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REDUCING GHG EMISSIONS THROUGH IMPROVED WASTE MANAGEMENT: CASE STUDY OF THE CITY OF PRNJAVOR

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ABSTRACT

Waste management is becoming an increasingly important factor in the context of climate change, particularly due to methane emissions from landfills, which have a significantly stronger warming effect than carbon dioxide. The City of Prnjavor, facing challenges related to the growth of municipal waste and limited infrastructure, represents a representative example of a local community in transition toward a more sustainable waste management system. The aim of this research is to assess greenhouse gas (GHG) emissions from the waste sector and identify optimal strategies for their reduction.

The methodology is based on the IPCC Tier 1 approach for GHG emission estimation, applied to three waste management scenarios: full landfilling, partial recycling, and a combination of recycling and composting. The analysis includes emissions from waste collection, transport, and final treatment, as well as avoided emissions resulting from the processing of recyclable and biodegradable fractions.

Results show that the scenario combining recycling and composting can reduce total GHG emissions by 37% compared to the baseline scenario.

The conclusions suggest that transitioning to selective waste collection and treatment, along with strengthening institutional capacities, has the potential to enable efficient emission reductions and improve the waste management system, without the need for major infrastructure investments.

Keywords: GHG emissions, waste management, IPCC.

INTRODUCTION

The growing development of industry has provided numerous advantages for humanity, such as a higher standard of living, technological progress, and access to various products and energy sources. However, the negative effects of industrialization have become increasingly evident, particularly through the rising pollution of water, air, and soil. Population growth and increased consumption of food and various goods have led to a continuous rise in the amount of waste generated. If waste is not properly collected and managed, it can cause serious environmental and public health consequences. In order to mitigate the negative impacts of waste, it is essential to properly organize its collection, transportation, and final disposal.

Waste management is today one of the key societal issues, primarily due to significant environmental and climate-related challenges. The waste management sector is a major global source (GHG) emissions, which directly contribute to climate change. According to the Intergovernmental Panel on Climate Change (IPCC), the waste sector is responsible for approximately 3–5% of global anthropogenic GHG emissions, with the majority of these emissions stemming from methane (CH_4), a gas generated through the anaerobic decomposition of biodegradable waste in landfills (IPCC, 2014). Methane has about 28 times greater global warming potential than carbon dioxide (CO_2) over a 100-year period, making it a priority target in efforts to combat climate change (IPCC, 2014).

Bosnia and Herzegovina, like many other countries, faces challenges in establishing an efficient and sustainable waste management system. The United Nations Environment Programme (UNEP) states that proper waste management—including separation, recycling, composting, and reducing landfilling, can be an important factor in reducing GHG emissions (UNEP, 2010). Sustainable waste management involves minimizing waste generation, recycling, treatment, energy recovery, and the safe disposal of waste that cannot be reused. The Republic of Srpska has developed a regional municipal waste management system to ensure controlled and safe disposal of waste (MPUGE RS, 2020).

The City of Prnjavor is part of the Banja Luka region, which utilizes the Ramići regional sanitary landfill, located 54 km from the city and managed by the public utility company JP "DEP-OT" Banja Luka. PU "DEP-OT" was established in 2003 through a joint initiative of the City of Banja Luka and surrounding municipalities, with the aim of centralizing waste disposal at a single location (LWMP, 2021).

Operational waste collection in Prnjavor is carried out by the public utility company “Park” a.d. Prnjavor. The system covers approximately 30 local communities, while two remain outside the organized collection system, indicating partial service coverage (LWMP, 2021). In urban areas, waste is collected daily, in suburban areas weekly, and in rural parts every two weeks. In addition to regular waste collection, the company also provides waste collection upon request, by placing containers with a capacity of 7 m^3 and 1.1 m^3 (KP “Park” a.d., 2024).

In the city area, there are so-called “green islands” with six sets of containers for PET, metal, glass, and paper, as well as an additional 14 metal mesh containers for PVC packaging. However, the total number of containers for secondary raw materials and hazardous fractions is insufficient for optimal system functionality (KP “Park” a.d., 2024).

