Quantification of climate change mitigation potential at Novi Sad landfill

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Abstract. Unsanitary landfills and inadequate waste management system represent the 3rd largest global anthropogenic source of methane emissions in the environment. Waste management system in Novi Sad, the second largest city in Serbia, significantly contributes to the national carbon footprint. Unsanitary Municipal solid waste landfill in Novi Sad receives and deposits mixed waste without any treatment, thus causing the organic waste to biodegrade within the landfill body, and produce and emit the landfill gas (mostly CH₄ and CO₂) in the environment. Other potential sources of greenhouse gas emissions from waste management system include vehicles used for waste collection, machinery used at the landfill and landfill fires. The purpose of this study is to determine total baseline emissions of relevant greenhouse gases from the waste management system in Novi Sad, and to estimate and quantify the emission reduction potential for defined organic waste treatment scenario. The potential scenarios for organic waste diversion and treatment from the landfill include composting, anaerobic digestion, mechanical biological treatment, waste to energy, etc. Quantification of baseline emissions and climate change mitigation potential are estimated using the Solid Waste Emissions Estimation Tool, the model developed by Climate and Clean Air Coalition.

1. Introduction

Waste management system represents the third most important anthropogenic source of emissions of methane, which is considered as primary driver of climate change. This sector produces emissions of methane, carbon dioxide and black carbon, as the main source of particulate matter in the air. Novi Sad is the second largest city in Serbia, with a population of approximately 340,000 as of 2014. Novi Sad and the municipalities of Backa Palanka, Backi Petrovac, Beocin, Zabalj, Srbobran, Temerin, Vrbas, and Becej form the South Backa Waste Management Region (SBWMR). The SBWMR has a combined population of approximately 600,000 and encompasses approximately 3,000 square kilometers (km²). General information about SBWMR is presented in Table 1.
Table 1. General information about SBWMR

|                          | Total population | kg/capita/day | MSW (t) | Garden waste (t/year) | Food waste (t/year) | Total organic waste (t/year) | Rural population (%) |
|--------------------------|------------------|---------------|---------|-----------------------|---------------------|-------------------------------|----------------------|
| Serbia                   | 7,164,132        |               |         |                       |                     |                               |                      |
| Autonomous province (AP) of Vojvodina | 1,912,095 |               |         |                       |                     |                               |                      |
| Novi Sad                 | 346,163          | 1.07          | 135,194 | 18,075                | 40,788              | 58,863                        | 15                   |
| Becej                    | 36,663           | 0.94          | 12,579  | 2,533                 | 4,139               | 6,672                         | 37                   |
| Beocin                   | 15,551           | 0.94          | 5,336   | 713                   | 1,610               | 2,323                         | 52                   |
| Backa Palanka            | 54,631           | 0.94          | 18,744  | 4,658                 | 6,127               | 10,785                        | 50                   |
| Backi Petrovac           | 13,222           | 0.86          | 4,150   | 838                   | 1,144               | 1,982                         | 52                   |
| Temerin                  | 28,244           | 0.94          | 9,691   | 1,952                 | 3,188               | 5,140                         | 10                   |
| Zabalj                   | 25,873           | 0.86          | 8,122   | 1,641                 | 2,393               | 3,880                         | 64                   |
| Srbobran                 | 16,073           | 0.94          | 5,515   | 1,114                 | 1,520               | 2,634                         | 26                   |
| Vrbas                    | 41,378           | 0.94          | 14,197  | 2,859                 | 4,671               | 7,530                         | 42                   |
| SBWMR                    | 577,798          | 1.01          | 213,526 | 34,384                | 65,426              | 99,810                        | 26                   |

The nine municipalities in the SBWMR produce approximately 214,000 tons per annum (t/year) of solid waste. Nearly half of the solid waste generated in the region is organic. Overall, the region produces approximately 65,500 t/year of food waste and 34,500 t/year of garden waste.

The Novi Sad commercial sector (hotels, restaurants, and cafeterias) produces 805 t/year of organic waste from approximately 730 facilities. In addition, the city’s schools produce 283 t/year in food waste. Overall, these large-scale generators produce about 1,100 t/year of organic waste, primarily food waste, representing about 3 percent of the total organic waste produced in Novi Sad.

Landfilling is primary waste management practice in all municipalities. In addition, recycling is present, but only in certain municipalities and in small percentages. Although there were some attempts to introduce partial source separation system, it has not come to life in any of the municipalities. Relatively greater amounts of recyclable materials are separated within the waste separation line in Novi Sad. Since the input material for the separation line is mostly “low-quality” separated dry recyclables waste stream, the percentage of sorted materials is not high, and does not exceed 10%. Also, the capacity of the current plant is insufficient, and only about 10-15% of the total MWS generated in Novi Sad can be processed.

Therefore, all biodegradable waste is disposed of on landfills without any pretreatment and without controlled emissions of Greenhouse gases (GHG), which poses significant environmental risk that can be measured in metric tons CO₂ equivalent. In order to decrease the emissions, it is necessary to diver significant amount of bio waste from the landfill and find the best possible options for treating this waste stream. The most common treatment methodologies, feasible and potentially affordable for the developing countries include composting and anaerobic digestion (AD).

