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GHG Emissions in the Current and Future MSW Management System in Zvornik, Bosnia and Herzegovina

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Abstract: Each and every step in the process of municipal solid waste (MSW) management generates the greenhouse gases (GHG). Therefore, it is imperative to focus on MSW from the source to the final waste disposal in order to decrease the negative impact on the environment. This study aims to calculate the GHG emissions at the present moment (Status Quo) for waste management as well as on the improved MSW management that should be implemented in this local community by 2027 (Scenario 2027). To visualize waste streams in these two scenarios, the STAN 2.5 software was used, and for the calculation of GHG emissions in the City of Zvornik, the IWM-2 software was used. The MSW management Status Quo is basically characterized by the collection communal of waste and its deposition on the landfill without a degasification system and landfill gas treatment. The guidelines and recommendations for MSW management improvement, Scenario 2027 propose the establishment of separate collections of secondary raw materials and biodegradable waste, and improved collection and treatment of landfill gas at the landfill site. The implementation of these measures would result in a reduction of approximately 40% in GHG emissions compared to the Status Quo. The most significant impact would be realized in the environment due to the collection and treatment of landfill.

INTRODUCTION

Traditionally, the term "waste" has a negative connotation and comprehends something undesirable, discarded by people due to inadequate or inaccurate thinking about the waste (Seadon, 2010).
Waste is any substance or object that the holder discards, intends to discard, or is required to discard; waste management means the collection, transport, recovery, and disposal of waste, including the supervision of such operations and the subsequent care of disposal sites, including actions taken as a dealer or broker (Directive 2008/98/EC). Communal waste is household waste, as well as other waste that is, by nature or due to its content, similar to household waste (Official Gazette of the Republic of Srpska no. 111/13, 106/15, 16/18, 63/21, 65/21). The impact of waste on the environment is mainly achieved by the pollution emitted throughout the entire life cycle of the waste, from the point of waste creation, when a product has no utility, through waste collection, waste treatment processes (recycling, composting, combusting, depositing on the landfill, etc.) (Vergara and Tchobanoglous, 2012).
In 2020, Bosnia and Herzegovina (B&H) generated 1200000t of municipal waste, and the population of B&H produced an average of 354 kg of municipal waste (Agency of Statistics of B&H, 2022).
Waste depositing is still the major method of waste treatment in B&H.
There are several active regional sanitary landfills in B&H: Sarajevo, Banja Luka, Bijeljina, Zenica, Mostar, Zvornik, Živinice (still under construction), and Prijedor (still under construction). However, the number of illegal dumpsites is still high. Also, the country lacks facilities for disposal of special

categories of waste, which usually ends up at municipal landfills, threatening human health and the environment. Current recycling rates are far lower than those achieved in other European countries (Ionkova, Doychinov, Silajdzic, *et al*., 2019). A number of illegal dumpsites, low recycling rates, and the number of non-compliant municipal landfills threaten the environment and climate change through pollution and human health in general (Bjelić, Čarapina, Markić, *et al*., 2015).

Human activities and natural systems are the two main sources of greenhouse gases (GHG) (Xi-Liu and Qing-Xian, 2018). The three most important greenhouse gases in terms of abundance and contribution to the greenhouse effect are water vapor (H_2O), carbon dioxide (CO_2), and methane (CH_4) (Berman, Fladeland, Liem, *et al*., 2012). Human activities are the major cause of the increased CO_2 concentration in the atmosphere. In recent decades, two-thirds of the greenhouse effect has been caused by human activities (Songolzadeh, Soleimani, Takht Ravanchi, *et al*., 2014). The total GHG emissions generated by waste management contribute up to 5% of the total GHG emissions into the atmosphere. (Gautam and Agrawal, 2021). The GHG compounds relevant to climate change caused by solid waste management activities include CH_4, CO_2, and N_2O (King and Gutberlet, 2013).

