute to CO_2 and methane emissions through energy consumption (Campos *et al.*, 2016; Chai *et al.*, 2015; Goliopoulos *et al*., 2022). However, direct CO_2 emissions from WWTPs are often excluded in the calculation of GHG emissions as they are deemed part of the natural carbon cycle (biogenic origin). For that reason, CO_2 emission sources in WWTPs are primarily related to energy consumption (Karakas et al., 2024).

The environmental impacts of WWTPs are not limited to the operational phase; the construction phase of the plant can also contribute significant carbon emissions, although typically less than the operational phase (Chai *et al.*, 2015). In general, the construction industry, a significant contributor to

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global GHG emissions, has a substantial impact on global warming (Arıoğlu Akan *et al.*, 2017; Hammond and Jones, 2008; Hong et al., 2015; Labaran et al., 2021; Purnell and Black, 2012). It has been reported that the building and construction sector contributed to approximately 37% of global carbon emissions in 2022 (United Nations Environment Programme, 2024) (Wang et al., 2022) Emissions during the construction phase of WWTPs generally result from various activities such as material production, transportation, the use of construction vehicles, and land preparation. On-site electricity use and the production of construction materials are the two largest contributors to GHG emissions (Hong et al., 2015; Purnell and Black, 2012; Stokes and Horvath, 2006) Assessing carbon emissions during the construction phase is also important to more comprehensively understand the environmental impacts of WWTPs throughout their lifecycle and to develop mitigation strategies.

Carbon footprint analysis serves as a critical tool for evaluating the climate change impact of WWTPs. It also facilitates the identification of strategies to reduce GHG emissions and the evaluation of their effectiveness. In general terms, carbon footprint is the measurement of the amount of GHGs generated because of the activities, expressed in units of CO_2e. GHG emission sources that contribute to the carbon footprint can be analysed in two categories: direct and indirect. Direct sources are CO_2 emissions from the use of fossil fuels, including energy consumption related to electricity, fuel, transportation, etc., while indirect sources are CO_2 emissions from the production of materials used and the eventual degradation of these products (Karakas *et al.*, 2024).

Different standards and methods can be used in the calculation of a carbon footprint. The most widely accepted methodologies in this field are the Greenhouse Gas Protocol (GHG), prepared by the Business Council for Sustainable Development and ISO 14064 Greenhouse Gas Calculation and Verification Management System, published by the International Organization for Standardization. In GHG inventory calculations, data are generally evaluated using IPCC Tier-1 and Tier-2 methodologies and ANNEX, DEFRA conversion factors, within the framework of the GHG Protocol and ISO 14064 standard (IPCC, 2006; Lin, 2020; Tosun and Tunç Dede, 2024; TSE, 2019a, 2019b). Another method encountered in the literature is the CCaLC2 program, created by the University of Manchester based on ISO 14044 and PAS 2050 rules, which aims to perform life cycle analysis (Azapagic, 2012).

The present research forecasts the environmental impacts of the construction and operational phases of the WWTP under construction in Batlama Neighbourhood of Central District of Giresun Province. The GHG of construction phase of a WWTPs are limited in the literature and the available studies are mainly focused on the operational phases. This study aims to present a holistic overview of the WWTP's energy consumption and GHG emissions during both construction and operational phases and could shed light on the WWTP, energy and GHG emission relationship.

Materials And Methods

Study Area

The WWTP is situated in the west-central part of Giresun city, Turkiye. The plant covers an area of approximately 2.2 hectares (ha) in the central Batlama district. The land elevation varies between 5-25 m, and approximately 2 ha are located on nearly flat terrain. The distance of the land to the coast is approximately 300 m. The plant will treat domestic and industrial wastewater collected by the combined sewer system of Giresun city centre. The design parameters of the WWTP are 141 982 population equivalents (PE), with a daily flowrate of 19 653 m^3/day. A general view of the WWTP is given in Fig. 1. The WWTP is designed to incorporate a coarse screen, inlet pumping station, fine screen, grit and grease removal, primary sedimentation tank, anaerobic mixing tanks, activated sludge tank, membrane bioreactor (MBR) units, secondary sedimentation tank, disinfection, and filtration units. The plant is currently under construction and is planned to be operational after March 2025. GHG emissions from the construction phase are calculated based mainly on energy consumption, while GHG emissions for the operational phase are calculated based on feasibility report data.