The aim of this paper is to estimate total emissions of methane and black carbon from waste management sector of SBWMR and compare them with emission reductions for different biowaste treatment technologies, in order to facilitate decision making regarding mitigation of climate change effects.
2. Material and methods

As part of the research conducted for the purposes of this project, the calculation of baseline GHG emissions is based on implementation of the SWEET tool developed for the Climate and Clean Air Coalition (CCAC).

SWEET assists stakeholders in estimating emissions and comparing the emissions reduction benefits of different waste management scenarios. The tool can be used to inform MSW management decision-making and priority setting and allows cities to benchmark and project their emissions over time.

The tool assists users in determining first-order city-level estimates of annual emissions of methane, black carbon, and other pollutants (e.g., carbon dioxide) from various sources including:

- Waste collection and transportation
- Waste burning (including open burning and fires at landfills and dumpsites)
- Landfills and dumpsites
- Waste handling equipment (e.g., forklifts, bulldozers)
- Organic waste management facilities (e.g., composting facilities)
- Waste combustion equipment (e.g., waste-to-energy facilities)

Emissions are expressed in metric tons CO\textsubscript{2} equivalent.

SWEET is designed to provide estimates of waste sector Short-lived Climate Pollutants (SLCPs) emissions for cities throughout the world, and to evaluate the effects of alternative waste management strategies on those emissions. Although SWEET uses state-of-the-industry assumptions and calculation methods, the emissions estimates should be considered as approximate and not a substitute for detailed technical analyses and feasibility assessments.

In order to assess the current state of greenhouse gas emissions using the model described in the previous chapter, it is necessary to define the input parameters that include the following information:

- Population covered by the waste collection system – 564,290.
- Climate conditions – Average annual precipitation 578 mm/year and mean annual temperature 11.2°C.
- Waste generation data – 1.01 kg/capita/day with average annual growth rate in quantity of 1%.
- Composition of waste – biowaste 44.6%, recyclables 34.8% and others 20.6%.
- Waste quantities treated by alternative methods (composting, AD, incineration, recycling) – 50,000 tons per year for both scenarios.
- Number and type of waste collection vehicle – 41 heavy-duty trucks and 9 light-duty trucks, all trucks use diesel, 730 working hours per year for each truck.
- Data on uncontrolled incineration of waste (landfill fires and open-air burning) – 3% of waste burned in open by residents and 1% of waste burned at the landfills or dumpsites.
- Number and type of waste handling machinery at the landfill – 5 forklifts, 6 bulldozers and 5 tractors.
- Landfill information – site opening year 1980, annual disposal – 107,139 tons per year, average waste depth 25m, without active gas extraction.

3. Results and discussion

The results of emission reductions for composting and AD are shown in the Tables 2 and 3 respectively, in comparison with the emissions from current waste management practice (Business as usual – BAU). The emission results are presented for CH\textsubscript{4}, as well as particulate matter (PM\textsubscript{2.5}, PM\textsubscript{10}) resulting from the black carbon emission.
Table 2. Emission reduction for Scenario with Composting plant (Metric tons)

| Year | CH₄  | PM₂.₅ | PM₁₀ | Total emission eq CO₂ |
|------|------|-------|------|-----------------------|
| 2020 | 0    | -25   | -10  | 0                     |
| 2021 | 0    | -25   | -10  | 0                     |
| 2022 | 4,593| -27   | -11  | 3,633                 |
| 2023 | -1,141| -27   | -11  | -2,110                |
| 2024 | -6,091| -27   | -11  | -7,069                |
| 2025 | -10,376| -27  | -12  | -11,365               |
| 2026 | -14,101| -28   | -12  | -15,099               |
| 2027 | -17,350| -28   | -12  | -18,359               |
| 2028 | -20,197| -28   | -12  | -21,216               |
| 2029 | -22,702| -28   | -12  | -23,731               |
| 2030 | -24,917| -29   | -12  | -25,956               |
| 2031 | -26,885| -29   | -12  | -27,934               |
| 2032 | -28,643| -29   | -12  | -29,703               |
| 2033 | -30,222| -30   | -12  | -31,292               |
| 2034 | -31,649| -30   | -13  | -32,730               |
| 2035 | -32,946| -30   | -13  | -34,037               |
| 2036 | -34,131| -30   | -13  | -35,234               |
| 2037 | -35,222| -31   | -13  | -36,336               |
| 2038 | -36,231| -31   | -13  | -37,356               |
| 2039 | -37,171| -31   | -13  | -38,307               |
| 2040 | -38,051| -32   | -13  | -39,198               |
| 2041 | -38,879| -32   | -14  | -40,039               |
| 2042 | -39,665| -32   | -14  | -40,835               |
| 2043 | -40,412| -33   | -14  | -41,594               |
| 2044 | -41,127| -33   | -14  | -42,322               |
| 2045 | -41,815| -33   | -14  | -43,021               |
| 2046 | -42,480| -34   | -14  | -43,698               |
| 2047 | -43,124| -34   | -14  | -44,355               |
| 2048 | -43,751| -34   | -15  | -44,994               |
| 2049 | -44,364| -35   | -15  | -45,619               |
| 2050 | -44,965| -35   | -15  | -46,233               |

The construction of a composting plant with a total capacity of 50,000 t/year implies a diversion of that amount of waste from landfills, and therefore a reduction in emissions in comparison to BAU. The composting plant is proposed to start operating in 2022. Therefore, the trend of a constant increase in total emissions will be discontinued in that year, and total emissions will continue to decrease until 2033, followed by a further increase.