There are currently several dedicated research studies on the GHG emissions caused by MSW management in B&H.

In Daul's (2014) research, three different waste management scenarios in the Federation of B&H were compared using GHG emission calculation. This research concludes that the primary cause of the substantial amount of GHG emissions is directly attributed to waste management. Therefore, it is necessary to supplement existing waste management practices with waste recycling in order to decrease GHG emissions.

Therefore, it is necessary to supplement existing waste management practices with waste recycling in order to reduce greenhouse gas emissions. Bjelic, Markic, Pesic, *et al.* (2017) conducted a study analyzing three scenarios for municipal solid waste (MSW) management in the area of the city of Banja Luka (B&H). They applied the Life Cycle Assessment (LCA) to quantify emissions into the environment. One of the environmental impact categories considered in this study is the Global Warming Potential (GWP). The study revealed that the highest value of GWP is associated with waste disposal on dumpsites or illegal dumping sites, as well as on landfills without the proper collection and treatment of the landfill gas.

A significantly larger number of studies on the GHG emission from waste have been conducted in neighboring countries. For example, in the Republic of Serbia, studies by Mihajlović, Pešić, Jovanović, 2019; Stanisavljević, Ubavin, Batinić, *et al.,* 2012; and Djekic, Miloradovic, Djekic, *et al.,* 2019, were conducted. Similarly, in the Republic of Croatia studies by Anić-Vučinić, Hublin, Ružinski, 2010; Schneider, Kirac, Hublin, 2012; 2013; were carried out.

The research objective of this paper is to calculate the GHG emissions in the current waste management system for the City of Zvornik (B&H), and to predict the GHG emission by proposing improvements to the existing waste management system. This research can serve as a recommendation for improving the management of mixed communal waste. It can serve as an example of other local communities facing similar waste management challenges, aiming to minimize the negative environmental impacts and their consequences on human health and well-being.

MATERIALS AND METHODS

The City of Zvornik covers a territory of 371.95 km^2 and is located in the northeastern part of the Republic of Srpska (RS), B&H. It is considered one of the more developed self-governing local communities within the RS.

According to the last population census conducted 2013, the City of Zvornik had population of 54,407 inhabitants (Republika Srpska Institute of Statistics, 2017). Out of the total population, approximately 11,082 inhabitants, or 20.36% live within the downtown area.

The dominant fraction of municipal waste in Zvornik is organic waste (31.45%), while recyclable raw materials make up about 41.49% of MSW (11.28% paper and cardboard, 11.05% foil, 7.53% glass, 6.93% plastic, and 4.70% metal).

All quantitative indicators, including waste generation, collection, transport, and treatment, rely on a good understanding of waste flows through the entire waste management system. The MSW waste flow monitoring methodology, therefore, includes a detailed analysis of the amount of waste generated as well as further waste processing and treatment flows using the Sankey's material flow diagram, in this case specifically adapted for waste. In this study, waste streams were constructed using STAN2.5 software (Cencic and Rechberger, 2008).

For the GHG calculation, the IWM-2 software was used. As outlined by McDougall, White, Franke, et al. (2008), the IWM-2 software is a life cycle inventory (LCI) tool specifically engineered to aid in the development of sustainable solid waste management systems. IWM-2 is a widely available analytical tool based on life cycle assessment (LCA) intended for waste managers and policy makers in waste management. Within the context of Zvornik, Bosnia and Herzegovina, we applied the IWM-2 software to perform an LCA for both the current and anticipated future waste management systems.

Advanced waste management systems have the potential to substantially reduce gas emissions that contribute to GWP. The environmental impact indicator used in this research measures the effect of waste management in the City of Zvornik on global warming. The scenarios "Status Quo" and "Scenario 2027" were modeled using data from the Local Waste Management Plan for the City of Zvornik for the period 2022–2027 (UNDP, Environmental Protection and Energy Efficiency Fund of the Republic of Srpska and the City of Zvornik, 2022).

