Proceedings of the 8th International Conference on Civil Engineering for Sustainable Development
(ICCESD 2026), 5~7 February 2026, KUET, Khulna, Bangladesh

A LIFE CYCLE ASSESSMENT APPROACH TO QUANTIFY THE EMISSION OF GREENHOUSE GASES THROUGH MUNICIPAL SOLID WASTE MANAGEMENT SYSTEM IN CHATTOGRAM

Pragga Paromita Paul[1], Quazi Hamidul Bari[2], Md. Al Amin*[3]

[1]*Graduate Student, Ingram School of Engineering, Texas State University, USA, e-mail: praggaparomitapaul.ce@gmail.com*
[2] *Professor, Department of Civil Engineering, Khulna University of Engineering and Technology, Bangladesh, e-mail: qhbari@ce.kuet.ac.bd*
[3]*Research Assistant, Department of Civil Engineering, Khulna University of Engineering and Technology, Bangladesh, e-mail: mdalamin2308@gmail.com*

***Corresponding Author**

ABSTRACT

Life cycle assessment (LCA) is a systematic and frequently applied tool to assess the environmental attributes of waste management options. The OpenLCA is a powerful LCA tool for scrutinizing performance and identifying environmental hotspots by appraising waste treatment options in any desired city. In this study, the current waste management options in Chattogram City Corporation have been evaluated by this software (OpenLCA version 2.0) to determine the most critical environmental impact. Being Bangladesh's second largest metropolitan city, the city generated a solid waste of 1069 tons/day, which is increasing day by day. Currently, the municipal solid waste management options for this city are the open dumping sites, which are situated in Ananda Bazar at Halishahar and Arefin Nagar at Pahartali. The OpenLCA analysis shows that, considering the eighteen prime environmental impact categories, climate change (Global Warming Potential) has grossed the highest with a total of 535 tons of CO_2/day and a net amount of 195275 tons of CO_2 annually. The other important categories that have been found too major for the environment are human toxicity, marine ecotoxicity, and freshwater ecotoxicity. Whereas water depletion, natural land transformation, and freshwater eutrophication impact categories have shown a minimal impact on the environment. This highlights the vital need for an efficient waste-handling system within urban areas, as open dumping sites are no longer a sustainable solution for a growing city like Chattogram. To ensure sustainability in waste management, such as open dumping, which is a current practice, it's imperative to enhance other existing waste management solutions, such as incineration or sanitary landfilling. This study shows that the rising global warming potential is deeply concerning for both the country and the world, highlighting the urgent need to improve waste management practices to protect the environment and public health.

Keywords: *OpenLCA; Greenhouse Gas; Open Dump; Waste Management; Carbon Emissions*

1. INTRODUCTION

Rapid urban growth and shifting consumption patterns have led to a steady increase in municipal solid waste (MSW) around the world. The World Bank's (What a Waste 2.0) report notes that global waste generation was about 2.01 billion tons in 2016 and could reach roughly 3.40 billion tons by 2050. This projected rise underscores how urgently countries need stronger waste management strategies and more sustainable treatment options (Kaza et al., 2018). Waste mismanagement and open dumping directly affect greenhouse-gas (GHG) emissions, mostly methane (CH_4), a significant source of global greenhouse gases and an important area to focus on for reducing emissions soon (IPCC (WGIII), 2022).

In South Asian countries, numerous challenges make waste management difficult, such as a large amount of waste being organic, limited and improper source separation, and most waste still being dumped into open dumps or unsanitary landfills (Idris et al., 2004; Siddiqua et al., 2022). Regional plans highlight the need to strengthen 3R (Reduce, Reuse, Recycle) strategies and increase investment in waste-management infrastructure to help cities move away from uncontrolled dumping (Hossain et al., 2024; Shumshunnahar, 2024). Analyses by the Asian Development Bank also show that better MSW systems are closely connected to achieving SDG 11.6, which aims to reduce the environmental impacts of urban areas (Jagath & Gamaralalage, 2020).

In Bangladesh, waste generation has been increasing progressively for many years. The "Bangladesh Waste Database 2021" shows that the urban waste generation rate is rising, and several major cities now generate more than 850 tons of waste per day (Waste Concern, 2021). Limited collection efficiency and poor waste separation continue to push many areas toward open dumping and burning (Roy et al., 2022).

Chattogram, is the second-largest city of Bangladesh which also has a major seaport, reflects these waste challenges sharply (Laurent et al., 2014). The Chattogram City Corporation (CCC) has been depending on two dumping sites, Anandabazar (Halishahar) and Arefin Nagar (Pahartali), both of which have a very low sanitary landfill standard (Alam et al., 2024). Both the Arefin Nagar (73 acres) and Halishahar (10 acres) sites have no leachate management system, so polluted liquid can easily spread and affect the environment (Ali Ashraf et al., 2015). Daily waste generation (2,500–3,000 t/day) far exceeds safe handling capacity, with most still ending up in unsanitary dumping sites.