Total emissions under this Scenario are projected to increase by about 6% between 2019 and 2050, but compared to BAU, total emissions are down approximately 17.7% over the same time period.
Table 3. Reduction of emissions for Scenario with AD plant

| Year | CH₄  | PM₂.₅ | PM₁₀ | Total emission eq CO₂ |
|------|------|-------|------|-----------------------|
| 2020 | 0    | -25   | -10  | 1                     |
| 2021 | 0    | -25   | -10  | 1                     |
| 2022 | 1,288| -27   | -11  | 213                   |
| 2023 | -5,171| -27 | -11  | -6,256                |
| 2024 | -10,753| -27 | -12  | -11,850               |
| 2025 | -15,595| -27 | -12  | -16,703               |
| 2026 | -19,811| -28 | -12  | -20,929               |
| 2027 | -23,495| -28 | -12  | -24,625               |
| 2028 | -26,730| -28 | -12  | -27,870               |
| 2029 | -29,582| -29 | -12  | -30,735               |
| 2030 | -32,111| -29 | -12  | -33,274               |
| 2031 | -34,363| -29 | -12  | -35,539               |
| 2032 | -36,382| -29 | -12  | -37,369               |
| 2033 | -38,200| -30 | -13  | -39,399               |
| 2034 | -39,848| -30 | -13  | -41,059               |
| 2035 | -41,350| -30 | -13  | -42,573               |
| 2036 | -42,728| -31 | -13  | -43,964               |
| 2037 | -44,000| -31 | -13  | -45,248               |
| 2038 | -45,181| -31 | -13  | -46,442               |
| 2039 | -46,285| -32 | -13  | -47,558               |
| 2040 | -47,322| -32 | -14  | -48,607               |
| 2041 | -48,301| -32 | -14  | -49,600               |
| 2042 | -49,232| -32 | -14  | -50,544               |
| 2043 | -50,122| -33 | -14  | -51,446               |
| 2044 | -50,975| -33 | -14  | -52,313               |
| 2045 | -51,798| -33 | -14  | -53,149               |
| 2046 | -52,595| -34 | -14  | -53,959               |
| 2047 | -53,369| -34 | -15  | -54,748               |
| 2048 | -54,125| -34 | -15  | -55,518               |
| 2049 | -54,866| -35 | -15  | -56,272               |
| 2050 | -55,592| -35 | -15  | -57,012               |

The construction of an AD plant with a total capacity of 50,000 t/year implies a diversion of that amount of waste from landfills, and therefore a reduction in emissions in comparison to BAU. The plant is proposed to start operating in 2022, and the trend of a constant increase in total emissions will be discontinued that year. Total emissions will decline until 2042, followed by a slight increase again in 2050.

Total emissions under this Scenario are projected to decrease by about 1% between 2019 and 2050, but compared to BAU, total emissions are down approximately 22.4% over the same time period.
A Graph that combines total emissions from both scenarios, as well as total emissions for the BAU is presented in Figure 1. The graph clearly ranks options based on total emissions from the waste management system. Continuation of existing practices is definitely leading to the highest emissions and a constant upward trend is observed. Significant emission reductions are observed for both scenarios, in which equal amounts of organic waste (50,000 t/year) are diverted, but the difference in total emissions is affected by the type of treatment. Therefore, the solution that contributes to the highest emission reductions is the diversion of 50,000 t/year of organic waste from the landfill and treatment within the AD plant, whose emissions in 2050 (after 28 years of use) would reach the level from the beginning of the plant's operation.

4. Conclusions
The research was conducted to consider the impact of waste management system and implementation of different biowaste treatment scenarios in SBWMR on greenhouse gas emissions. Without any changes to waste management practice, emissions will constantly increase and will reach over 200 000 tons of CO$_2$ equivalent in 2050.

Considering the requirements of the Landfill Directive regarding the reduction of biodegradable waste landfill disposal that should successively reach 65% reductions from the reference year, it turned out that the current system could not result in meeting this objective.

Both proposed scenarios contribute to achieving the objectives of diversion of biodegradable waste from landfills under the aforementioned Directive, which would also result in a more drastic reduction of GHG emissions, around 25% for the Composting Scenario and about 30% for the AD Scenario.

Therefore, in order to reach the biodegradable waste diversion goals, the decision makers within SWMBR will need to start implementing solutions for treatment of biodegradable waste, which include source separation and various treatment options for separately collected organic waste (food waste and green waste).
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