The current MSW management in Zvornik – Status Quo

Waste management in the City of Zvornik primarily involves the collection of mixed communal waste into a single container. About 60% of the inhabitants is currently covered by the waste collection service. The collected waste is subsequently transported to the regional landfill "Crni vrh" which was established in 2017. This landfill accepts waste from several municipalities, including Kalesija, Sapna, Šekovići, Osmaci, and Bratunac. The landfill span 69 hectares and has an annual capacity of 40,000 t of MSW, with an expected operational lifespan of 20 years. In 2020, about 8,220 t of MSW was collected from the area of the City of Zvornik. The waste management in Zvornik in 2020 was based on: (1) waste collection; (2) transporting the waste to the landfill; and (3) depositing the waste in the landfill (Figure 1).

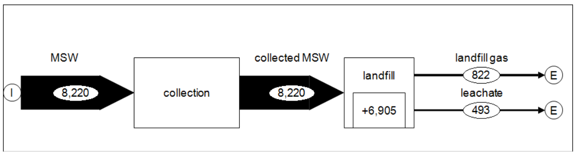


Figure 1. MSW management in Zvornik – Status quo

The waste collection is the collection of waste, including the previous separation and temporary storage of waste, for transport to the waste treatment facility (Official Gazette of the Republic of Srpska no. 111/13, 106/15, 16/18, 63/21, 65/21). The waste collection in the City of Zvornik is done by nine vehicles, seven of which are constantly used for waste collection and transport, and the remaining two are in reserve (in case of malfunction or need to engage due to extraordinary circumstances). The average age of the vehicle fleet for waste collection is 20 years. Among the vehicles used for waste collection and transport, one is equipped with a Euro diesel II engine, another with a Euro diesel V engine, while the remaining five vehicles operate on Euro diesel III engines.

In 2020, approximately 37,300 L of diesel was used for communal waste collection in Zvornik. Given the total amount of waste collected, which stands at 8,220 t, it can be concluded that around 4.54 L of diesel is required to collect 1 t of waste. Of the total diesel consumed, vehicles with Euro II engines used 7,000 L (19%), vehicles with Euro III engines used 20,900 L (56%), and vehicles with Euro V engines used 7,000 L (25%).

Taking into account the capacity of each vehicle involved in the waste collection process in 2020, as well as the number of trips made daily, weekly, and annually, we calculated the maximum possible amount of waste that each vehicle could collect. According to our findings, the maximum waste collection potential was 25,898 t. Considering that approximately 8,220 t of waste was collected in 2020 it can be concluded that the vehicles of this communal company were operating at an average capacity of 32%.

Literature data on diesel consumption for waste collection varies significantly depending on local conditions, ranging from 1.6 to 10.1 L of diesel/t of collected waste. The highest consumption was observed in the seldom populated regions of Denmark (Larsen, Merrild, Christensen, 2009). In urban areas with a high population density, diesel consumption is 3.2 L/t of collected waste, while in areas with a lower population density, the diesel consumption increases to approximately 14.6 L/t of collected waste (Nguyen and Wilson, 2010). Diesel consumption, which accounts for emptying containers and traversing the distance between them, ranges from 3.7 to 4.6 L/t of waste (Eisted, Larsen, Christensen, 2009).

The waste transport is a process that includes loading, transport (as well as reloading), and unloading of waste (Official Gazette of the Republic of Srpska no. 111/13, 106/15, 16/18, 63/21, 65/21). One of the most crucial factors in the transport of communal waste is the density and degree of waste compression, as this can affect the amount of waste collected before unloading. Metal and scraps, which have a high density, are less compressible than materials such as plastic or paper that have lower density (Yaman, Anil, Jaunich, *et al.,* 2019). The vehicles used in the City of Zvornik transport the collected waste to the landfill situated approximately 15 km from downtown. The total annual diesel consumption for this task amounts to 12,200 L. Given that the quantity of waste transported in 2020 was 8,220 t, it implies that transporting of 1t of waste requires 1.48 L of diesel.

