Sigma J Eng & Nat Sci 38 (4), 2020, 1729-1739

Sigma Journal of Engineering and Natural Sciences
Sigma Mühendislik ve Fen Bilimleri Dergisi

Research Article

CARBON DIOXIDE EMISSION IN THRACE REGION AND NEIGHBORING COUNTRIES AS A RESULT OF AEROBIC STABILIZATION OF URBAN TREATMENT SLUDGES

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Received: 23.04.2020 Revised: 11.08.2020 Accepted: 18.08.2020

ABSTRACT

The aim of this study was to investigate the effect of aerobic sludge stabilization on global carbon dioxide emission. Treatment sludge formed in the whole region has been determined based on the current population of provinces and districts. Aerobic sludge stabilization efficiency was obtained as a result of experimental study. The solid matter per capita obtained from the treatment sludges formed in the existing domestic treatment plants (TP1-TP4) was applied to the entire region population. The estimated minimum and maximum annual total treatment sludge produced in these three provinces and districts are respectively 20,627 and 32,605 tons for the year 2020. The average annual solid material equals 2.66% of the total solids to be produced nationwide in Turkey (1 million tons) and 0.205% of the total amount in the European Union (13 million tons). The total CO_2 emission in the provinces of Tekirdağ, Edirne, and Kırklareli, together with their districts were calculated as minimum and maximum for 2020 with the following results, respectively: 32,532 and 51,420 tons of CO2/year. Estimated minimum and maximum CO_2 emission (total of Tekirdağ, Edirne, and Kırklareli provinces and their districts) for 2050 were found to be 47,442 and 74,989 tons of CO_2/year, respectively. The highest carbon dioxide emission per capita produced in the region occurs in Cyprus and Greece.
Keywords: CO_2 emission, global warming, treatment sludge, sludge stabilization.

1. INTRODUCTION

The world population is growing rapidly and concentrated in urban centers. Cities produce billions of tons of domestic treatment sludge every year. The unstabilized sludge has high water and high biochemical oxygen demand. In an aerobic environment, bacteria break down the organic substances in a mixture quickly to convert them into carbon dioxide and other products [1].

Traditionally, the sludge is biologically stabilized through aerobic or anaerobic methods. In aerobic stabilization conditions, microorganisms consume their own protoplasms to obtain energy for cell maintenance. As a result, the carbon part of the sludge is aerobically oxidized to CO_2 and H_20 and nitrogenous compounds are oxidized to NH_4^+ and nitrate [2]. The sludge formed during a biological treatment is regularly removed from the whole process. Sludge retention time (SRT)

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is the main factor affecting aerobic sludge stabilization. On the 20th to 30th day of the SRT, sludge stabilization in the aeration tank is almost complete [3-5]. Aerobic digester (aerobic stabilization) works on a pri nciple similar to the activated sludge process [6]. The reduction in volatile suspended solids and total organic carbon(TOC) in the treatment sludge during aerobic stabilization is 40% and 75%, respectively [7]. Generally, aerobic stabilization is a more cost effective solution for treatment plants serving 50,000 or less populations. Aerobic stabilization does not need a big investment or a lot of maintenance, but requires additional electrical energy [8]. Treatment sludge stabilization is an important step in sludge treatment and aerobic stabilization is one of the most important options for sludge stabilization in small and medium-sized treatment plants, due to low investment and operating costs [9]. Stabilization of sludge is considered to be one of the most important problems due to high energy and treatment costs [10-12]. Aerobic sludge stabilization is widely used [13].