On average, around 25 tons of waste are transported daily from the area of Prnjavor to the regional landfill. The main problems encountered during collection include inadequate waste bins, improperly parked vehicles, and incorrectly disposed waste. Currently, there are no identified illegal dumpsites, but there is a persistent issue of overflowing containers, which requires an increase in their number, especially in the city center (KP “Park” a.d., 2024).

The company’s vehicle fleet consists mainly of older diesel trucks, which have relatively high gas emissions. The utility company plans to construct a transfer station, but there is currently no designated location or financial means for its construction (KP “Park” a.d., 2024).

The Local Waste Management Plan envisions the introduction of primary waste separation in households, institutions, and businesses using two color-coded bins for dry recyclable and wet non-recyclable waste. The waste would be transported to separation lines for further processing and recovery. Additionally, it foresees intensified collection of biodegradable waste during peak periods, such as autumn (leaves, branches). For bulky waste and special fractions, the plan proposes the establishment of a sorting center and seasonal collection. However, these recommendations have not yet been implemented, which slows down the establishment of a functional and sustainable system (LWMP, 2021).

In the Republic of Srpska, five regional landfills are operational: Banja Luka, Bijeljina, Zvornik, Prijedor, and Doboj, which are designated for the disposal of municipal and non-hazardous industrial waste. The landfill in Ramići is the largest among them, receiving waste from eight local communities, including Prnjavor, and covering an area with approximately 357,595 inhabitants. The landfill is equipped with the necessary infrastructure for controlled waste management, including systems for leachate control and landfill gas flaring (MPUGE RS, 2020).

The City of Prnjavor is facing a continuous daily increase in the amount of generated waste, while the existing waste management system does not fully meet ecological and climate-related goals. The aim of this paper is to provide a quantitative assessment of GHG emissions resulting from waste management in Prnjavor, using internationally recognized IPCC methodologies. Three waste management scenarios were modeled: landfilling, partial recycling, and a combination of recycling with composting. The analysis includes emissions from waste collection, transportation, and disposal, as well as avoided emissions resulting from recycling and composting activities. The results of this analysis are intended to serve as a basis for improving the current waste management system in Prnjavor and for achieving both local and national environmental objectives.

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 through a joint initiative of the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). The main reason for its creation was the growing concern over the rising concentration of GHG in the atmosphere and their impact on the planet's climate (IPCC, 2014). During the 1980s, numerous scientific studies indicated alarming trends such as the increase in average global temperatures, rising sea levels, and more frequent extreme weather events (WMO & UNEP, 1988; IPCC, 2007). In response to these challenges, the IPCC was founded as a scientific body that does not conduct its own research, but rather synthesizes existing literature and provides objective information on climate change to governments and policymakers (IPCC, 2014).

The primary role of the IPCC is to develop scientifically based methodologies for quantifying GHG emissions from various sectors, including the waste sector. The methodologies developed by the IPCC are known as emission inventory guidelines and are categorized into three tiers (Tier 1, Tier 2, and Tier 3), depending on data availability and the required level of detail for assessment (IPCC, 2006; IPCC, 2019a). The Tier 1 methodology is the most basic approach, relying on standardized emission factors and simple formulas, and is recommended for use in developing countries and communities with limited access to detailed data (IPCC, 2006).

Municipal waste management is a significant source of GHG emissions, as every stage of the system, from collection and transportation to final disposal, contributes to overall emissions. The most important GHGs generated in this sector are methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O). The largest share of these emissions originates from sanitary landfills, where biodegradable waste decomposes anaerobically, producing methane (Bjelić et al., 2023). According to Gautam and Agrawal (2021), the waste sector contributes approximately 5% of total global GHG emissions, with a particularly high percentage coming from landfills that do not have systems in place for the collection and treatment of landfill gas.