Over the years, many researchers have turned to life cycle assessment (LCA) to get a clearer picture of how different waste-management systems perform in practice. LCA has been used to look beyond simple disposal and compare options like landfilling, composting, incineration, and recycling by weighing both their benefits and their trade-offs. These studies show how each method carries its own environmental footprint, and they help reveal whether a system remains sustainable as waste volumes grow and conditions change (Wu et al., 2015). LCA provides a way to assess the entire solid waste management pathway, from generation to final disposal, and identify the stages that produce the greatest environmental impacts.

LCA is a systematic method used to evaluate the environmental impacts of a product, process, or system throughout its entire life cycle, from resource extraction to final disposal (Klinglmair et al., 2014). Building on this approach, many studies have applied LCA to assess environmental impacts and greenhouse gas emissions in MSW (Gautam & Agrawal, 2021; Yadav & Samadder, 2018; Zhao et al., 2009). Paul et al. (2025) conducted an LCA of MSW management in Khulna City, using OpenLCA and the ReCiPe midpoint method. In their study, they modeled the environmental impacts associated with different end-of-life (EOL) treatment scenarios for 1 ton/day of MSW, including open dumping, sanitary landfilling, and hybrid combinations.

This study examines the environmental impacts of the current MSW management system operated by the CCC using an LCA approach using OpenLCA software. The goal of this study is to understand how the existing system affects the environment, identify the main hotspots, especially those contributing to climate change, and determine which waste management processes create the greatest ecological burden.

Through this assessment, the study evaluates how the current waste system in Chattogram contributes to carbon emissions, identifies the stages that generate the highest carbon-related environmental burdens, and determines which components of the system pose the greatest overall climate risk. This approach makes it possible to systematically identify environmental hotspots throughout the entire waste management process, from household generation to final disposal, reflecting the real-world operations of the CCC.

2. METHODOLOGY

2.1 Study Area

Chattogram, located in southeastern Bangladesh along the Bay of Bengal, is the country's largest seaport and its second-biggest city. Covering about 155 square kilometers, it now has a population of over five million people. As the city continues to grow, so does the amount of MSW, reaching roughly 1,069 tons each day (Alam et al., 2025). Most of this waste is taken to two major open dumping sites, Ananda Bazar in Halishahar and Arefin Nagar in Pahartali, as shown in Fig. 1, where everything is disposed of together without any form of sorting. This approach has created significant environmental and public health challenges. The region's hot, humid weather and intense monsoon seasons worsen the situation by increasing both leachate generation and greenhouse gas releases from the unmanaged waste piles.

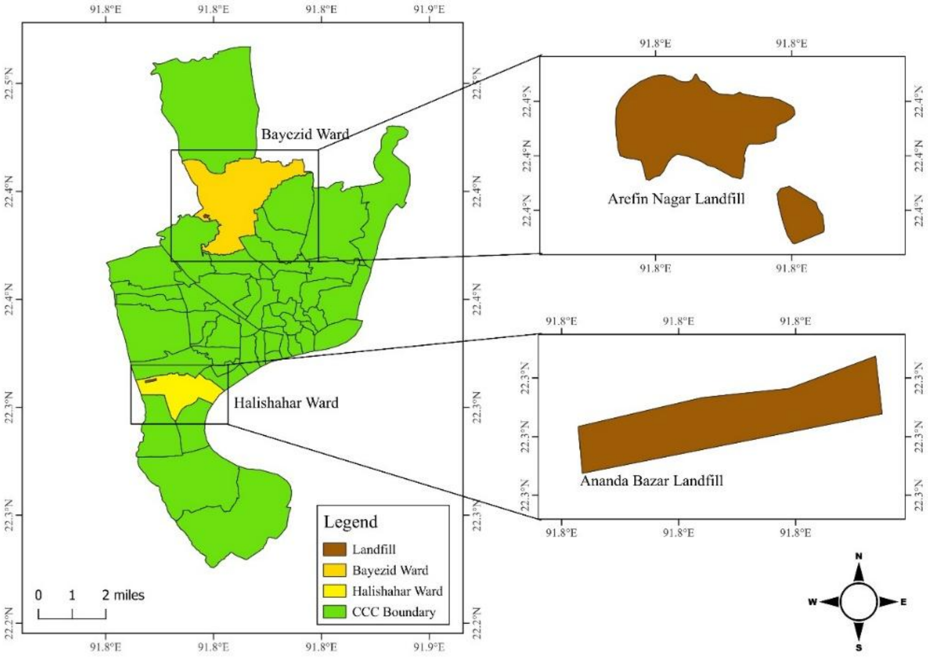

Fig. 1: Chattogram City Corporation (CCC) Landfill

2.2 Functional Unit

In this study, the functional unit was set as the total amount of MSW generated each day in CCC, 1,069 tons. This represents the city's average daily waste production and serves as the baseline for evaluating environmental impacts. The modeled waste stream reflects the reported composition of MSW in Chattogram, dominated by food waste (approximately 78%), followed by plastic (8%), paper (4%), fabric (3%), wood (2%), and other materials (5%), which were used to define material fractions entering the system (Alam et al., 2025). All inputs, emissions, and outputs within the system boundaries were calculated based on this amount. These composition shares were directly incorporated into the life cycle inventory through the background datasets rather than modeled as separate foreground processes.

