Prediction of greenhouse gas emissions resulting from medical waste collection and transport in the city of Kocaeli

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Abstract. This study investigates future medical waste generation and greenhouse gas emissions resulting from medical waste collection and transportation activities in the city of Kocaeli, Turkey, between the years of 2020 and 2040. Population predictions were carried out by using Ilbank method, arithmetic method and United Nations Development (UNDP) method. Then, medical waste amounts were calculated based on the predicted populations. Among the three methods, arithmetic method was seemed to reflect the most reliable prediction. GHG emissions were calculated based on the fuel consumed by medical waste collection vehicles. The targeted GHGs were CH$_4$ and CO$_2$. Results of this work showed that the total medical waste generated per year was predicted to increase from 2,978 tons in 2020 to 5,203 tons in 2040. Finally, it was determined in this study that medical waste collection and transport would generate a total GHG emission of 11,229-ton CO$_2$-e from 2020 to 2040. Furthermore, average global warming factor (GWF) was calculated as 0.00013 tCO$_2$-e per ton of medical waste collected and transported. This study showed that medical waste collection and transportation generates significant amounts of GHG emissions. Results of this study will guide the local authorities when they plan to replace diesel fuel with alternative fuel types.

1. Introduction
Due to serious health hazards, proper management of medical waste is extremely important. Recently, many attempts have been made by authorities and scientists to manage the medical waste problem. Authorities and scientists define medical waste as waste generated during the diagnosis and treatment of humans and animals. If not handled properly, medical waste creates a major risk of infection by spreading pathogens to the environment [1]. Medical devices have been produced exclusively for single use in recent years, thus, increasing the amount of medical waste in developing countries. This has led to a rapid increase in the amount of medical waste that needs to be disposed of safely [2]. There are different names in the literature for medical waste such as hospital waste, regulated medical waste and infectious waste [3, 4]. The term infectious waste is often described as waste that cannot be disposed of in the municipal solid waste landfill due to its pathogenic content. Safe disposal of infectious waste is a major concern for authorities and the public [4].

Generation, transport and disposal of waste are the main sources of greenhouse gas emissions (GHG) for waste management activities [5]. The total greenhouse gas emissions generated by the global waste sector are around 1.3 gigaton (Gt) CO$_2$-e, which corresponds to about 2.8% of the total greenhouse gas emissions [6]. Methane gas generated by waste landfilling accounts for about 3-4 percent of annual global greenhouse gas emissions [7]. About 3.3% of total greenhouse gas emissions in Turkey stems from the waste management sector [8]. Only 1% of the total greenhouse gas emissions in Kocaeli city
(study region) results from wastewater and waste management practices. Approximately, 0.5% of the total greenhouse gas emissions of Kocaeli city arises from waste management activities [9]. Greenhouse gas emission units are converted to CO$_2$ equivalent (CO$_2$-e) to better define and evaluate its impact.

Another term commonly used to better define the greenhouse gas emission value is the global warming factor (GWF). GWF shows how much greenhouse gas emissions are produced per 1 ton of medical waste collected and transported. The global warming factor used in this study is based on a 100-year period and is taken from the latest IPCC evaluation report [10]. Consumption of fossil fuel especially diesel fuel during the transportation of medical waste can generate considerable amounts of GHGs. This study investigates future medical waste amounts and greenhouse gas emissions resulting from medical waste collection and transportation activities in the city of Kocaeli, Turkey, between the years of 2020 and 2040. Greenhouse emissions generated during the collection and transportation is also investigated and discussed. This study addresses important results for the local authorities when they consider alternative and environment friendly fuels for waste transportation.

2. Materials and methods
Kocaeli is an industrial city with a population of 1,830,772 (as of 2016 census) and is located in the northwest region of Turkey (Figure 1). According to Turkish Statistical Institute, 81,024 tons of medical waste was collected and disposed in Turkey in 2016 [11]. This means that approximately 450 million health facility visits were recorded in 2016. The collected medical waste is temporarily stored in specially designated rooms and collected daily by licensed vehicles. Kocaeli Metropolitan Municipality has 9 medical waste collection vehicles serving 29 health institutions. The collected medical wastes are transported to be treated in a sterilization facility with a capacity of 8 tons day$^{-1}$ located by the Kocaeli landfill site.

![Figure 1. Map of the study area showing the city districts in the city of Kocaeli [12]](image)

2.1. Population calculation methods
Estimations have been made using population projections for Kocaeli province, using the Ilbank method, arithmetic increment method and UNDP method.
2.1.1. Ilbank method. In Ilbank method, annual population growth rate (P) is calculated using the Equation (1):

\[ P = \left[ \left( \frac{N_f}{N_i} \right)^\frac{1}{a} - 1 \right] \times 100 \]  

(1)

where P is population growth rate coefficient, \(N_f\) is result of the last census, \(N_i\) is first census result and a is the year difference between the two censuses. The Population growth rate coefficient is calculated according to this principle:
- If \(P \geq 3\), \(P = 3\)
- If \(P \leq 1\), \(P = 1\)
- If \(1 < P < 3\), then P is taken its own value.