The contribution of a greenhouse gas to global warming is generally expressed as its global warming potential (GWP), which allows a comparison of the global warming effect of this gas and CO_2 as the typical reference gas. The largest (58.6%) share of greenhouse gases (GHGs) is CO_2 emissions from the burning of fossil fuels[14]. Total global GHG emissions continued to increase by 0.5% (± 1%) in 2016, reaching approximately 49.3 gigatons equivalent of CO_2 (Gt CO_2 equivalent) [15]. Based on a 100-year projection, the global warming potentials of CO_2, CH_4, and NO_2 are 1, 25, and 298, respectively [16]. These gases increase the heat on the earth and prevent the heat from spreading in the atmosphere. Total greenhouse gas emission in 2015 was estimated to be 475.1 million tons as CO_2 equivalent. While CO_2 equivalent emission per capita was 3.88 tons in 1990, it increased to 6.07 tons by 2015 [17].These gases are mainly expressed as kg CO_2. In the last 200 years, atmospheric concentrations of greenhouse gases increased [2, 14-16, 18,19]. According to the data published by the Turkish Statistical Institute on April 11, 2019, the amount of CO_2 emissions in 2017(the most recent available data) was 526.3 million tons and the increase in emission in the period 1990-2017 was 140.1%. Figures for greenhouse gas emissions in urban areas vary depending on the methods used for estimation, the scope of global warming gas emissions, emission sources, and the urban area defined and is a complex process because of the need to set a limit [18, 19]. Human activities such as agriculture, industry, waste disposal, deforestation, and especially burning fossil fuels contribute to the increase in the amount of greenhouse gases. The concentrations of CO_2 increased from about 280 ppm per unit volume in pre-industrial times to 372.3 ppm in 2001 and continued to increase by about 0.5% each year [20]. Carbon dioxide is removed from the atmosphere when it is absorbed by plants as part of the biological carbon cycle [21].

Treatment sludge is a biomass (solid matter) removed from treatment plants. The daily amount of sludge is the sum of all sludge removed from active treatment plants. Greenhouse gases emitted from waste and wastewater make up 2.8% of greenhouse gases [22]. The present studies [23,24] provide the following values for the annual amount of dry sludge (DS) produced per person: In Bulgaria, 12.6 kg; Greece 15 kg; Cyprus, 32.1 kg; Romania,14.1 and Turkey,12.78 kg. The average sludge value for 15 European Union countries is estimated a daily 53 g solid matter per capita [23, 24].

The total carbon dioxide emissions during the aerobic stabilization of domestic waste treatment sludge (solid matter) were estimated for the Trakya Region (Tekirdağ, Kırklareli, and Edirne provinces) of Turkey depending on population density. As a result of the field study, sewage sludge per capita was determined.

2. MATERIAL AND METHOD

The study area is located in northwestern Turkey (Fig.1). It comprised of three provinces and their districts. Projections of population for the provinces of Tekirdağ, Edirne, and Kırklareli, together with their districts are made. Populations of provinces and their districts were calculated based on the mathematical method of population estimation (geometric increase method) [25]. In 2020 and 2050: The population of Tekirdağ provinces and districts were 1,039,203 and 1,589,756, Edirne provinces and districts were 418,053 and 563,457, and the population of Kırklareli provinces and districts were 365,752 and 505,424. Greece, Bulgaria, Turkey and Romania population data were taken from the existing literature[26]. Annual sludge per capita in these countries are taken from the literature [23, 24]. Total urban sludge and carbon dioxide emissions were calculated for each country. Annual carbon dioxide per capita were calculated by dividing the total amount of carbon dioxide by the existing population (2020).

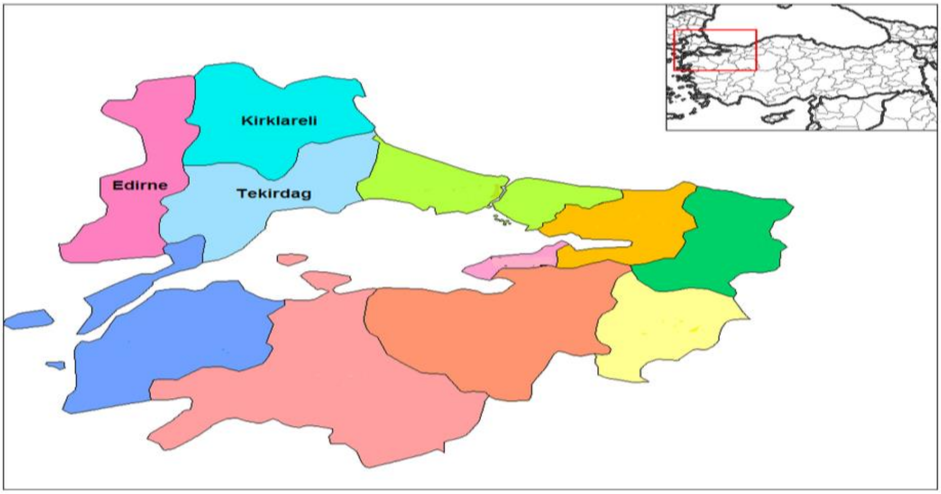

Figure 1. The location of the provinces of Tekirdağ, Edirne, and Kırklareli in the region of Trakya.