2.3 System Boundary

In this study, the system boundary in Fig. 2 encompasses the waste generated at households through to final disposal at open dumping sites. The assessment includes household waste collection, transportation to temporary transfer points, and final hauling to the Ananda Bazar (Halishahar) and Arefin Nagar (Pahartali) dumping locations. Due to the absence of primary data on fuel consumption, transportation-related fuel use and emissions were estimated using a freight lorry with a load capacity of 3.5–7.5 metric tons compliant with the EURO 1 emission standard, based on the ecoinvent 3.8 cut-off regional datasets. Recycling, composting, and energy recovery processes were excluded from the system boundary, as these practices are not implemented at a meaningful scale within the current MSW management system of Chattogram. Additionally, the major emissions associated with this system are outlined in Fig. 2.

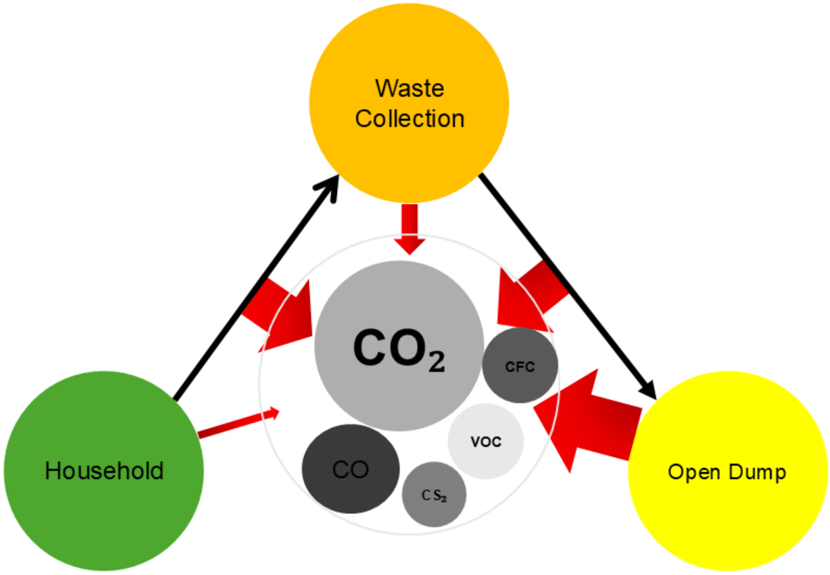

Fig. 2: Conceptual system boundary and major emission pathways for municipal solid waste management in Chattogram City

2.4 Impact Assessment Method

The environmental impacts of Chattogram's MSW management system were assessed using the midpoint approach in OpenLCA (version 2.0). Among the prime eighteen environmental impact factors, the carbon-related emission factors have been considered for this study to identify the carbon profile, which includes Climate Change, Ionizing Radiation, Photochemical Oxidant Formation, Particulate Matter Formation, and Ozone Depletion. To quantify these impacts, the ReCiPe Midpoint (H) methodology was used, which provides factors to translate emissions and resource use into measurable environmental impact scores (Huijbregts et al., 2017). Data on waste collection, transportation, and disposal were modeled using the ecoinvent 3.8 cutoff region database, ensuring reliable and consistent life cycle inventory data (Wernet et al., 2016).

3. RESULTS & DISCUSSIONS

The carbon-equivalent emission profile of the selected impact categories from the municipal solid waste management system in CCC is illustrated in Fig. 3. The results are expressed on a logarithmic scale to emphasize the relative magnitude of each environmental impact. The five major categories considered in this study include Climate Change (GWP100), Ionizing Radiation (IRP), Photochemical Oxidant Formation (POFP), Particulate Matter Formation (PMFP), and Ozone Depletion (ODPinf).