Carbon Footprint Calculations

Within the scope of this study, the carbon footprint of the Giresun WWTP, currently under construction in Batlama, Central District of Giresun Province, was assessed. GHG emissions and carbon footprint calculations for the construction and operational phases of WWTP were determined according to TSE EN ISO 14064 Guidelines for the Calculation of Greenhouse Gases and CCaLC2 software within the framework of GHG Protocol standards (IPCC, 2006; TSE, 2019b, 2019a, 2019c). The CCaLC2 program was developed by researchers at the University of Manchester to calculate the carbon footprint of products over their life cycle as a part of project. This software, developed within the scope of a project, divides the sectors that produce carbon emissions into groups. Within the program's interface, the product life cycle is analysed in four sections: raw materials, production, storage and use. The waste component is divided into sub-sections within each section. The program includes a database on wastewater treatment, and the carbon emission value of sewage sludge is automatically calculated according to the amount of sludge. The researcher follows ISO 14044 and PAS 2050, the internationally accepted life cycle methodology, for the development of the program and supported with over 50 case studies (Azapagic, 2012). The potential direct and indirect sources of GHG emissions from the construction and operational phases of any WWTP can be summarized as shown in Table 1.

Figure 1. The general view of the Giresun WWTP

Considering the information provided in Table 1, GHG emission and carbon footprint calculations of Giresun WWTP were conducted separately for the construction and operational phases. The available data on the WWTP primarily included energy consumption data, and the calculations focused on GHG emissions resulting from energy consumption. For the construction phase, the years 2022 and 2023 were used as a baseline, and data on electricity consumption, fuel consumption of construction vehicles and rental vehicles were used. All data used in the calculations were declared by the authorities of the construction company. Other data (construction materials, transportation, etc.) were not included in the calculations due to their unavailability.

For the operational phase, since the plant is still under construction, calculations were made based on the feasibility report and in line with the available data declared by construction company (electricity use, amount of wastewater treated, use of polyelectrolyte and $FeCl_3$ chemicals, sludge formation and disposal) for the planned operation of the plant. The formulas and the emission factors used in the calculations were determined according to relevant guidelines and are presented in Table 2.

Results and Discussions

Assessment of the carbon footprint for construction phase

The activities that may cause emissions during the construction phase of the Giresun WWTP are primarily fuel consumption, electricity consumption, building materials production, and construction waste generation. Within the scope of this paper, fuel consumption (both direct and indirect) and electricity consumption data were included in the carbon footprint calculations. Due to the unavailability of detailed information on building materials and waste, these data could not be incorporated into calculations. The carbon footprint of the Giresun WWTP during the construction phase was calculated for the years 2022 and 2023 by determining the carbon dioxide equivalents (tCO_2e) of GHG emissions. Emission values for 2022 and 2023 are tabulated in Table 3 and Table 4, respectively. In 2022 and 2023, the construction company reported an average daily fuel consumption of 1000 L for construction vehicles and 100 L for rental vehicles. As all construction vehicles and rental vehicles used diesel fuel, calculations were made accordingly, using the annual fuel consumption amounts, assuming 360 working days per year based on information received from company authorities. The annual electricity consumption were 56 026 kWh and 125 000 kWh for 2022 and 2023, respectively. Based on Table 3, the total GHG emission from the WWTP during the construction phase in 2022 was determined to be 1077.55 tCO_2e. The emission sources and their percentage contribution are visualized in Fig(2). As illustrated, the largest contribution to GHG emissions originated from the fuel consumption of construction vehicles, accounting for 88.6% of the total in 2022. This was followed by emissions from indirect consumption, contributing 8.9% and emissions from electricity consumption with 2.5%.

Table 1. Possible sources of GHG emissions from construction and operational phases of WWTPs (Chai et al., 2015; Hong et al., 2015; Labaran et al., 2021; Parravicini et al., 2016)

	Source of Direct GHG Emissions	Source of Indirect GHG Emissions
Construction phase	- Energy consumption of construction vehicles - On-site transportation - Construction electricity usage - Construction chemical use - On-site worker activities	- Construction materials (production, transportation, demolition and other non-building activities) - Transportation of construction vehicles - Off-site worker activities (electricity use, transportation, other necessities)
Operational phase	- Wastewater collection system - Treatment process • *CO_2 emissions from organic matter degradation* • *N_2O emissions from the nitrification/ de-nitrification process* • *CH_4 and N_2O emissions from anaerobic digestion* - Discharging	- Electricity usage - Chemical and additives usage -Transportation (chemicals, sludge) - Sludge final disposal