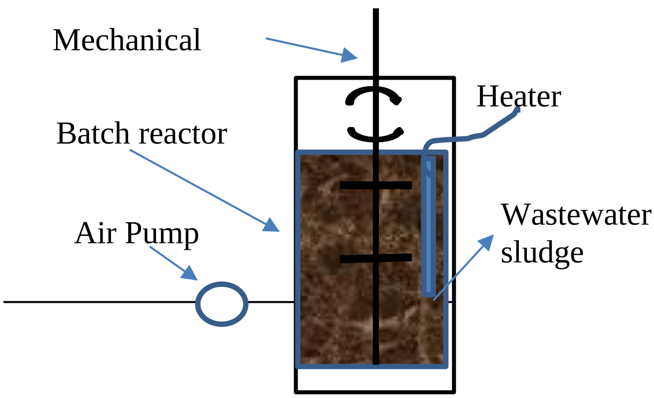

Figure 2. Laboratory Scale Experimental Setup

Aerobic stabilization processes were carried out by putting five liters of sludge into the reactor with a total volume of seven liters (Fig.2). The reactor was operated intermittently. The reactor was continuously aerated and the dissolved oxygen concentration was kept above 2.0 mg/l. The temperature in the reactor is 25 ± 1 C^o. The reactor mixture was provided with mechanical mixers. The pH was kept at 7 ± 0.5 with the addition of $NaHCO_3$. Mixed liquor suspended solid (MLSS) and mixed liquor volatile suspended solid (MLVSS) measurements were made according to Standard Methods [27]. Total organic carbon (TOC) measurements were made with the Shimadzu TOC instrument. Dissolved oxygen concentration measurements was made with Hanna DO analyzer. CO_2 emissions were calculated from the efficiency obtained from TOC removal as a result of aerobic stabilization. TOC, MLSS and MLVSS were measured at the end of 8,16,24,32 and 40 days from the aerobic stabilization.

Urban wastewater treatment plants(in the region) sludges were taken and analyzed in the laboratory. The results are shown in Table 1. Leaching of the sewage sludge was carried out by extraction (liquid / solid ratio 20: 1) using acetic acid solution (pH = 2.8) as the medium. The sludge samples were placed on a rotary shaker with the leaching liquid and agitated at 120 rpm for 20 hours. After extraction, the samples were centrifuged for 20 minutes at 4000 rpm and the water phase was filtered through a 0.45 μm membrane filter [28]. Heavy metal analysis was done with Unicam Model 929FAAS with a deuterium lamp and an air acetylene burner. The amount of sludge produced per capita (40± 9 g SM) was determined from the daily minimum and maximum sludge amounts formed in the existing treatment plants in this region (Table 2). In this study, the sludge (solid matter) amounts formed in domestic/urban wastewater treatment plants were calculated using the average data of 40 ± 9 g SM per capita day. Here, the standard deviation is ± 9 g solid matter (SM) per capita per day and the minimum daily SM amount per capita is 31 g, the average is 40 g, and the maximum is 49 g. Therefore, the sludge amounts were estimated with the addition of the standard deviation on the average value (Figure 4).

Table 1. Wastewater Sludge Characteristic (Treatment Plant1,Treatment Plant 2,Treatment Plant 3 and Treatment Plant 4)

Parameters		Metcalf &Eddy[29]	Arnaiz et al. [30]
Total Organic Carbon (TOC), g/l	40-64	--	--
Mixed Liquor Suspended Solids (MLSS), g/L	8.9-36	--	17,980
Mixed Liquor Volatile Suspended Solids (MLVSS), g/L	7.2-28.7	--	14,53
pH	6.7-7.5	5-8	7.4
Lead(mg/kg)	14-38	13-26,000	--
Arsenic mg/kg	0.8-12	1.1-230	--
Cadmium mg/kg	2.4-6.9	1-3,410	--
Copper mg/kg	12-32	84-17,000	--
Nickel mg/kg	0.8-2	2-5,300	--
Chromium mg/kg	5-9	10-99,000	--
Mercury mg/kg	0.2-4	0,6-56	--

Table 2. Existing urban wastewater treatment plants and daily minimum and maximum sludge amounts in this region.(4% Solid Matter)