Waste deposit refers to any procedure or method that involves the permanent disposal of waste following the D-list, which is a set of regulations that outlines the categorization, testing, and classification of waste (Official Gazette of the Republic of Srpska no. 111/13, 106/15, 16/18, 63/21, 65/21). Waste deposited on the landfill undergoes complex biochemical and physical processes of decomposition, resulting in the production of leachate and landfill gas (Vaverková, Toman, Kotovicová, 2012). If not properly managed, the emission of these substances can pose significant environmental challenges and health risks to humans (Kotovicová, Toman, Vaverková, *et al.,* 2011). Additional issues related to the landfills include the risk of fires and explosions, damage to vegetation, unpleasant odors, surface contamination, and air pollution (Calvo, Moreno, Zamorano, *et al.,* 2005).

Waste deposit remains the most common method of waste treatment worldwide (Aljaradin and Persson, 2012; Ismail and Manaf, 2013).

The decomposition processes of waste, particularly organic waste under anaerobic conditions, generate significant quantities of landfill gases. These gases tipically consist of CH_4 (40-60%), CO_2 (35-50%), N_2 (0-20%), O_2 (0-1%) and H_2S (70-280 mg/m^3), along with trace amounts of compounds such as *n*-aliphatic and aromatic hydrocarbons and halogen compounds (total concentration of 2,000 mg/m^3) (Vaverková, Toman, Kotovicová, 2012). Landfill gas should be collected as much as possible through a degasification system and then either flared or utilized for other purposes. The waste of the City of Zvornik is disposed of at the "Crni vrh" landfill according to all regulations that define waste disposal, but the landfill gas generated there is released directly into the atmosphere without prior treatment.

MSW management in the future in Zvornik–Scenario 2027

Compared to the quantity value of waste in the year 2020 (8,220 t), it is estimated that the quantity of communal waste in 2027 will be increased by about 40%, whereas the quantity of waste in 2027 would be 11,644 t. The increase in waste quantity includes parameters such as an increase in the degree of collected waste, a rise in the Gross domestic product (GDP), and an increase in the generated quantity of waste per inhabitant of the City of Zvornik.

The waste management system in Zvornik should undergo certain improvements up to the year 2027: (1) separate collection of packaging and biodegradable waste, treatment of that waste (including separating, recycling, and composting), and collection and depositing of the remaining waste; (2) improvement of the transportation fleet used for collecting and waste transportation, and (3) construction of a degasification system for treatment of landfill gas, which should include gas collection and flaring.

By the year 2027, the separation of 10% of secondary raw materials for recycling is planned. Out of the generated waste that is projected in the quantity of 11,644 t, 10% of the waste would be separated, apropos 1,164 t of secondary raw material (by primary or secondary recycling). Of this separated quantity, it is estimated that 284 t would be paper, 568 t of plastic,121 t of metal, and 191 t of glass.

The quantity of biodegradable waste expected be collected and composted separately is projected to be around of 987 t. The quantity of waste that would be deposited at the "Crni vrh" landfill, in this case, would be around 9,494 t.

The waste flow in Scenario 2027 is presented in Figure 2.

The proposal for upgrading the waste collection system in Zvornik introduces a "two bins" system. In the first bin/container, all the fractions of so-called "dry" waste are collected, apropos secondary raw material: plastic (PET, plastic foil, plastic bags), paper and cardboard, metal, rubber, and glass. In contrast, the second bin/container is meant for all "wet" fractions of the remaining communal waste.

For the separate collection of secondary raw materials, it is planned to collect packaging waste in a single container. This means citizens would separate paper, cardboard, plastic, metal, and glass into one container. The parameters taken into consideration when estimating the number of these containers/bins include:(1) the density of packaging waste (185 kg/m^3), (2) the degree of fullness of the container (80%), (3) the volume of the container (1.1m^3) and (4) collection once per week. Up to the year 2027, it is necessary to purchase and place 138 containers with a volume of 1.1m^3.