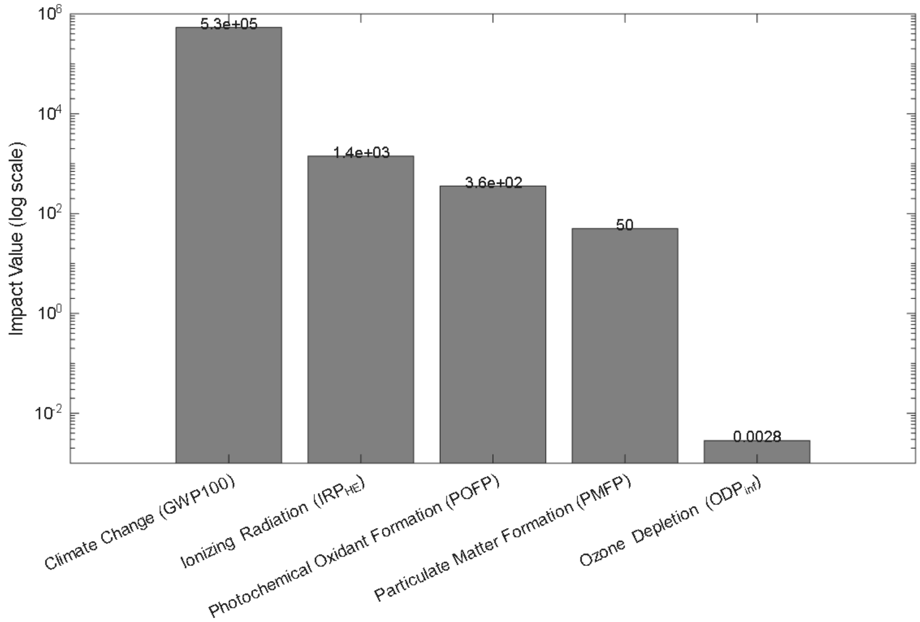

Fig. 3: Carbon-equivalent emission profile of impact categories (logarithmic scale)

3.1 Climate Change (GWP100)

Climate change emerged as the dominant impact category in Fig. 3, with the highest equivalent emission of approximately 5.3×10^5 kg CO_2-eq per day, indicating that current waste management practices in Chattogram are strongly climate-intensive. This result is caused by open dumping and uncontrolled anaerobic degradation of organic waste, which generates substantial methane (CH_4) emissions. Given methane's significantly higher global warming potential relative to CO_2, even partial degradation under unmanaged landfill conditions leads to disproportionately high climate impacts.

Table 1: Greenhouse Gas Emissions from the Existing MSW Management System in Chattogram

Metric	**Emission Rate**
Daily CO_2-eq emissions	535-ton CO_2-eq / day
Annual CO_2-eq emissions	195,275-ton CO_2-eq / year
Daily waste (functional unit)	1,069-ton waste/day
CO_2-eq per ton of waste	0.500-ton CO_2-eq / t waste (≈ 500.5 kg CO_2-eq/t)

CO_2-eq per person per year (pop = 5,000,000)	0.039-ton CO_2-eq / person / year (≈ 39.1 kg)
CO_2-eq per person per day (pop = 5,000,000)	0.000107-ton CO_2-eq / person / day (≈ 0.107 kg)

Similar magnitudes and dominant contributions from methane emissions have been reported in LCA studies of MSW systems in Khulna and other South Asian cities, where open dumping and limited gas capture were identified as the main drivers of GWP (Paul et al., 2025; Khandelwal et al., 2019). The consistency of these findings suggests that the elevated GWP observed here reflects structural characteristics common to rapidly urbanizing cities with disposal-oriented waste systems. A detailed breakdown of daily, annual, per-ton, and per-capita carbon emissions is provided in Table 1, further illustrating the scale of climate burdens associated with the existing system.

3.2 Ionizing Radiation (IRP)

Ionizing Radiation (IRP) ranked as the second-highest impact category in Fig. 3 with a value of around 1.4×10^3 Bq Co-60-eq. This elevated contribution is mainly caused by upstream electricity generation embedded in transportation and waste handling processes, which are modeled using grid-based energy mixes dominated by non-renewable sources in the background datasets. The absence of energy recovery or controlled treatment means that all waste transport and handling burdens are directly borne by fossil-based electricity and fuel systems, amplifying indirect radiation-related emissions. Compared to particulate matter and photochemical oxidant formation, ionizing radiation remains higher because it captures cumulative upstream energy supply effects rather than direct emissions alone. These results indicate that reducing transport intensity or shifting toward cleaner energy sources could substantially lower IRP impacts, even without major changes in disposal practices.

3.3 Photochemical Oxidant Formation (POFP)

Fig. 3 shows that photochemical oxidant formation (POFP) reaches approximately 3.6×10^2 kg NMVOC-eq, making it one of the dominant atmospheric impact categories. This impact is primarily driven by VOC and NO_x emissions from diesel fuel combustion during waste collection and long-distance transport to disposal sites. Given that Chattogram's MSW system relies heavily on road-based transport with limited emission controls, these precursors substantially contribute to ozone formation in the lower atmosphere. The elevated POFP values, therefore, reflect the transport-intensive nature of the current waste management system, which highlights crucial air quality deviation depending on fuel-oriented collection and disposal systems.