	City Population in 2020	Minimum Sludge Daily(Tone/day) (%4 SM)	Maximum Sludge Daily(Tone/day) (%4 SM)
TP 1	274,000	207.5	330
TP 2	206,000	160	250
TP 3	151,000	117.5	205
TP 4	187,000	157.5	225
Total	818000	642.5 (25.7 tone SM/day)	1,010 (40.4 tone SM/day)
Per capita sludge		31 g SM /per capita.day	49 g SM/per capita.day

TP: Treatment Plant, SM: Solid matter

The elemental composition of the solid treatment sludge is C5H7O2N [29]. The treatment plants specified in this study (TP1, TP2, TP3 andTP4) are urban wastewater treatment plants. These treatment plants have carbon, nitrogen and phosphorus removal processes. The treatment sludge used in this study was taken from the final settling tanks of the treatment plants (equal amounts and mixed). As a result of the experiment carried out in the laboratory, the sludge stabilization efficiency (E) was found to be 81% (Fig.4). Based on the sewage sludge formula given in the current literature[29,31], the carbon dioxide amounts were calculated from the dry biomass stabilization.

$$C_5H_7O_2N + 5\ O_2 \longrightarrow 5\ CO_2 + 2\ H_2O + NH_3 \quad (1)$$

$C_5H_7O_2N/CO_2$ ratio is 113/220, which equals 1/1,947. This means that 1,947 kg CO_2 is generated for the aerobic decomposition of 1 kg biomass [29,31].

$$CO_2(kg) = X_{sludge} * E * 1,947 \quad (2)$$

On the basis of the amounts of solid matter (sludge) per capita, the minimum, average, and maximum amounts of solid for the years 2020 and 2050 were estimated for Tekirdağ, Edirne, and Kırklareli provinces and their districts in the basin of Trakya. 81% (E) TOC removal obtained as a result of this study was taken into account in carbon dioxide calculations.

3. RESULTS AND DISCUSSION

Table 1 shows the characterization range of the sludges obtained from the final settling tanks. Analysis results showed a wide range of heavy metal contents in urban sewage sludge. Heavy metal analysis results are also given to know the effect of heavy metals on biological sludge stabilization. The values obtained are within the limits of the current literature[29,30,32]. The sewage sludge contains heavy metals such as Zn, Pb, Cu, Cr, Ni, Cd, Hg and As. Certain pre-treatment procedures must be applied to reduce / stabilize heavy metals contained in sewage sludge prior to disposal [33]. In Table 2, the daily minimum(25.7 tone SM/day) and maximum (40.4 tone SM/day) sludge generated in the existing four urban treatment plants were determined. Daily minimum and maximum sludge per person were calculated from the amount of sludge and urban population values.

In Figure 3, TOC(total organic carbon), MLSS and MLVSS changes are shown as a result of the aerobic stabilization of the sludge. The treatment sludge influent TOC value is 54,000 mg/l. At the end of 16th and 40th days of sludge stabilization, effluent TOC values were found to be 30,300 and 10,200 mg /l, respectively. At the end of the stabilization period, the mixed liquor suspended solid (MLSS) value decreased from 45,000 mg / L to 24,000 mg / L. Mixed liquor volatile suspended solids(MLVSS) concentration decreased from 37,800 mg / l to 18,000 mg/l during 40 days of stabilization. MLVSS removal efficiency shows the internal respiration rate of the sludge. Mantas et al. found that 25000 mg/L TOC value decreased to 5900 mg/L after 20 days of aerobic sludge stabilization[7]. Based on the TOC removal efficiency(81%), sludge stabilization efficiency was taken as a basis in carbon dioxide calculations. Complex organics, microbial aggregates, extracellular polymeric substances and various inhibitory compounds significantly inhibit aerobic and anaerobic sludge stabilization [12]. The data obtained as a result of the laboratory study were found to be compatible with the existing literature [34]. TOC removal efficiency increased rapidly at the end of the 16th day. In other time periods, the yield increased gradually. At the end of the 8th, 16th, 24th, 32th and 40th days, the mixed liquor volatile suspended solids removal efficiency was 11, 22, 40, 47 and 52.4%, respectively. The retention time and temperature of the system are very important in aerobic sludge stabilization [33]. Mixed liquor suspended solids(MLSS) removal efficiency was found to be 46.7% at the end of stabilization. As a result of the stabilization of the sludge, MLVSS/MLSS ratio decreased from 0.84 to 0.75. The results were found to be compatible with other studies[22,24-26]. In their study, Mantaş et al. found that the VSS/SS value decreased from 0.59 to 0.50 after 20 days of aerobic stabilization of the sludge. In the same study, VSS and SS removal efficiencies were found to be 43% and 33% [7].