Table 2. The factors used in the calculation of GHG emissions (IPCC, 2022, 2006; TUIK, 2024)

Factors	Source	Emissions			
Consumption data	Scope 1: Transportation (work vehicle)	Diesel			
	Scope 2: Electric	Electricity			
	Scope 3: Transportation (rental vehicles	Diesel			
Emission	GHG = Activity data x emission factor	Diesel[1]	CO_2 (kg/TJ)	CH_4 (kg/TJ)	N_2O (kg/TJ)
			74 100	3	0.6
		Electric[2] (kg/kWh)		0.478	
Net calorific value[3]	Fuel type	Diesel (TJ/Gg)		43.0	
Global warming potential (GWP)[4]	Greenhouse gas type	CO_2: 1 CH_4: 27 (non-fossil) and 29.8 (fossil) N_2O: 273			
Density	Fuel type	Diesel: 0.83 kg/m^3			
Percentage of oxidized carbon[5]	Fuel type	Diesel: 0.984=1 (In IPCC Tier-1 approaches, all values are taken as 1)			
Emission (E)	E = FV x EF x YF	FV: Activity data EF: Emission factor (kg/TJ) YF: Oxidation factor			
	FV = Fuel amount x NKD	NKD: Net calorific value (TJ/Gg)			

[1] Tablo 2.2 Default Emission Factors for Stationary Combustion in the Energy Industries from IPCC Report (IPCC, 2006)
[2] Electricity Consumption Point Emission Factors (The Ministry of Energy and Natural Resources, 2024a).
[3] Table 3.17 Average NCVs of fuels from Turkish Greenhouse Gas Inventory 1990 – 2022 (The Ministry of Energy and Natural Resources, 2024b).
[4] IPCC Report - Climate Change 2022 (IPCC, 2022)
[5] Table 3.6 Country specific oxidation factor of fuels from Turkish Greenhouse Gas Inventory 1990 – 2022 (The Ministry of Energy and Natural Resources, 2024b).

Table 3. Carbon emission values for the construction period of WWTP for 2022

Energy source		Density	Consumption	NKD	Energy Consumption	Emission Factor	Emission	Percent of oxidized carbon	GWP	CO_2 Emission
		(kg/m^3)	(kg)	(TJ/Gg)	(TJ)	(kg/TJ)	(t)			(tCO_2e)
CO_2 emissions from construction vehicles										
CO_2	Diesel (L) 360 000	0.83	298 800	43	12.85	74 100	952.18	1	1	952.18
CH_4	Diesel (L) 360 000	0.83	298 800	43	12.85	3	0.038	1	29.8	1.13
N_2O	Diesel (L) 360 000	0.83	298 800	43	12.85	0.6	0.007	1	273	1.91
								Total emission (tCO_2e)		**955.22**
CO_2 emissions from energy consumption										
Electric (kWh)	56 026					0.478 (kg/kWh)				26.78
								Total emission (tCO_2e)		**26.78**
Indirect consumption (rental cars)										
CO_2	Diesel (L) 36 000	0.83	29 880	43	1.285	74 100	95.22	1	1	95.22
CH_4	Diesel (L) 36 000	0.83	29 880	43	1.285	3	0.0038	1	29.8	0.11
N_2O	Diesel (L) 36 000	0.83	29 880	43	1.285	0.6	0.0008	1	273	0.22
								Total emission (tCO_2e)		**95.55**
								Total CO_2 emission for 2022 = 1077.55 tCO_2e		

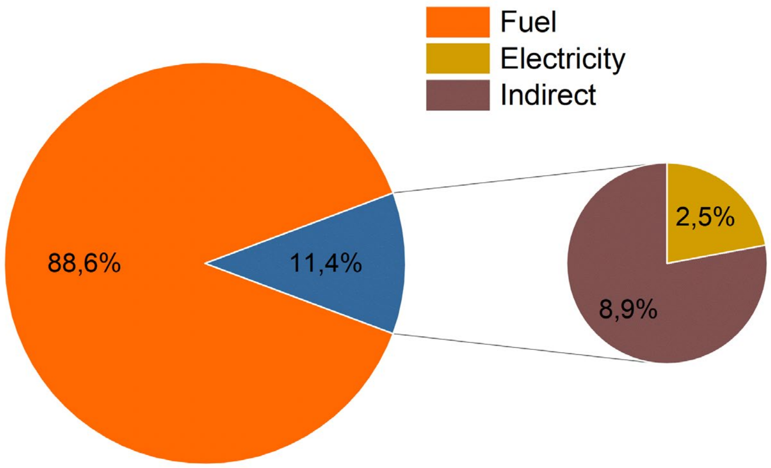

Figure 2. The distribution of emission sources for construction phase of WWTP in 2022