A significant potential for reducing GHG emissions lies in improving the operation of sanitary landfills, primarily through the installation of systems for methane collection and flaring. Such systems can reduce emissions by up to 70% compared to the initial state. Additionally, the integration of separate waste collection and recycling further contributes to emission reductions through so-called "avoided emissions," which result from replacing primary raw materials with secondary resources (Bjelić et al., 2023). Turner et al. (2015) emphasize that recycling materials such as plastic, metal, and glass has particularly high potential for emission reduction.

Composting organic waste also contributes to lowering GHG emissions, as it prevents anaerobic decomposition and methane formation in landfills while replacing chemical fertilizers. According to Thanh, Yabar, and Higano (2015), one ton of compost can significantly reduce the need for mineral fertilizers and thus indirectly lower emissions associated with their production.

Emissions from waste transport represent an important component of the total emissions in the waste management sector. Older vehicles, diesel fuel, a high number of daily routes, and non-optimized logistics increase emissions of CO_2, NO_x, and particulate matter. Fleet modernization, route optimization, and the use of cleaner fuels can reduce waste transport emissions by up to 18% (Bjelić et al., 2022).

The reduction of emissions from the waste sector has been recognized as an important objective in international climate commitments, such as the Paris Agreement and the Nationally Determined Contributions (NDCs). Therefore, the implementation of effective waste management measures, such as separate waste collection, recycling, composting, and landfill gas management is recommended not only for reducing emissions, but also for strengthening the capacity of local communities to address climate change (UN Environment, 2018; IPCC, 2019a; World Bank, 2018). These activities simultaneously support socio-economic development, employment, and more efficient use of local resources, thereby contributing to the overall sustainable development of communities (King & Gutberlet, 2013; Ludwig et al., 2012).

The subject of this paper is the calculation of GHG emissions from the municipal solid waste management sector in the area of the City of Prnjavor, using the IPCC Tier 1 methodology. The analyzed scenarios include landfilling, partial recycling, and a combination of recycling and composting, with quantified emissions from landfilling, waste collection, transport, as well as avoided emissions due to recycling and composting. The aim of this study is to identify, based on the conducted analysis, the measures that can improve the existing waste management system, reduce its negative environmental impact, and contribute to achieving sustainable and climate-resilient objectives, in accordance with local and national strategic documents. The paper also aims to provide useful insights for decision-makers and local government units, and to serve as a starting point for developing improved local waste management plan.

MATERIAL AND METHODS OF WORK

As part of the analysis, the impact of different municipal solid waste management scenarios on GHG emissions in Prnjavor was assessed for a total annual waste quantity of 6507 tonnes. The morphological composition of the waste was based on the results of a study conducted at the "Ramići" landfill within the framework of the EIB project (EIB, 2024). Recyclable materials make up approximately 49,6% of the total waste, while the organic component accounts for 17,2%, making them key factors in the assessment of GHG emissions.

The objective of this study is to quantify emissions for four different scenarios and identify measures for their reduction.

Scenario 1 (Baseline scenario) reflects the current state, with no organized recycling or composting, where all waste is disposed of in the landfill without any treatment. Emissions result from the anaerobic decomposition of organic waste and the transport of waste to the landfill. This scenario serves as a reference base for comparison (LWMP, 2021).

Scenario 1a (Transport improvement) represents a technical enhancement through the construction of a transfer station and the introduction of a semi-trailer for waste transport, optimizing logistics, reducing fuel consumption, operational costs, and emissions from transportation. This scenario has been proposed in the Local Waste Management Plan as a priority measure (LWMP, 2021).

Scenario 2 (Partial recycling) involves establishing a basic system for source separation of recyclable waste, in which 10% of the total waste volume is diverted from disposal. The separated materials are recycled, thereby reducing landfill volumes and emissions through avoided production of primary raw materials LWMP, 2021).