3.4 Particulate Matter Formation (PMFP)

Fig. 3 indicates that particulate matter formation (PMFP) reaches approximately 50 kg PM_{10}-eq, reflecting a substantial air-quality burden in this system. This impact is mainly driven by diesel exhaust emissions from waste collection and long-distance transportation, as well as uncontrolled waste burning at open dumping sites, both of which are known sources of fine particulate matter. Similar PMFP dominance has been reported in LCA studies of MSW systems, where fuel-intensive transport and open disposal practices were identified as the primary contributors to particulate emissions (Hamanaka & Mutlu, 2025). Fine particles released from these sources can significantly degrade air quality and pose serious health risks, including respiratory and cardiovascular diseases. The elevated PMFP observed in this study, therefore, underscores the strong linkage between disposal-oriented waste management, transport dependence, and urban air-pollution exposure in Chattogram.

3.5 Ozone Depletion (ODPinf)

Ozone Depletion (ODPinf) has the lowest observed impact among all the categories in Fig. 3, with an equivalent emission value of 0.0028 kg CFC-11-eq. Although the magnitude is minimal, this impact category is still environmentally significant. The release of halogenated compounds from certain waste materials and discarded appliances contributes to the breakdown of stratospheric ozone, which shields the Earth from harmful ultraviolet (UV) radiation (Breivik et al., 2004). Ozone layer thinning can lead to increased UV exposure, causing skin cancer, cataracts, and adverse effects on marine life.

3.6 Carbon-Based Elementary Flow Analysis

Fig. 4 presents the aggregated carbon-based emissions across all elementary flows reported in the life cycle inventory. A logarithmic scale was applied to account for large differences among flows, ranging from 10^{-16} to 10^{0} kg. Fossil CO_2 emissions dominate the profile, followed by biogenic CO_2 and non-fossil CO_2. Carbon monoxide (both fossils and non-fossils) also contributes noticeably. Carbon disulfide and soil-bound organic carbon appear in trace quantities but remain relevant for toxicity-related impact categories.

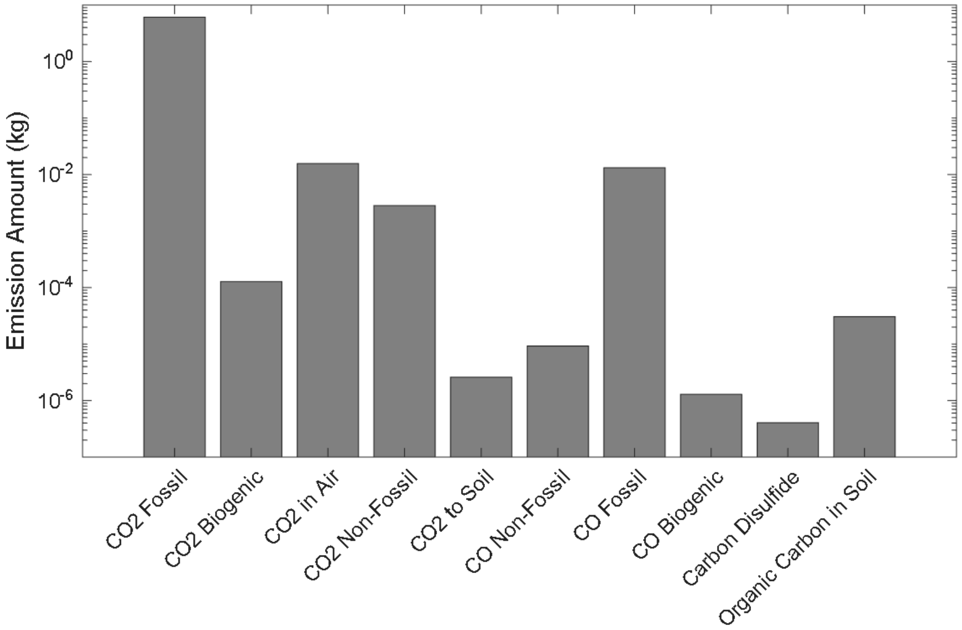

Fig. 4: Distribution of Carbon-Based Elementary Flows in the MSW System (Log Scale)

3.6.1 CO_2 Fossil

Fossil carbon dioxide is the most dominant emission in the profile in Fig. 4. This mainly comes from fuel use during waste collection and transportation, as the trucks rely heavily on diesel. Emissions also arise indirectly from electricity use in system processes, when electricity is generated from fossil-based power sources. Fossil CO_2 is of particular concern because it directly contributes to climate change, adding long-lasting greenhouse gases to the atmosphere.