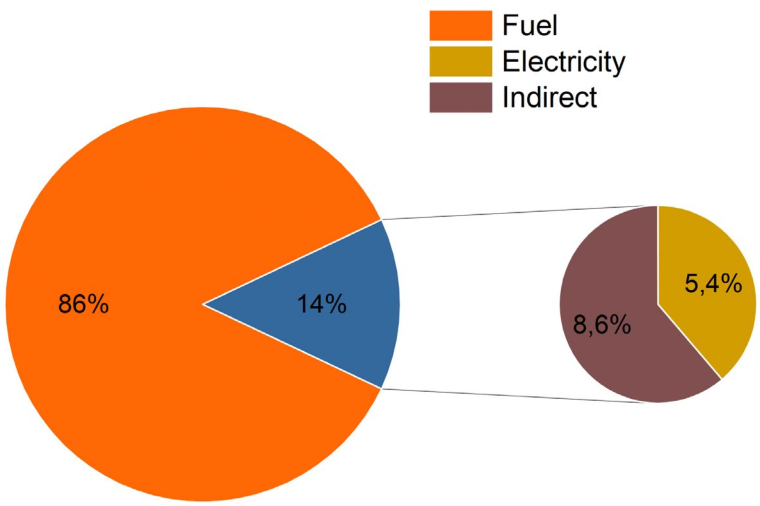

Figure 3. The distribution of emission sources for construction phase of WWTP in 2023

Table 4. Carbon emission values for the construction period of WWTP for 2023

Energy source			Density	Consumption	NKD	Energy Consumption	Emission Factor	Emission	Percent of oxidized carbon	GWP	CO_2 Emission
			(kg/m^3)	(kg)	(TJ/Gg)	(TJ)	(kg/TJ)	(t)			(tCO_2e)
CO_2 emissions from construction vehicles											
CO_2	Diesel (L)	360 000	0.83	298 800	43	12.85	74 100	952.18	1	1	952.18
CH_4	Diesel (L)	360 000	0.83	298 800	43	12.85	3	0.038	1	29.8	1.13
N_2O	Diesel (L)	360 000	0.83	298 800	43	12.85	0.6	0.007	1	273	1.91
									Total emission (tCO_2e)		**955.22**
CO_2 emissions from energy consumption											
Electric (kWh)		125 000					0.478 (kg/kWh)				59.75
									Total emission (tCO_2e)		**59.75**
Indirect consumption (rental cars)											
CO_2	Diesel (L)	36 000	0.83	29 880	43	1.285	74 100	95.22	1	1	95.22
CH_4	Diesel (L)	36 000	0.83	29 880	43	1.285	3	0.0038	1	29.8	0.11
N_2O	Diesel (L)	36 000	0.83	29 880	43	1.285	0.6	0.0008	1	273	0.22
									Total emission (tCO_2e)		**95.55**
									Total CO_2 emission for 2023 = 1110.52 tCO_2e		

Based on Table 4, the total GHG emission from the WWTP during construction phase in 2023 was determined to be 1110.52 tCO_2e. The emission sources and their percentage contributions are visualized in Fig. 3. As illustrated, the largest contribution to GHG emissions came from the fuel consumption of construction vehicles, accounting for 86% of the total in 2023. This was followed by emissions from indirect consumption with 8.6% and emissions from electricity consumption contributing 5.4%. Total CO_2 emission for 2023 is slightly higher than in 2022, due to increased electricity consumption in 2023.