Scenario 3 (Integrated system with recycling and composting) represents the most advanced approach, combining recycling (15%) and composting (10%) of biodegradable waste from kitchens and gardens. A portion of the waste is composted centrally, while another portion is processed through household composters. This scenario significantly reduces the amount of landfilled waste, eliminates part of the transport demand, and aligns most closely with sustainable waste management principles outlined in the strategic documents of the Republic of Srpska (MPUGE RS, 2020; SEI, 2022).

In this paper, GHG emissions from municipal waste disposal were estimated using the basic approach (IPCC Tier 1), recommended for emission inventory development when detailed local data on waste composition and decomposition dynamics are unavailable (IPCC, 2019b). The Tier 1 methodology employs internationally accepted default values derived from global research, enabling a practical estimation of emissions based on fundamental information such as waste quantity, composition, disposal method, and the presence of emission control systems.

The methodology assumes that methane emissions occur in the same year the waste is landfilled, without detailed modeling of the temporal dynamics of decomposition. The estimation is performed using a standardized mathematical formula prescribed by the IPCC, which takes into account: the quantity of waste, the proportion of biodegradable material in the waste, the type of landfill, and the presence of methane capture systems and oxidation in the landfill's upper layers (IPCC, 2019b).

$$CH_4 \text{ emissions (Gg/y)}=[(MSW_T \cdot MSW_F \cdot L_0)-R](1-OX)$$

Where is:

MSW_T – total generated municipal solid waste (Gg/year)

MSW_F – fraction of generated waste disposed to landfill
L_0 – methane generation potential
R - fraction of methane recovered (Gg/year)
OX – oxidation factor

All parameters that are not locally known were taken from IPCC recommendations. The DOC content is calculated based on the composition of the waste (IPCC, 2019b):

$$DOC = 0,4 \times A + 0,17 \times B + 0,15 \times C + 0,3 \times D$$

Where is:
A – share of paper and textiles,
B – share of garden and green waste,
C – share of kitchen waste,
D – share of wood waste.

In addition to emissions from the landfill, emissions from diesel fuel consumption during waste collection and transport were also calculated. For avoided emissions, emission factors were used for individual recycling streams (paper, plastic, metals, glass) and composting (Vogt et al., 2023).

RESULTS AND DISCUSSION

The results obtained using the IPCC Tier 1 methodology enabled a quantitative assessment of GHG emissions from the municipal waste sector in the city of Prnjavor for the defined waste management scenarios. The analysis includes emissions from landfilled waste, as well as emissions resulting from waste collection and transport activities. All data were analyzed for a single calendar year, using reference values recommended by the IPCC (2006; 2019b). The results of the GHG emission estimates by analyzed scenarios and their components are presented in Figure 1.

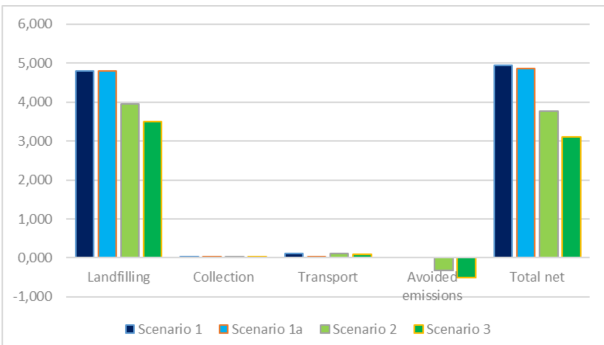

Figure 1. Comparison of GHG emission ccomponents by MWM sscenarios.

In Scenario 1, where all waste (6507 tonnes) is landfilled without prior treatment, methane emissions amount to 0,171 Gg (4,791 Gg CO_2eq), while emissions from collection and transport reach 0,036 Gg and 0,117 Gg CO_2eq, respectively. The total net emissions amount to 4,944 Gg CO_2eq, making this scenario the most unfavourable in terms of climate impact.

Scenario 1a involves the improvement of waste transport logistics through the introduction of a transfer station. Emissions from landfilling and collection remain the same, while transport emissions decrease to 0.037 Gg CO_2eq. The total net emissions are reduced to 4.864 Gg CO_2eq, confirming that transport optimisation can make a measurable contribution to GHG reduction with limited costs.