Separate collection of biodegradable waste in Zvornik should be organized for individual households, especially in rural areas, so that each household has one composter at its disposal. It is necessary to obtain, in total, 6,766 wooden composters with a volume of 380 L by2027 (UNDP, Environmental Protection and Energy Efficiency Fund of the Republic of Srpska and the City of Zvornik, 2022).

In the system of waste collection and transport, it is planned to reduce diesel consumption by approximately 18%. This will be achieved by procuring newer trucks that have smaller capacity and use less diesel fuel (UNDP, Environmental Protection and Energy Efficiency Fund of the Republic of Srpska and the City of Zvornik, 2022).

One of the most important upgrades in this landfill management system is the construction of a degasification system located at the newly built sanitary landfill "Crni vrh". Furthermore, this will be achieved by collecting about 60% of the landfill gas and treating it in a flare.

In the year 2027, the quantity of waste that will be recycled and composted is projected to be 2,150 t, of which approximately 18.46% will be directed to other flows. As a result, the quantity of waste deposited should be reduced by this percentage.

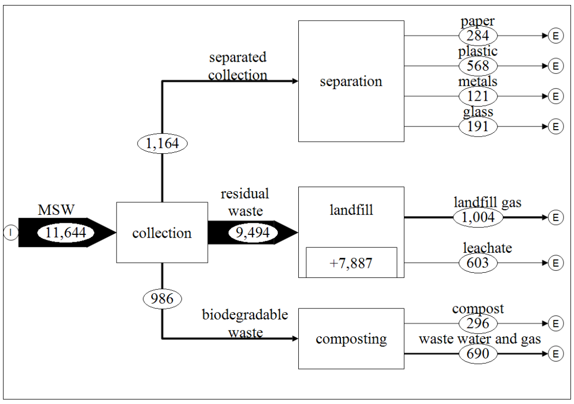


Figure 2. MSW management in Zvornik in Scenario 2027

RESULTS AND DISCUSSION

Status Quo

Based on the data related to the length of the collection route and the number of trips during a day and a week, the calculation of GHG for 2020 has been done (Figure 3).

The total emission of GHG for the collection process in the City of Zvornik amounts to100.52 t $CO_{2\text{-}eq}$/year.

Based on the calculated GHG emissions from all seven vehicles and the quantity of waste collected in 2020, the GHG emissions per ton (t) of collected waste amount to 12.23 kg $CO_{2\text{-}eq}$/t of waste. A study conducted in Denmark in 2009, which focused on the calculation of GHG emissions during the collection of waste from residential blocks, reported a GHG emission range 5.0-5.4 kg of $CO_{2\text{-}eq}$/t of collected waste (Larsen, Vrgoc, Christensen, *et al.,* 2009). The total GHG emissions from transporting vehicles in 2020 amounted to 32.87 t of $CO_{2\text{-}eq}$/year. The average GHG emissions per t of transported waste was calculated to be 4.0 kg $CO_{2\text{-}eq}$/t of waste. When considering both the collection and transportation of waste in Zvornik, the total GHG emissions reached 133.39 t of $CO_{2\text{-}eq}$/year. Recalculating it per t of waste, the GHG emissions amounted to 16.23 kg $CO_{2\text{-}eq}$/t of waste. In many studies, the GHG emissions generated by collecting and transporting waste vary from 7.7 kg of $CO_{2\text{-}eq}$/t of waste (Korkut, Yaman, Küçükağa, *et al.,* 2018), to 9.3-9.9 kg $CO_{2\text{-}eq}$/t of waste (Larsen, Vrgoc, Christensen, *et al.,* 2009). The reason for the high values of GHG generated by vehicles, as stated in the literature, is the type of waste treatment, whether it is local or regional.