Assessment of the carbon footprint for operational phase

The activities that may cause emissions during the operational phase of the Giresun WWTP are mainly involve electricity consumption, fuel consumption, waste sludge management, and the use of polyelectrolyte and $FeCl_3$, as well as wastewater emissions. As the plant is still under construction, the data for the operation phase were obtained from the feasibility report and incorporated in the carbon footprint calculations. Carbon footprint calculations were performed in accordance with GHG Protocol and using CCaLC2 program. Emission sources and carbon dioxide equivalents (tCO_2e) of GHG for the operational phase of the WWTP are tabulated in Table 5. Emission values from sewage sludge and wastewater treatment were generated using the CCaLC2 software and are also presented in Table 5. The feasibility report indicated that the generated sludge (5.35 ton/day) would be transferred to a nearby cement factory (approximately 80 km from the WWTP) for disposal. To calculate the carbon emissions from sludge transportation, it was assumed that a 6-wheeled truck (consuming an average of 13 L diesel fuel per 100 kilometres) with a volume of approximately 20 tons would make two trips per week. Accordingly, the average daily fuel consumption for sludge transport was included in the calculations as 10.4 L, totalling 1082 L annually.

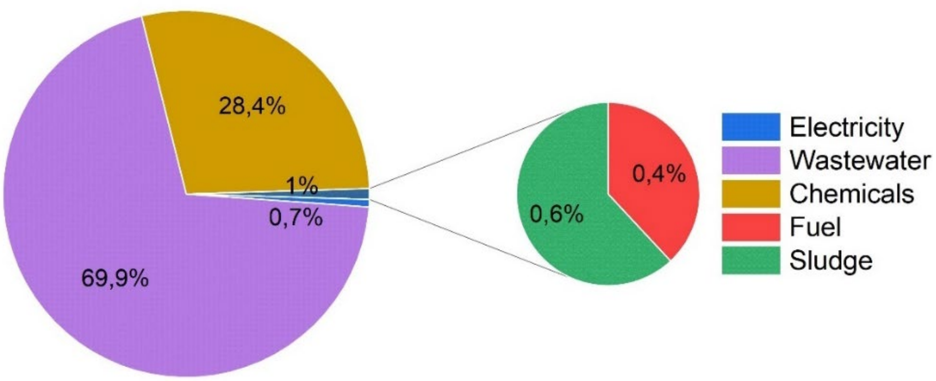

Figure 4. The distribution of emission sources for operational phase of WWTP

Based on Table 5, the total GHG emission from the WWTP during the operational phase was found to be 800.64 tCO_2e. Emission sources and their percentage contributions are illustrated in Fig. 4. It is seen that the largest contribution to GHG emissions originated from the wastewater treatment, accounting for 69.9%. This is followed by emissions from chemical consumption with 28.4%. However, the use of a biogas unit for electricity production has a positive impact, decreasing the carbon emission value by 2.18 tCO_2e/year.

Table 5. The annual carbon emission values for operational period of WWTP

Energy source		**Density**	**Consumption**	**NKD**	**Energy Consumption**		**Emission Factor**	**Emission**	**Percent of oxidized carbon**	**GWP**	**CO_2 Emission**
		(kg/m³)	(kg)	(TJ/Gg)	(TJ)		(kg/TJ)	(t)			(tCO_2e)
Transportation of activated sludge											
CO_2	Diesel (L)	1 082	0.83	898.1	43	0.039	74 100	2.89	1	1	2.89
CH_4	Diesel (L)	1 082	0.83	898.1	43	0.039	3	0.0001	1	29.8	0.003
N_2O	Diesel (L)	1 082	0.83	898.1	43	0.039	0.6	0.00002	1	273	0.005
									Total emission (tCO_2e)		**2.90**
CO_2 emissions from energy consumption											
Electric (kWh/year)			10 975				0.478 (kg/kWh)				**5.25**
CO_2 emissions from waste											
Sludge amount (t/year)			1953								**4.72**
CO_2 emissions from wastewater											
Amount of wastewater (m³/day)			19 653								**560**
CO_2 emissions from chemicals								**Emission factor (kg CO_2e)**			
Polyelectrolyte amount (t/year)				15.77				1.182			**18.64**
$FeCl_3$ amount (t/year)				388				0.539			**209.13**
								Total CO_2 emission = 800.64 tCO_2e			

Biogas electric production		**Emission factor (kg/kWh)**	**Reduction in CO_2 emission due to electricity production (tCO_2e/year)**
Electric (kWh/year)	4 568	0.478	**2.18**

Conclusion

Wastewater treatment plants play a crucial role in waste disposal and pollutants treatment, rendering wastewater harmless to the environment. However, it is paramount to examine the carbon emissions resulting from activities within wastewater treatment plants, which directly contribute to global warming.