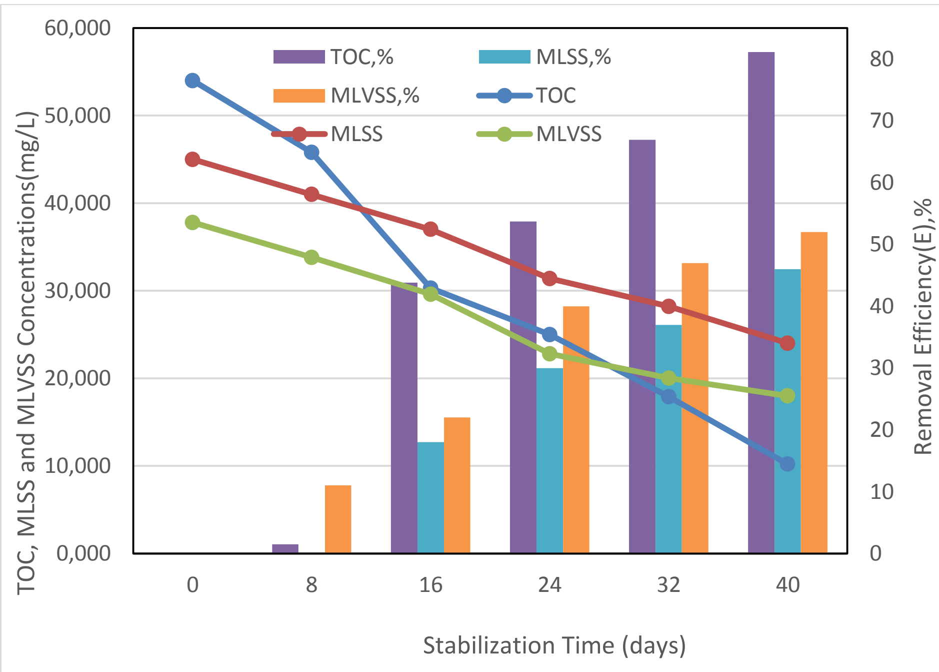

Figure 3. Variation of TOC, MLSS and MLVSS in domestic wastewater sludge during aerobic stabilization

Population calculations were made to calculate the daily sludge and carbon dioxide amounts. The total population of Tekirdağ, Edirne, and Kırklareli was 1,823,008 in 2020 and the population estimates for 2050 is 2,658,637, respectively. The population distribution in the region of Trakya in 2020 is as follows: 57% of the population in the basin lives in Tekirdağ and its districts, 22.9%

in Edirne and its districts, and 20.1% in Kırklareli and its districts. The total population of these three provinces and districts which corresponds to 2.19% of Turkey's population.