Based on the waste composition analysis (morphological composition of the waste obtained through a standard for separate components of waste in RS), the quantity of waste deposited in 2020 was approximately 8,220 t. Additionally, the method of waste deposition, characterized by direct release of landfill gas into the atmosphere without prior treatment, necessitated the calculation of GHG emissions.

The total GHG emissions from the Zvornik landfill amount to 11,356 t of $CO_{2\text{-}eq}$/year, apropos 1.38 t of $CO_{2\text{-}eq}$/t of deposited waste.

In their study, Manfredi, Tonini, Christensen, *et al.* (2009) made different calculations of GHG emission for different types of landfills and obtained the following results: (1) dumpsites: >1 t of $CO_{2\text{-}eq}$/t of deposited waste, (2) conventional landfill: 0.3 t of $CO_{2\text{-}eq}$/t of deposited waste, (3) landfill with a low content of carbonite: 0.07 t of CO_2-eq/t of deposited waste, (5) landfill using the landfill gas for producing the energy: from 0.07 to 0.030 t of $CO_{2\text{-}eq}$/t of deposited waste.

The primary GHG emitted from landfills is CH_4. The GWP of the CH_4 depends on its conversion to CO_2 through various processes such as combustion in flares, utilization in gas engines, or by microbial oxidation in the soil top cover of the landfill. It is important to note that when CH_4 is converted to CO_2, its contribution to GWP does not account, as CO_2 is a less potent greenhouse gas than CH_4 (Maria, Góis, Leitão, 2020).

Based on the recalculated emission for the reference year 2020, it can be concluded that in the waste management system in Zvornik, which involves waste collection, transportation, and depositing waste, the highest GHG emissions from the landfill (98.84%) is attributed to the uncontrolled release of landfill gas without prior treatment. The process of waste collection contributes to a mere 0.87% of GHG emissions, while transportation accounts for approximately 0.29%.

The landfill is still the most dominant factor in total GHG emissions. By improving the landfill operation, the emissions into the environment can be reduced significantly, even up to 50-70%. The greatest benefit for the environment from the GHG emission aspect is the exploitation of landfill gas for obtaining energy (heat and/or electric energy).

Scenario 2027

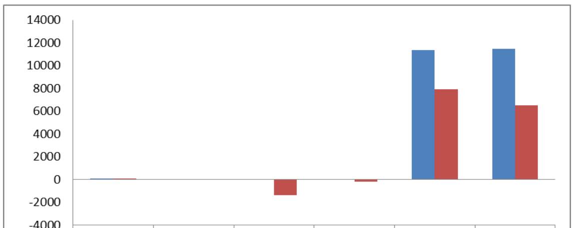
In the foreseeable future, the enhancement of waste collection and transportation of waste in the City of Zvornik should have as a priority the reduction of diesel consumption. The European Commission adopted a strategy for reducing diesel consumption and CO_2 emissions from heavy-duty vehicles in 2014 (European Commission, 2014).

According to this strategy, upgrading of technology in heavy-duty vehicles can lead to reductions in diesel consumption and CO_2 emission. Significant reductions in diesel consumption and emission of CO_2 in heavy-duty vehicles can be achieved through various technological improvements, such as motor improvements (including heat recuperation), transmission upgrades, improvements in aerodynamics, wheels optimization, and the use of additional equipment. Furthermore, reducing vehicle mass can also contribute to efficiency gains. Additionally, efficiency can be increased through better management of the vehicle fleets, and staff training (European Commission, 2014).

The proposed solution to reduce the diesel consumption associated with activities like waste collection and transportation in the City of Zvornik is a novelty in the vehicle fleet.