Within the scope of this study, the environmental impacts of the construction phase (based on 2022 and 2023) of the WWTP in the Batlama Neighbourhood of the Central District of Giresun Province were evaluated in terms of GHG emissions, and the carbon footprint of the plant was calculated. In addition, estimated carbon footprint calculations of the operational phase were conducted based on design data provided in the feasibility report. Carbon footprint calculations were performed using TSE EN ISO 14064 Greenhouse Gas Calculation Guidelines and CCaLC2 software, within the framework of GHG Protocol standards.

For the construction phase, fuel consumption (both direct and indirect) and electricity consumption data were included in the carbon footprint calculations, while for the operational phase, estimated values of electricity consumption, fuel consumption, waste sludge, the chemicals polyelectrolyte and $FeCl_3$, and wastewater treatment amount were utilized.

The calculated carbon footprint during the construction phase was 1077.55 tCO_2e for 2022 and 1110.52 tCO_2e for 2023. Emissions from fuel consumption made the highest contribution to the carbon footprint for both years. The estimated total carbon emission for the operational phase was calculated as 800.64 tCO_2e, with the main contribution stemming from wastewater treatment, followed by chemical consumption. Furthermore, electricity generation from biogas unit was estimated to prevent 2.18 tCO_2e/year of emissions.

In line with the literature, the carbon emission values obtained for the construction phase are lower than those for the operational phase (Chai et al., 2015). However, the calculations can be further elaborated by including information on the construction material used, on-site and off-site worker activities and transportation data. The estimated CO_2 emission value calculated for the operational phase of the WWTP was compared with similar studies in the literature and is tabulated in Table 6. WWTPs having the similar capacity were used for the comparison purposes. All research studies have been used IPCC (2006) method in their calculations while some have additionally used the CCALC2 method (Güller & Balcı, 2018; Ateş, 2021; Erşan, 2022). It is seen that the calculated carbon footprint value is relatively low in comparison with other WWTPs in the literature. The main reason for this difference is the lack of real-time operational data. Nevertheless, the calculations made using the design data will provide a valuable resource for future studies.

The carbon footprint calculations conducted in this research indicate that GHG emissions are directly proportional to energy consumption. The calculations demonstrate the contribution of activities carried out during both the construction and operational phases of a WWTP to carbon emissions. It is therefore essential to evaluate activities within WWTPs, which play a vital role in treating wastewater and discharging it into the environment, in terms of carbon emissions. Various measures are being implemented globally and nationally reduce carbon footprint.

Creating carbon sink areas by planting trees is an effective solution to reduce carbon emissions. The company can contribute to emission reduction by afforesting the areas surrounding its facilities. In fact, the amount of emission sequestration varies based on the type and age of each tree, but detailed research is required to determine specific values. As the construction company has indicated that the plant will be completed and begin operating shortly, recommendations have been made based on the carbon emission value for the operational phase. The emission value of 800.64 tCO_2e/year for the operational phase corresponds to approximately 72 785 trees (assuming one tree absorbs 11 kg CO_2 per year) (Tosun and Tunç Dede, 2024).

Another recommendation to reduce carbon emissions is to provide electricity from renewable energy sources, such as photovoltaic panels, to absorb emissions from energy consumption sources as much as possible. Photovoltaic panels are devices that capture solar energy and convert it into electrical energy. If a 540 W panel generates an average of 0.54 kW of electricity in 1 hour of sunshine per day and considering that the average annual sunshine duration for Giresun province is 2.2 hours/day according to the National General Directorate of Meteorology, the annual average electrical energy generation capacity of a 540 W panel would be 433.6 kW. Given that the annual electricity consumption value of the plant was reported as 10 975 kWh, it was determined that this value corresponds to the use of approximately 25 photovoltaic panels with 500 W capacity.

Table 6. The annual carbon emission values for different WWTPs

Place	Wastewater (m^3/day)	Carbon footprint (tCO_2e/year)	Reference
WWTPs from China	20 000	5 817-9 928	(Chai et al., 2015)
WWTP Puducherry, India	25 000	3 716	(Vijayan et al., 2017)
WWTP Muğla, Turkiye	17 111	77 316-82 946	(Güller and Balcı, 2018)
WWTP Bingöl, Turkiye	15 840	45 238	(Ateş, 2021)
WWTP, Sivas, Turkiye	78 516	76 141-74 520	(Erşan, 2022)
WWTPs from China	20 000	2 345-3 586	(Chen et al., 2023)
WWTP in Erzurum, Turkiye	13 000	10 389-53 529	(Karakas et al., 2024)
WWTP Giresun, Turkiye	19 653	800.64	This study