The projected population growth rate and the population projection for the coming years are calculated with the Equation (2):

\[ N = N_f \times \left( 1 + \frac{P^*}{100} \right)^n \]  

(1)

where N is future population, Nf is the result of the last census, \(p^*\) is population growth rate and n is the period until the year to be calculated.

2.1.2. Arithmetic Increment Method. In the Arithmetic increment method, the annual population growth rate (ka) is calculated using the Equation (3) as follows:

\[ ka = \frac{N_f - N_i}{a} \]  

(3)

where ka is population growth rate, Nf is the result of the last census, Ni is the result of the first census and a is year difference between two censuses. The projected population growth rate and the population projection for the coming years are calculated using Equation (4):

\[ N = N_f \times \left[ ka(tn - ti) \right] \]  

(4)

where N is future population, Nf is the result of the last census, ka is population growth rate, tn is next year and ti is year of the first census. In the calculations, since Ilbank method and geometric increment method give similar results, geometric increment method was not taken into consideration. As a result of the comparisons between the methods used, the arithmetic increment approach was adopted because it gives close values to the results of the address-based population registration system that was carried out in the study region.

2.1.3. United Nations (UNDP) method. In UNDP method, future population (N) is calculated using the Equation (5):

\[ N = Ni + \left( Ni \times \frac{P}{100} \right) \]  

(5)

where N is future population, P is population growth rate coefficient, and Ni is first census result. Population growth rate (P) coefficient is calculated according to Table 1.
2.2. Medical waste projection

The amounts of medical waste projection between 2020 and 2040 was made using the population data estimated for the city of Kocaeli.

2.3. Greenhouse gas projection

To determine the total diesel fuel consumed by medical waste collection vehicles, an average fuel consumption of 0.5 L per km traveled was selected [13]. Frueggaard, Astrup and Ekvall [14] reported that for each 1 L diesel fuel use, 0.5 kg CO$_2$-e for provision and 2.7 kg CO$_2$-e for combustion are produced, which corresponds to a total of 3.2 kg CO$_2$-e.L$^{-1}$. These values were used to calculate the total greenhouse gas emissions in this study. After determining the total amount of greenhouse gas emissions, a global warming factor (GWF) was determined by dividing the total amount of greenhouse gas emissions by medical waste collected annually.

3. Results and discussions

Results of this study showed that the projected population is expected to increase from 2,018,593 in 2020 to 2,920,748 in 2040 (Figure 2). According to the methods used to predict the future population, arithmetic method was the most realistic prediction method, thus, the future medical waste amounts and associated GHG emissions from collection and transportation were calculated based on this method. According to the arithmetic method, total medical waste projected per year increased from 2,978 tons in 2020 to 5,203 tons in 2040 (Figure 3). The study region has 9 medical waste collection vehicles operating for the 29 healthcare centers, which have a total of 2,141 hospital beds. The amount of medical waste generated per hospital bed varied between 0.21 and 2.00 kg/bed-day with an average value of 1.19 kg/bed-day as of December 2019. This range is similar to a study for Istanbul city, which showed the daily averages of medical waste per bed varied between 0.43 and 1.68 kg/bed-day [13]. Also, Mato and Kassenga [15] showed that medical waste amounts varied between 0.84 and 5.8 kg/bed-day. Abu-Qudais [16] reported for Jordanian hospitals that the amount of medical waste was between 0.29 and 1.36 kg/bed-day. In another study surveyed for Italian hospitals, the amounts of medical waste were between 0.2 and 3.5 kg/bed-day [17].

Approximately, a total of 85,900 tons of medical waste was expected to be generated in the study area between 2020 and 2040. Authorities reported that each medical waste collection and transport vehicle carries about 1 ton of medical waste per trip. Therefore, the total number of trips between 2020 and 2040 was estimated to be 85,900; this included the return trip from the first collection point to the sterilization facility and back the same collection point. It was then calculated that, approximately, 3,564,832 liters of gasoline was predicted to be consumed by the medical waste vehicles between 2020 and 2040. In the calculation of fuel use, an average diesel consumption of 0.5 liters per 1 km was selected, which was also recommended by Korkut [13]. Table 2 shows the predicted amounts of medical waste, fuel usages and associated GHG emissions between 2020 and 2040.

### Table 1. UNDP Turkey's population growth rates (P).

| Years       | High   | Medium | Low   |
|-------------|--------|--------|-------|
| 2020-2025   | 1.166  | 0.83   | 0.471 |
| 2025-2030   | 1.041  | 0.73   | 0.388 |
| 2030-2035   | 0.926  | 0.616  | 0.275 |
| 2035-2040   | 0.842  | 0.493  | 0.123 |
Figure 2. Projected population in the study region between 2020 and 2040.