By procuring the vehicles with Euro V or Euro VI motors (capacity<7.5 t), with an average diesel consumption of approximately 0.25 L/km instead of 16.400 L consumed by two old vehicles, the diesel consumption would be reduced to 7.500 L for the new vehicles. This transition to newer vehicles would result in cost savings and lead to a reduction in diesel

consumption generated by the collection and transport of the waste by up to 18% annually.
Furthermore, if these measures of vehicle fleet improvement and collection system enhancement were implemented, the total GHG emissions resulting from waste collection would amount to 81 t of $CO_{2\text{-}eq}$/year. The GHG emissions from waste transport would amount to 26 t of $CO_{2\text{-}eq}$/year. Consequently, the GHG emissions from waste collection in 2027 would be reduced by 20% and from waste transportation by 15%, compared to the current waste collection practices. By improving the fleet, GHG emissions would decrease from 12.23 kg $CO_{2\text{-}eq}$/t of waste (Status Quo) to 9.19 kg $CO_{2\text{-}eq}$/t of waste (Scenario 2027). The estimated GHG range from 9.4 to 368 kg $CO_{2\text{-}eq}$/t of waste, depending on factors such as the collection method, capacity and selection of transport equipment, as well as the travel distances involved (Eisted, Larsen, Christensen, 2009).
The negative values of GHG represent savings, i.e. benefits in the environment, and the positive values represent ballast or pollution of the environment.
In Figure 3, it is evident that recycling and composting processes have negative values, indicating their positive environmental benefits within the waste management system. In contrast, activities such as waste collection and transportation have positive values, indicating their negative impact on the environment.
The process of separating and recycling secondary raw materials enables the reuse of materials and the production of new products using recycled materials. This directly reduces the need to extract and exploit natural resources, which minimizes negative impacts on the environment. In addition, the separation of secondary raw materials reduce the amount of waste that is deposited of, which further contributes to the reduction of waste and benefits for the environment. The recovery of high-frequency materials such as LDPE, PET, textiles, steel cans, and aluminum cans has resulted in significant avoided GHG emissions. This emphasizes the crucial role of effective source-segregated recycling of these key waste materials in reducing the GHG impacts associated with waste management (Turner, Williams, Kemp, 2015).
The process of composting, which involves generating the compost of high quality for agriculture use, results in negative GHG emissions, and thus provides environmental benefits. Instead of depositing the biodegradable waste in the landfill, which is currently practiced and represents a negative impact on the environment due to the significant GHG generation, composting enables the production of a valuable product known as compost.
Composting presents a high potential for GHG reduction by avoiding chemical fertilizer production since the compost product is used as an agricultural fertilizer to replace the chemical alternative. One ton of compost product can supply the soil with nutrients of 7.1 kg of nitrogen, 4.1 kg of phosphorus, and 5.4 kg of potassium (Thanh, Yabar, Higano, 2015).



	collection	transport	recycling	composting	landfill	total
2020	100	33	0	0	11356	11489
2027	81	26	-1361	-167	7919	6498

Figure3. GHG emissions (in a t of $CO_{2\text{-}eq}$) in scenario Status Quo and Scenario 2027

The largest GHG emission in 2020 was from the landfill. One of the most important upgrades in the landfill management system is the construction of a degasification system to treat the gas on a flare. It is expected that the construction of the degasification system will be completed in 2023, which will enable the collection and treatment of landfill gas at approximately 60% capacity by 2024. This system is anticipated to significantly reduce GHG emissions from the landfill by 2027. Instead of directly releasing landfill gas directly into the atmosphere, the gas will be flared, producing CO_2, which has a lower greenhouse effect (about 25 times less potent). This results in a direct decrease in GHG emissions by approximately 40% annually.

The calculations for the GHG emissions from the waste management system in Zvornik include separate processes of waste collection, transport, recycling, composting, and landfill deposition, as presented in Figure 4. It can be concluded that the GHG emissions per t of waste generated in Scenario 2027 is significantly lower compared to the Status. In 2020, the GHG emissions per t of MSW were measured at 1,400 kg of $CO_{2\text{-}eq}$. However, it is anticipated that by 2027, this value will significantly decrease to approximately 560 kg of $CO_{2\text{-}eq}$/t of MSW, resulting in a reduction of about 60% in GHG emissions. This significant decrease can be attributed to the upgrade of landfill, which plays a crucial role in reducing GHG emissions per t of waste. Depending on the type of landfill, the GHG emissions from the landfilling of waste have been calculated to range from −145 to 1,016 kg $CO_{2\text{-}eq}$/t of wet waste (Friedrich and Trois, 2013).