Despite evaluating the carbon footprint of the WWTP in Giresun, this paper acknowledges several limitations and areas for additional research. The calculations for construction phase are mainly based on energy and electricity consumption. The construction materials and transportation emissions can contribute to GHG emissions. However, these data could not be included in the calculations due to unavailability. The operational phase analysis relies solely on estimated data, as the system is still under construction and has not yet operational. Due to the dynamic nature of operational conditions, alterations in these parameters can influence emission factors, energy consumption patterns, and chemical consumption patterns. Once the WWTP is operational, the calculations should be renewed according to actual data. Therefore, further research is imperative to expand the scope of the findings and investigate carbon footprints under various operating conditions. Optimizing wastewater treatment plant operation can be important at the local level and can help improve the carbon footprint of urban areas.

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Conflicts of interest: *The authors declare no conflicts of interest.*

References

Arıoğlu Akan MÖ, Dhavale DG, Sarkis J, (2017) Greenhouse gas emissions in the construction industry: An analysis and evaluation of a concrete supply chain. J. Clean. Prod. 167, 1195–1207. https://doi.org/10.1016/j.jclepro.2017.07.225

Ateş F, (2021) Evaluation of Bingöl wastewater treatment plant carbon footprint according to CCALC2 and GPS-X methods. MSc Thesis, Fırat University. https://tez.yok.gov.tr/UlusalTezMerkezi/ 674741

Azapagic A, (2012) CCaLC2 carbon footprint tool. http://www.ccalc.org.uk/latestccalc2.php?lsce=EEY8D00G

Campos JL, Valenzuela-Heredia D, Pedrouso A, Val Del Río A, Belmonte M, Mosquera-Corral A, (2016) Greenhouse Gases Emissions from Wastewater Treatment Plants: Minimization, Treatment, and Prevention. J. Chem. 2016. https://doi.org/10.1155/2016/3796352

Chai C, Zhang D, Yu Y, Feng Y, Wong MS, (2015) Carbon footprint analyses of mainstream wastewater treatment technologies under different sludge treatment scenarios in China. Water (Switzerland) 7, 918–938. https://doi.org/10.3390/w7030918

Chen, H., Zheng, Y., Zhou, K., Cheng, R., Zheng, X., Ma, Z., Shi, L., (2023) Carbon emission efficiency evaluation of wastewater treatment plants: evidence from China. Environ. Sci. Pollut. Res. 30, 76606–76616. https://doi.org/10.1007/s11356-023-27685-9

Erşan, F., (2022) Evaluation of greenhouse gas emissions originating from biological treatment units of Sivas domestic wastewater treatment plant. Msc. Thesis, Sivas Cumhuriyet University. https://tez.yok.gov.tr/UlusalTezMerkezi/ 752072

Goliopoulos N, Mamais D, Noutsopoulos C, Dimopoulou A, Kounadis C, (2022) Energy Consumption and Carbon Footprint of Greek Wastewater Treatment Plants. Water (Switzerland) 14. https://doi.org/10.3390/w14030320

Güller S, Balcı A, (2018) Carbon Footprint Assessment of Mugla Waste Water Treatment Plant. üleyman Demirel Univ. J. Nat. Appl. Sci. 22, 547. https://doi.org/10.19113/sdufbed.11001

Gupta R, Lee S, Lui J, Sloan WT, You S, (2024) Carbon footprint assessment of water and wastewater treatment works in Scottish islands. J. Clean. Prod. 450, 141650. https://doi.org/10.1016/j.jclepro.2024.141650

Hammond GP, Jones CI, (2008) Embodied energy and carbon in construction materials. Proc. Inst. Civ. Eng. Energy 161, 87–98. https://doi.org/10.1680/ener.2008.161.2.87

Hong J, Shen GQ, Feng Y, Lau WST, Mao C, (2015) Greenhouse gas emissions during the construction phase of a building: A case study in China. J. Clean. Prod. 103, 249–259. https://doi.org/10.1016/j.jclepro.2014.11.023

IPCC, (2022) Climate Change 2022 - Mitigation of Climate Change - Full Report, Cambridge University Press. https://doi.org/10.1017/9781009157926

IPCC, (2006) IPCC Guidelines for National Greenhouse Gas Inventories, IPCC Guidelines for National Greenhouse Gas Inventories. https://www.ipcc-nggip.iges.or.jp/public/2006gl/