Figure 3. Projected medical waste amounts between 2020 and 2040.
Table 2. Amounts of medical waste collected from 2020 to 2040, associated fuel usages and GHG emissions.

| Year | Medical waste generated (ton yr\(^{-1}\)) | Trip number to sterilization plant | Consumed diesel (Liter yr\(^{-1}\)) | GHG emissions (ton CO\(_2\)-e) | Global warming factor (GWF) (ton CO\(_2\)-e t\(^{-1}\)) |
|---|---|---|---|---|---|
| 2020 | 2,978 | 2,978 | 123,589 | 389 | 0.00013 |
| 2021 | 3,089 | 3,089 | 128,206 | 404 | 0.00013 |
| 2022 | 3,201 | 3,201 | 132,822 | 418 | 0.00013 |
| 2023 | 3,312 | 3,312 | 137,439 | 433 | 0.00013 |
| 2024 | 3,423 | 3,423 | 142,055 | 447 | 0.00013 |
| 2025 | 3,534 | 3,534 | 146,672 | 462 | 0.00013 |
| 2026 | 3,645 | 3,645 | 151,288 | 477 | 0.00013 |
| 2027 | 3,757 | 3,757 | 155,904 | 491 | 0.00013 |
| 2028 | 3,868 | 3,868 | 160,521 | 506 | 0.00013 |
| 2029 | 3,979 | 3,979 | 165,137 | 520 | 0.00013 |
| 2030 | 4,090 | 4,090 | 169,754 | 535 | 0.00013 |
| 2031 | 4,202 | 4,202 | 174,370 | 549 | 0.00013 |
| 2032 | 4,313 | 4,313 | 178,987 | 564 | 0.00013 |
| 2033 | 4,424 | 4,424 | 183,603 | 578 | 0.00013 |
| 2034 | 4,535 | 4,535 | 188,220 | 593 | 0.00013 |
| 2035 | 4,647 | 4,647 | 192,836 | 607 | 0.00013 |
| 2036 | 4,758 | 4,758 | 197,453 | 622 | 0.00013 |
| 2037 | 4,869 | 4,869 | 202,069 | 637 | 0.00013 |
| 2038 | 4,980 | 4,980 | 206,686 | 651 | 0.00013 |
| 2039 | 5,092 | 5,092 | 211,302 | 666 | 0.00013 |
| 2040 | 5,203 | 5,203 | 215,919 | 680 | 0.00013 |
| Total | 85,900 | 85,900 | 3,564,832 | 11,229 | |

Figure 4 shows the amounts of GHG emissions predicted to be generated during the collection and transportation of medical waste from 2020 to 2040. Annual greenhouse gas emission amounts arising from diesel fuel consumption were calculated based on 3.2 kg CO\(_2\)-e.L\(^{-1}\) emission factor, which was provided by Frueergaard, Astrup and Ekvall [14]. The total amount of GHG emissions predicted to be generated from the medical waste collection and transportation vehicles between 2020 and 2040 was calculated as 11,229 tCO\(_2\)-e. Then, the average global warming factor (GWF) was determined as 0.00013 tCO\(_2\)-e.t\(^{-1}\) by dividing the total GHG emissions by the amount of medical waste. In the literature, there are not many studies that investigated the GHG emissions from medical waste collection and transportation systems in the study region. However, collection and transport of medical waste would likely result in GHG emissions similar to GHG emissions from municipal solid waste (MSW) collection and transport activities as reported by several other studies [13, 18].
Figure 4. Amounts of GHG emissions predicted to be generated during collection and transportation of medical waste from 2020 to 2040.

4. Conclusion
It was shown in this study that medical waste collection and transport activities are expected to generate a total GHG emission of 11,229 tCO₂-e from 2020 to 2040. Furthermore, average global warming factor (GWF) was calculated as 0.00013 tCO₂-e per ton of medical waste collected and transported. However, precautions should be taken to reduce the amount of GHG emissions by, for example, using electric powered medical waste collection vehicles. Distance and fuel minimization, regulation of exhaust gases and use of newer collection vehicles are important aspects of reducing GHGs from diesel engine waste collection trucks. Parameterized collection models for the estimation of greenhouse gas emissions can be useful to estimate how much emission reduction is possible by making the proposed changes to the system. The predicted fuel consumption and greenhouse gas emissions are largely dependent on the assumed average fuel efficiency. Considering the potential harm that GHG emissions can cause to the global environment, GHG emissions should be reduced if not completely prevented. Global warming because of rising global temperatures caused by increased emissions of carbon dioxide and other greenhouse gases such as methane is expected to raise sea levels and cause extremes in climate patterns. Future studies should focus on using different engines such as compressed natural gas (CNG) or renewable energy-fueled vehicles.

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