In Scenario 2, 10% of the waste is recycled, which reduces landfill emissions to 3,954 Gg CO_2eq and transport emissions to 0,106 Gg CO_2eq. Avoided emissions amount to −0,319 Gg

CO_2eq, and the total net emissions to 3,776 Gg CO_2eq, representing a reduction of approximately 23,6% compared to the baseline scenario.

Scenario 3 includes 15% recycling and 10% composting of biodegradable waste. Landfill emissions amount to 3,489 Gg CO_2eq, while emissions from collection and transport are further reduced to 0,034 Gg and 0,100 Gg CO_2eq, respectively. The most significant contribution in this scenario comes from recycling, which results in avoided emissions of −0,507 Gg CO_2eq. These avoided emissions arise from the difference between the emissions that would have been generated by the production of new raw materials and products and those generated by the recycling process of materials such as paper, plastic, metal, and glass (Figure 2 and Figure 3). The total net emissions are reduced to 3,116 Gg CO_2eq, which is 1,828 Gg (37%) less compared to Scenario 1.

Scenario 3 demonstrates that an integrated waste management approach, combining decentralised measures such as household composting with institutionally organised recycling can lead to significant GHG emission reductions. This model does not require major infrastructure investments but relies on active citizen participation and efficient logistics for the collection and processing of secondary raw materials. Thus, Scenario 3 confirms its potential to become an applicable and adaptable model for other local communities aiming to reduce emissions and align with national and international climate goals. Notably, this approach contributes to building long-term climate resilience and strengthening the capacity of communities to address the challenges of climate change in a systematic and sustainable way.

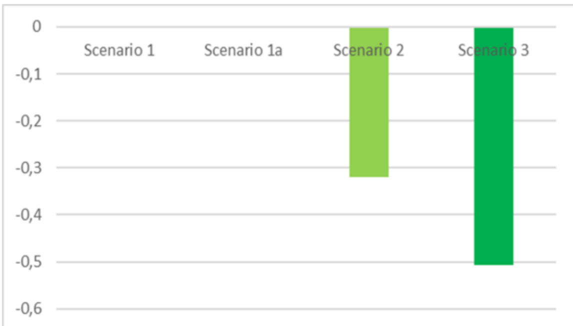

Figure 2. Avoided emissions in scenarios 2 and 3.

Scenario 3 therefore emerges as the recommended strategy in planning local waste management policies aimed at achieving environmental and climate balance.

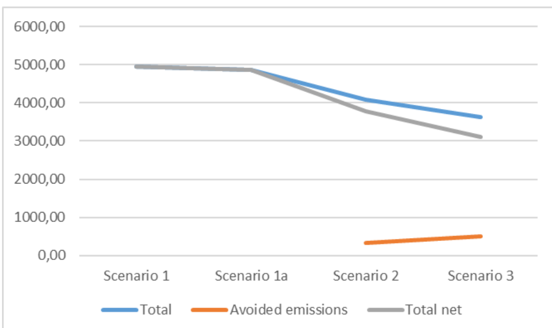

Figure 3. Contribution of avoided emissions to the reduction of total emissions.

The analysis results indicate a gradual reduction in net GHG emissions across the scenarios compared to the reference Scenario 1 (Figure 4). Technical optimisation of transport in Scenario 1a leads to a 1,62% reduction in emissions, while partial recycling in Scenario 2 results in a 23,65% reduction. The greatest reduction, 37%, is achieved in Scenario 3, which combines recycling and composting. The findings confirm that integrated approaches with local waste treatment have the highest potential for emissions reduction in the municipal waste sector.

Figure 5 shows the landfill emissions by scenario. The highest emissions are recorded in Scenarios 1 and 1a, where all waste is disposed of without treatment. In Scenario 2, recycling 10% of waste reduces emissions, while Scenario 3, with additional composting, records the lowest emissions. The results confirm that waste valorisation directly reduces GHG emissions.