Composting and recycling processes, as well as improved waste collection and transportation, lead to a reduction in GHG emissions (Eisted, Larsen, Christensen, 2009; King and Gutberlet, 2013).

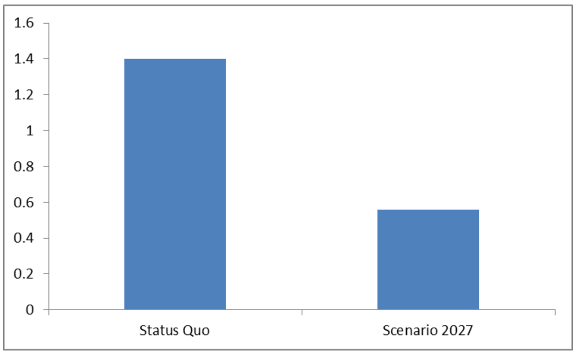


Figure 4. Total GHG emission (in kg/t of MSW) in the scenario Status Quo and Scenario 2027

CONCLUSION

The current system of waste management in the City of Zvornik (Status Quo) consists of the following processes: (1) collection of the mixed communal waste, (2) transportation of the mixed communal waste to the landfill, and (3) deposition the waste at the landfill. The city faces several challenges, including a very old vehicle fleet, low level of waste collection, and a lack of separate waste collection.

At present, the highest GHG emissions originate from the sanitary landfill, which lacks a degasification system and proper landfill gas treatment.

By constructing a degasification system and implementing landfill gas treatment until 2027 (Scenario 2027), a significant reduction in GHG emissions can be achieved. Additionally, a substantial GHG emissions reduction can be achieved by implementing a separate collection system for packaging and biodegradable waste, optimizing collection routes, and updating the waste collection vehicles.

This study can provide valuable insights for numerous local communities struggling with waste management issues. It can serve as a guiding resource for upgrading and improving their current waste management systems.

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Summary/Sažetak

Svaki korak u procesu upravljanja čvrstim komunalnim otpadom (MSW) stvara gasove staklene bašte (GHG). Stoga je imperativ fokusirati se na komunalni otpad od izvora do konačnog odlaganja otpada kako bi se smanjio negativan utjecaj na okoliš. Ova studija ima za cilj izračunavanje emisija stakleničkih plinova u sadašnjem trenutku (Status Quo) za upravljanje otpadom kao i za poboljšano upravljanje komunalnim otpadom koje bi trebalo implementirati u ovoj lokalnoj zajednici do 2027. godine (Scenario 2027). Za vizualizaciju tokova otpada u ova dva scenarija korišten je softver STAN 2.5, a za proračun emisija GHG u Gradu Zvorniku korišten je softver IWM-2. Status quo upravljanja komunalnim otpadom u osnovi karakteriše sakupljanje komunalnog otpada i njegovo odlaganje na deponiju bez sistema za degasizaciju i tretman deponijskog gasa. Smjernice i preporuke za poboljšanje upravljanja komunalnim komunalnim otpadom, Scenarij 2027, predlažu uspostavljanje odvojenih sakupljanje sekundarnih sirovina i biorazgradivog otpada, kao i poboljšano sakupljanje i tretman deponijskog gasa na lokaciji deponije. Implementacija ovih mjera rezultirala bi smanjenjem emisija stakleničkih plinova za približno 40% u odnosu na status quo. Najveći uticaj bi se ostvario na životnu sredinu zbog sakupljanja i tretmana deponije.