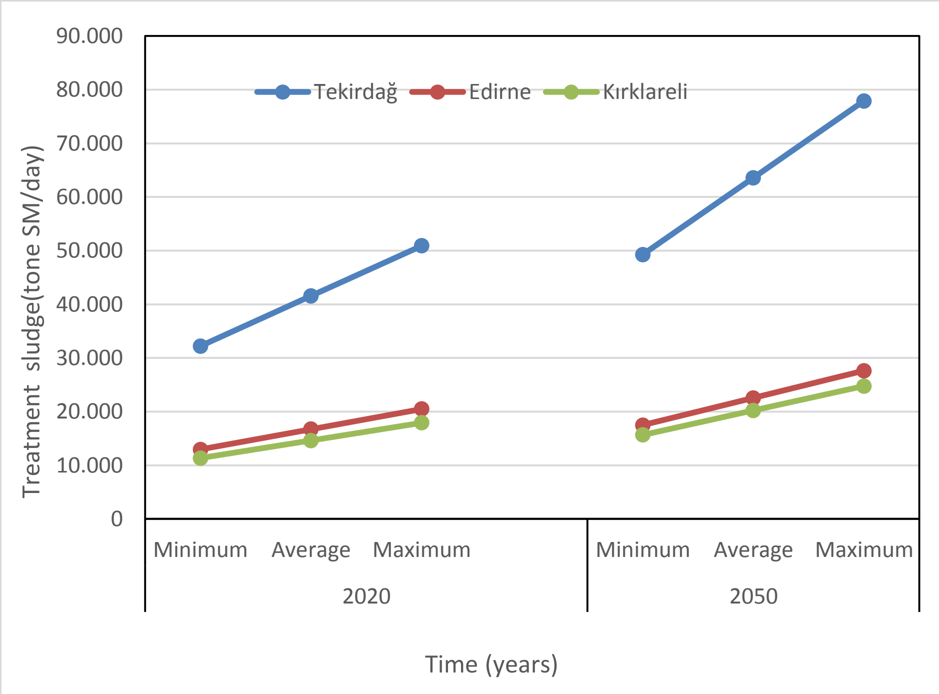

Figure 4. Daily minimum, average and maximum treatment sludge amounts in 2020 and 2050 projection years.

The total amount of sludge generated in Tekirdağ province (Fig.4) is minimum 32.215 tons solid matter (SM)/day, an average of 41.568 tons SM/day, and maximum 50.921 tons SM/day for 2020. This is the equivalent of 1.17 to 1.86% of the total amount of solid matter generated in Turkey in the year 2020. For the second projection year (2050), the minimum is 49.282 tons SM/day, average 63.590 tons SM/day, and maximum 77.898 tons SM/day. The minimum and maximum sludge amounts formed in Edirne and Kırklareli provinces and districts in 2020 are 12.960-20.485 and 11.338-17.922 tone SM/day, respectively. Similarly, minimum and maximum sludge amounts in Edirne and Kırklareli provinces and districts in 2050 are 17.467-27.609 and 15.668-24.766, respectively. 57% and 59% of the average total amount of sludge formed in the region in 2020 and 2050 occurs in Tekirdağ provinces and districts. Kırklareli is the province with the lowest population density in the Trakya Region. As a result, the lowest solid matter (treatment sludge) generation was found in this province (Fig.4).

According to the current situation in 2020, the average daily total solid increase rate 2050 was 45.83%. Estimates showed that 9.8 million tons of solid matter (sludge) in 2005 in the 15 members of European Union increased to 13 million tons by 2020 [35]. It is estimated that more than 1 million tons of wastewater treatment sludge in Turkey will be formed annually in 2020 [30]. The annual minimum, average, and maximum values of the total amounts of sludge generated in Tekirdağ, Edirne, and Kırklareli provinces and their districts in the projection year 2020 were found to be 20,627, 26,615 and 32,604.7 tons of solid matter/year, respectively. These three provinces contribute 2.06%, 2. 66%, and 3.26%, respectively, to the total minimum, average and maximum values generated annually (2020) in urban Turkey.