3.6.2 CO_2 Biogenic

Fig. 4 indicates that biogenic CO_2 is the second-largest carbon-related emission in the MSW system, mainly arising from the decomposition of organic waste such as food, yard waste, and paper at open dumping sites. In Chattogram, the high organic fraction of MSW combined with poorly controlled disposal conditions leads to substantial biogenic CO_2 release, reflecting inefficient recovery of biodegradable materials that could otherwise be composted. Similar dominance of biogenic CO_2 from unmanaged organic waste has been reported and emphasizing the influence of disposal-oriented systems on carbon emissions (Wu et al., 2015).

3.6.3 CO_2 in Air

In Fig. 4, CO_2 in air represents one of the highest carbon-related flows, indicating substantial release of carbon dioxide to the atmosphere under open dumping conditions. Continuous exposure of waste to air promotes aerobic degradation of organic matter, resulting in sustained CO_2 emissions throughout the decomposition process. In contrast, other carbon flows shown in Fig. 4 contribute comparatively less, highlighting that atmospheric CO_2 release dominates carbon exchange in the current system. The prominence of CO_2 in the air reflects the absence of waste covering, gas control, or biological stabilization in Chattogram's disposal sites and is consistent with observations from unmanaged dumping systems reported in previous LCA studies (Friedrich et al., 2011).

3.6.4 CO_2 Non-Fossil

Non-fossil CO_2 comes from materials that are made from biomass but don't break down as quickly as typical organic waste, as wood products or some types of paper composites. As these materials slowly decompose in dumpsites, they release carbon over a longer period, which still adds to the total CO_2 entering the atmosphere (Ximenes et al., 2018). The impact of this emission in Fig. 4 is also quite high compared to other categories, as these emissions fall somewhere between fossils and fully biogenic sources in their impact, but they still play a noticeable role in the overall greenhouse gas footprint of the system.

Table 2: Carbon-Based Elementary Flows in the MSW System of Chattogram

Carbon Flow Type	Description	Source Type
CO_2, fossil	Emissions from fossil-based materials (plastics, synthetic textiles, etc.)	Fossil
CO_2, from soil or biomass stock	Release due to decomposition of organic waste and soil respiration	Biogenic
CO_2, non-fossil	Biogenic CO_2 from natural degradation and composting	Biogenic
CO, fossil	Residual gases are formed due to the incomplete burning of fossil-derived carbon	Fossil
CO, non-fossil	Byproduct of the incomplete degradation of organic waste	Biogenic

3.6.5 CO_2 to Soil

CO_2 to soil represents carbon retained in the soil matrix at dumping sites due to incomplete degradation or burial of organic waste. In Fig. 4, this flow shows a comparatively lower contribution than CO_2 to the air, indicating that most carbon is released to the atmosphere rather than being stabilized in soils under open dumping conditions. The limited magnitude of CO_2 storage reflects the unmanaged nature of dumpsites in Chattogram, where fluctuating moisture and temperature hinder long-term carbon sequestration and can later remobilize stored carbon. Similar low soil-carbon retention relative to atmospheric CO_2 release has been reported for unmanaged disposal systems in developing cities, underscoring the instability of soil carbon storage in open dumps (Ma et al., 2024).

3.6.6 CO Non-Fossil and CO Fossil

Both fossil-based and non-fossil carbon monoxide are present at noticeable levels in Fig. 4. CO is mainly produced when combustion is incomplete, like when waste is burned in the open or when vehicle engines run inefficiently. This gas is harmful to human health because it reduces the body’s ability to carry oxygen, and it also affects the atmosphere by influencing how long methane stays in the air (Wang et al., 2023). Even though the amounts are smaller than CO_2, the presence of CO highlights potential air-quality issues around these waste-handling activities.

3.6.7 CO Biogenic

Biogenic CO is formed when organic waste breaks down in areas with little or no oxygen, which usually happens in tightly packed waste piles. Even though the amounts are small compared to other categories in Fig. 4, the presence of this CO shows that there are anaerobic spots in the dump conditions that can later lead to methane production, a much more potent greenhouse gas (Frontiers in Bioengineering and Biotechnology, 2023).

3.6.8 Carbon Disulfide

Carbon disulfide shows up only in tiny amounts, but it’s still important because of its toxicity in Fig. 4. It can come from industrial residues that end up in household waste or from chemical reactions as the waste breaks down. Even in these small quantities, carbon disulfide is hazardous and can have harmful effects on the environment (Chen et al., 2025).

3.6.9 Organic Carbon in Soil

This refers to organic carbon that gets stored in the soil instead of being released immediately as a gas. While soil carbon can help with long-term carbon storage, open dumping sites are unpredictable, so much of this carbon could eventually be released back into the atmosphere (Wang et al., 2013). Its presence shows that some organic matter is partially buried and hasn’t fully decomposed within the dumpsite, which is illustrated in Fig. 4.