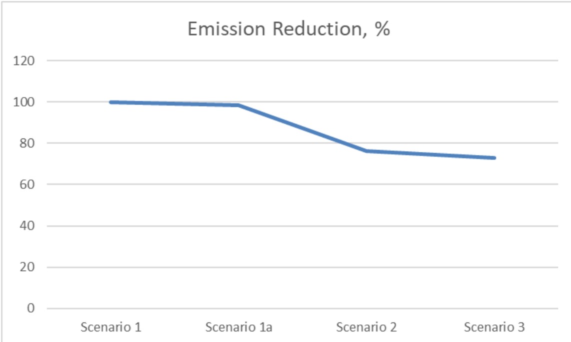

Figure 4. Emission reduction by scenarios compared to Scenario 1.

The obtained values are consistent with previous studies showing that shifting from landfilling to recycling and composting can reduce GHG emissions by 30% to 50% (Lou & Nair, 2009). The analysis by Zero Waste Europe (2019) further confirms that proper bio-waste management can reduce emissions by over 150 kg CO_2eq per capita annually.

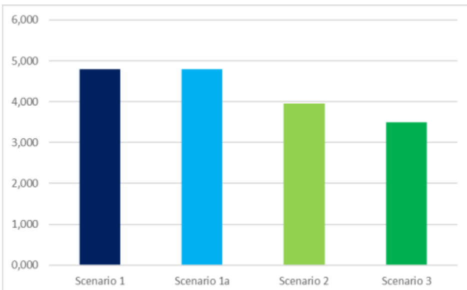

Figure 5. Graphical presentation of GHG emissions from waste disposal according to scenarios.

Special emphasis was placed on household composting, using a conservative avoided emissions factor of 0,054 tCO_2eq per tonne of waste (Vogt et al., 2023). The results show that household composting, especially when combined with other measures, can significantly contribute to emission reduction. The third scenario aligns with circular economy goals and supports Bosnia and Herzegovina's climate commitments under the Paris Agreement and the NDC.

To verify the reliability of emission estimates, a sensitivity analysis was conducted on two key parameters of the IPCC methodology: degradable organic carbon (DOC) and the methane correction factor (MCF). Increasing the DOC from 0,25 to 0,30 results in a methane emission increase of over 10%, while decreasing the MCF from 0,8 to 0,6 indicating improved landfill management, reduces emissions by up to 15%. These results confirm the findings of Zhao et al. (2019) and Rasouli et al. (2025), who reported that variations in these parameters can lead to emission differences of up to 30%. This highlights the need to use locally specific data to improve the accuracy of estimates.

The results obtained in this study can be compared with the analysis by Bjelić et al. (2023), who determined GHG emissions of 560 kg CO_2eq per tonne of waste for the city of Zvornik under a scenario similar to the one applied in this study. In contrast, Scenario 3 for the city of Prnjavor, which includes recycling and household composting, showed emissions of 482 kg CO_2eq per tonne of waste. This finding confirms that even partial implementation of recycling and composting measures can lead to significant reductions in GHG emissions with relatively low infrastructure investments. The results may serve as a valuable input for the development of local waste management plans tailored to the specific needs of local communities.

CONCLUSIONS

Based on the conducted research, which included an analysis of GHG emissions from the municipal waste management sector in the city of Prnjavor using the IPCC Tier 1 methodology and a comparison of four different scenarios, the following conclusions can be drawn:

The choice of waste management model has a decisive impact on GHG emissions,

landfilling (Scenario 1) results in the highest emissions, while integrated models (Scenario 3) significantly reduce them,

Technical measures such as transport optimization (Scenario 1a) and partial recycling (Scenario 2) enable moderate emission reductions, while combining recycling with composting (Scenario 3) achieves a 37% reduction.

Home composting proves to be a low-cost and effective measure, and integrated approaches allow for the avoidance of emissions associated with raw material production.

Achieving a sustainable waste management system also requires institutional support, education, and active community engagement..

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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