Karakas A, Tozum-Akgul S, Komesli OT, Kaplan-Bekaroglu SS, (2024) Carbon footprint analysis of advanced biological wastewater treatment plant. J. Water Process Eng. 61, 1–8. https://doi.org/10.1016/j.jwpe.2024.105254

Labaran YH, Mathur VS, Farouq MM, (2021) The carbon footprint of construction industry: A review of direct and indirect emission. *J. Sustain. Constr. Mater. Technol.* 6, 101–115.

https://doi.org/10.29187/jscmt.2021.66

Lin, L., (2020) Carbon emission assessment of wastewater treatment plant based on accounting perspective. E3S Web Conf. 194, 0–4. https://doi.org/10.1051/e3sconf/202019404049

Parravicini V, Svardal K, Krampe J, (2016) Greenhouse Gas Emissions from Wastewater Treatment Plants. Energy Procedia 97, 246–253. https://doi.org/10.1016/j.egypro.2016.10.067

Purnell P, Black L, (2012) Embodied carbon dioxide in concrete: Variation with common mix design parameters. Cem. Concr. Res. 42, 874–877. https://doi.org/10.1016/j.cemconres.2012.02.005

Robescu LD, Presură E, (2017) Reducing carbon footprint of a wastewater treatment plant using advanced treatment and renewable energy sources. Environ. Eng. Manag. J. 16, 1055–1062. https://doi.org/10.30638/eemj.2017.108

Stokes J, Horvath A, (2006) Life cycle energy assessment of alternative water supply systems. Int. J. Life Cycle Assess. 11, 335–343. https://doi.org/10.1065/lca2005.06.214

Tosun, G., Tunç Dede, Ö., (2024) Karbon Ayak İzi Hesaplamalarında Enerji Tüketiminin Örnek Bir Çalışma ile İncelenmesi. Karadeniz Fen Bilim. Derg. 14, 932–943. https://doi.org/10.31466/kfbd.1458712

The Ministry of Energy and Natural Resources, (2024a), Turkey Electricity Generation and Electricity Consumption Point Emission Factors - 2022. https://enerji.gov.tr/Media/Dizin/EVCED/tr/ÇevreVeİklim/İklimDeğişikliği/EmisyonFaktorleri/TEUVETN_Emisyon_Faktörleri_Bilgi_Formu.pdf. Accessed date: 15.02.2025

The Ministry of Energy and Natural Resources, (2024b), Turkish Greenhouse Gas Inventory 1990 – 2022. https://enerji.gov.tr//Media/Dizin/EVCED/tr/ÇevreVeİklim/İklimDeğişikliği/UlusalSeraGazıEmisyonEnvanteri/Belgeler/EK-1.pdf. Accessed date: 15.02.2025

TSE, (2019a) Greenhouse gases - Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals. Ankara. https://www.tse.org.tr/

TSE, (2019b) Greenhouse gases - Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements. Ankara. https://www.tse.org.tr/

TSE, (2019c) Greenhouse gases - Part 3: Specification with guidance for the verification and validation of greenhouse gas statements. Ankara. https://www.tse.org.tr/

TUIK, (2024) Turkish Greenhouse Gas Inventory 1990-2022, Oil: a Cultural and Geographic Encyclopedia of Black Gold: Volume 1-2. https://doi.org/10.1007/978-3-642-41714-6_72140

United Nations Environment Programme, (2024) Global Status Report for Buildings and Construction: Beyond foundations: Mainstreaming sustainable solutions to cut emissions from the buildings sector. Nairobi., 2023 Global Status Report for Buildings and Construction: Beyond foundations - Mainstreaming sustainable solutions to cut emissions from the buildings sector. https://doi.org/https://doi.org/10.59117/20.500.11822/45095

Vijayan G, Saravanane R, Sundararajan T, (2017) Carbon Footprint Analyses of Wastewater Treatment Systems in Puducherry. Comput. Water, Energy, Environ. Eng. 06, 281–303. https://doi.org/10.4236/cweee.2017.63019

Wang T, Li K, Liu D, Yang Y, Wu D, (2022) Estimating the Carbon Emission of Construction Waste Recycling Using Grey Model and Life Cycle Assessment: A Case Study of Shanghai. Int. J. Environ. Res. Public Health 19. https://doi.org/10.3390/ijerph19148507