4. CONCLUSION

This study clearly shows that Chattogram’s current MSW system is contributing heavily to carbon emissions and related environmental pressures. Using OpenLCA to assess the city’s daily waste load of about 1,069 tons, it becomes evident that fossil CO_2 is the dominant carbon output. This results in a large presence of plastics and other petroleum-based products in the waste stream. Substantial releases of biogenic CO_2 also occur as organic material decomposes in the open dumping sites. Smaller emissions of carbon monoxide, carbon disulfide, and soil-stored organic carbon further reveal the complex mix of breakdown processes happening within the unmanaged waste piles. When these emissions are translated into environmental impact categories, the picture becomes even more concerning. Climate change stands out as the most critical category, reaching roughly 535 tons of CO_2-equivalent per day, around 195,000 tons annually. This aligns with the strong fossil-carbon presence found in the emissions analysis. Several other categories, including ionizing radiation, photochemical ozone formation, and particulate matter formation, also show notable impacts, illustrating that the consequences extend well beyond global warming alone. Although ozone depletion is comparatively small, its presence still indicates that trace compounds from unmanaged waste are escaping into the atmosphere. Overall, the findings reinforce that open dumping cannot contain or reduce emissions. Chattogram’s humid tropical conditions, continuous decomposition of organic waste, and the absence of gas collection or treatment systems allow carbon to escape freely into the air. This study not only quantifies the city’s substantial carbon footprint but also sheds light on how carbon moves through the system from plastics, from decaying organic matter, from soil pathways, and ultimately into the atmosphere. These insights underscore the urgent need for Chattogram to shift toward more sustainable waste management strategies, such as sanitary landfills with gas capture, composting for organics, or controlled thermal treatment. Without meaningful intervention, waste-related emissions will continue rising alongside population growth and increasing waste generation, placing greater strain on both local air quality and the broader climate.

UNCERTAINTY AND LIMITATIONS

The results of this study are subject to uncertainty due to data limitations and modeling assumptions. Inventory data were primarily derived from secondary sources and generic datasets, which may not fully capture local variability in waste composition, transportation efficiency, and landfill operating conditions. Landfill emissions were modeled assuming average performance, whereas actual conditions in Chittagong may vary spatially and seasonally. As no formal uncertainty analysis was conducted, the results should be interpreted as relative comparisons between scenarios rather than absolute values; however, the consistent modeling framework ensures robust comparison of scenario trends.

FUTURE RESEARCH SCOPE

Future research can be done to build a more refined carbon flow model, which can differentiate emissions by waste type, seasonal variation, moisture content, etc. This would help identify which fractions of the waste stream contribute most to overall emissions.

AI DECLARATION

The author declares that generative AI tools were used only for language editing and improving clarity and readability. All research design, data analysis, interpretations, and conclusions were developed and approved by the author without the use of AI, and the author takes full responsibility for the work's accuracy and integrity.

ACKNOWLEDGMENT

The author sincerely thanks the SCIP Plastic Project at Khulna University of Engineering & Technology (KUET) for their generous support. Their funding made it possible to carry out this research, perform the necessary analyses, and bring the study to its completion.

REFERENCES

Alam, S., Rahman, K. S., Dey, J., & Das, N. (2024). An assessment of suitability for adopting waste-to-energy technology in developing countries of South Asia: A case study of Chittagong. In V. Vambol, S. Vambol, N. A. Khan, N. Mozaffari, & N. Mozaffari (Eds.), *Advances in energy from waste* (pp. 717–737). Woodhead Publishing. https://doi.org/10.1016/B978-0-443-13847-8.00022-1

Alam, S., Rokonuzzaman, M., Rahman, K.S. A comparative analysis of forecasting algorithms for predicting municipal solid waste generation in Chittagong City. *International Journal of Environmental Science and Technology*. **22**, 14213–14224 (2025). https://doi.org/10.1007/s13762-025-06488-0

Ali Ashraf, M., Rezuanul Islam, M., & Gani Adnan, S. (2015). Gis And Multi-Criterion Decision Method Based Approach of Identifying Appropriate Landfill Sites for the City of Chittagong. *International Journal of Environment*. https://doi.org/10.3126/ije.v4i1.12174

Breivik, K., Cossa, D., Jones, K. C., & Polder, A. (2004). *The role of waste management in the control of hazardous substances: lessons learned. Environmental Sciences Europe*, **24**, 35. https://doi.org/10.1186/2190-4715-24-35

Chen, C., Zhang, H., Yan, W., Zhang, Q., & He, K. (2025). *Rapid growth of secondary organic aerosols via aqueous-phase oxidation due to elevated daytime aerosol water contents*. *Environmental Pollution*. Advance online publication. https://doi.org/10.1016/j.envpol.2025.127621