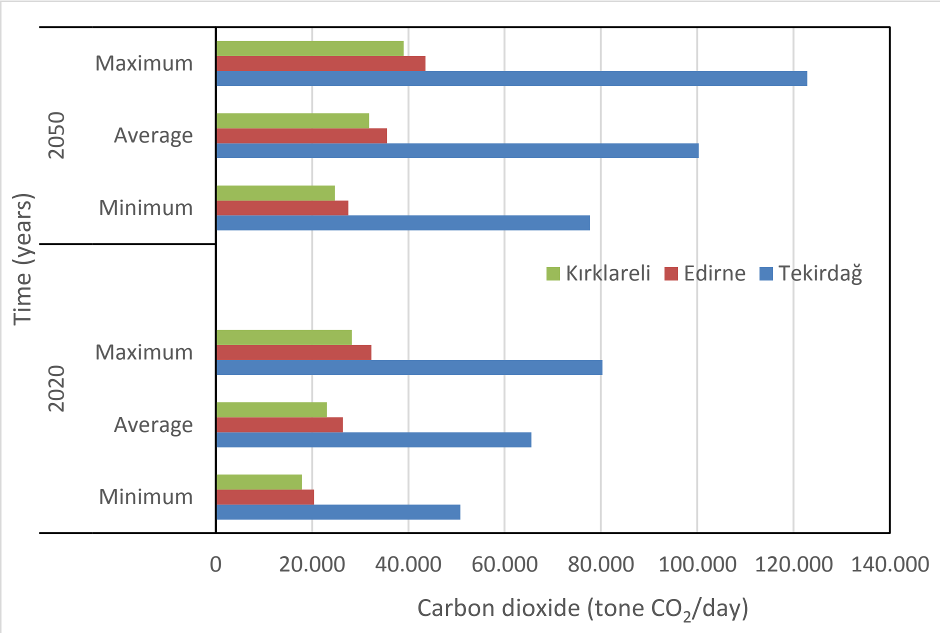

Figure 5. Minimum, Average, and Maximum Carbon Dioxide Emissions(Aerobic) in the Tekirdağ, Edirne and Kırklareli Provinces in 2020 and 2050

Figure 5 shows the daily carbon dioxide emissions in Tekirdağ, Edirne and Kırklareli provinces and its districts in 2020 and 2050. 57% of the average total carbon dioxide originates from Tekirdağ province and its districts. Tekirdağ province has more industries and population than other provinces. Similarly, in 2050, total minimum and maximum carbon dioxide amount was found as 47,442 and 74,989 tons. The year 2020 in Edirne, kırklareli and Tekirdağ overall, in comparison to the projection year 2050 shows an increase rate of CO_2 emission estimated from an average solid matter (49 g SM/per capita per day) generation projected to a 30-year time period was found as 45.8%. In the reference scenarios, CO_2 emissions as a result of burning fossil fuels and industrial processes globally increased from 7 gigatons carbon/year in 2000 to 22.5 to 24.0 gigatons carbon/year in 2100; that is, roughly 3 to 3½ times the current levels [36].

Population growth in developing countries is an important factor in manipulating the global increase in CO_2 emissions. A linear relationship was found between population growth and CO_2 concentration [37].

Table 3. Carbon dioxide per capita produced from urban treatment sludges for the Thrace region and other neighboring countries (for 2020)

	Population-2020	Kg DM*/per capita.year	Total sludge 2020(tone DM/year)	Total CO2** (tone/year)	Kg CO_2/per capita.year
Turkey	84,339,067	12.78	1,077,853	1,699,850	20.16
Thrace Region	1,823,008	14.6	26,616	41,975	23.03
Bulgaria	6,948,445	12.6	87,550	138,073	19.87
Greece	10,423,054	15	156,346	246,569	23.66
Cyprus	1,207,359	32.1	38,756	61,121	50.62
Romania	19,237,691	14.1	271,251	427,782	22.24

*Dry matter ** $CO_2(kg) = X_{sludge} *E* 1{,}947$

Annual carbon dioxide per capita were shown for the Thrace region and other neighboring countries (Table 3). Thrace region covers three provinces and districts (Tekirdağ, Edirne and Kırklareli). The carbon dioxide emission per capita in the Thrace region for 2020 is 23.03 kg. The highest carbon dioxide emission per capita was found in Cyprus. Turkey, Greece, Cyprus, Bulgaria and Romania carbon dioxide emissions in 2020 were calculated as 20.16, 23.66, 50.62, 19.87 and 22.24 tons of CO_2 / per capita year, respectively. In 2020, the total CO_2 emissions in Turkey, Thrace Region, Bulgaria, Greece, Cyprus and Romania were found as 1,699,850;41,975;138,073;246,569;61,121 and 427,782 tons of CO_2/year, respectively. In this region, Turkey contributes to global warming at the highest rate.

4. CONCLUSION

The study was conducted on the three provinces of the Trakya Region of northwestern Turkey. Among them, the province of Tekirdağ located in this basin is quite dense in population as a result of intensive industrial activities. The minimum (20,627 tons/year), average (26,616 tons/year), and maximum (32,605 tons/year) total sludge generated in the provinces of Tekirdağ, Edirne, and Kırklareli in 2020 corresponds respectively to 0.16%, 0.21%, and 0.25% of the total treatment sludge generated in the European Union overall (13 million tons/year) in 2020[34]. The minimum maximum total carbon dioxide amount in all three provinces varies between 32,532 and 51,420 tons in 2020. Carbon dioxide emissions generated in three provinces correspond 0.0062 % and 0.0098% of carbon dioxide formed in Turkey (Compared to 2017 data). The highest carbon dioxide emission per capita produced in the region occurs in Cyprus, Greece and Thrace, respectively.

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