Friedrich, E., Trois, C., & Buckley, C. A. (2011). Quantification of greenhouse gas emissions from waste management processes for municipalities: A comparative review focusing on Africa. *Waste Management, 31*(7), 1585–1596. https://doi.org/10.1016/j.wasman.2011.02.028

Frontiers in Bioengineering and Biotechnology. (2023). Biological treatment of biowaste as an innovative source of CO — The role of composting process. Frontiers in Bioengineering and Biotechnology, 11. https://doi.org/10.3389/fbioe.2023.1126737

Gautam, M., & Agrawal, M. (2021). *Greenhouse Gas Emissions from Municipal Solid Waste Management: A Review of Global Scenario* (pp. 123–160). https://doi.org/10.1007/978-981-15-9577-6_5

Hamanaka, R. B., & Mutlu, G. M. (2025). *Particulate matter air pollution: effects on the respiratory system*. *Journal of Clinical Investigation*. DOI 10.1172/JCI194312

Hossain, I., Haque, A. K. M. M., Ullah, S. M. A., Kadir, A., & Hossain, K. (2024). *Local Government Challenges in Implementing the 3R Strategy for Sustainable Waste Management* (pp. 465–490). https://doi.org/10.4018/979-8-3693-7001-8.ch017

Huijbregts, M. A. J., Steinmann, Z. J. N., Elshout, P. M. F., Stam, G., Verones, F., Vieira, M. D. M., ... & van Zelm, R. (2017). ReCiPe 2016: A harmonized life cycle impact assessment method at midpoint and endpoint level. *International Journal of Life Cycle Assessment*, 22(2), 138–147. https://doi.org/10.1007/s11367-016-1246-y

Idris, A., Inanc, B., & Hassan, M. N. (2004). Overview of waste disposal and landfills/dumps in Asian countries. *Journal of Material Cycles and Waste Management*, *6*(2). https://doi.org/10.1007/s10163-004-0117-y

IPCC (WGIII). (2022). *WG III contribution to the Sixth Assessment Report List of corrigenda to be implemented*. https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Chapter_02.pdf

Jagath, P., & Gamaralalage, D. (2020). *Derek Hondo, Research Associate, Asian Development Bank Institute (ADBI) Linda Arthur, Senior Capacity Building and Training Specialist, ADBI*.

Kaza, S., Yao, L. C., Bhada-Tata, P., & Van Woerden, F. (2018). *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1329-0

Klinglmair, M., Sala, S., & Brandão, M. (2014). Assessing resource depletion in LCA: a review of methods and methodological issues. *The International Journal of Life Cycle Assessment*, *19*(3), 580–592. https://doi.org/10.1007/s11367-013-0650-9

Khandelwal, H., Thalla, A. K., Kumar, S., & Kumar, R. (2019). Life cycle assessment of municipal solid waste management options for India. *Bioresource Technology,* 288, 121515. https://doi.org/10.1016/j.biortech.2019.121515

Laurent, A., Bakas, I., Clavreul, J., Bernstad, A., Niero, M., Gentil, E., & Christensen, T. H. (2014). Review of LCA studies of solid waste management systems – Part I: Lessons learned and perspectives. *Waste Management*, 34(3), 573–588. https://doi.org/10.1016/j.wasman.2013.10.045

Ma, S., Lu, M., Yang, G., et al. (2024). Carbon-negative transition by utilizing overlooked carbon in waste landfills. *The Innovation: Geoscience*, *3*(1), 100109. https://doi.org/10.59717/j.xinn-geo.2024.100109

Paul, P. P., Bari, Q. H., Saju, J. A., & Islam, M. R. (2025). Life cycle assessment of municipal solid waste management in Khulna city of Bangladesh. *AIP Conference Proceedings, 3262*(1), 020023. https://doi.org/10.1063/5.0247428

Roy, H., Alam, S. R., Bin-Masud, R., Prantika, T. R., Pervez, Md. N., Islam, Md. S., & Naddeo, V. (2022). A Review on Characteristics, Techniques, and Waste-to-Energy Aspects of Municipal Solid Waste Management: Bangladesh Perspective. *Sustainability*, *14*(16), 10265. https://doi.org/10.3390/su141610265

Shumshunnahar, M. (2024). Beyond Collection and Disposal: Assessing the Potential of 3Rs Implementation for Municipal Solid Waste Reduction in Bangladesh. *Open Access Indonesia Journal of Social Sciences*, *7*(6), 1827–1841. https://doi.org/10.37275/oaijss.v7i6.273

Siddiqua, A., Hahladakis, J. N., & Al-Attiya, W. A. K. A. (2022). An overview of the environmental pollution and health effects associated with waste landfilling and open dumping. *Environmental Science and Pollution Research*, *29*(39), 58514–58536. https://doi.org/10.1007/s11356-022-21578-z

Wang, X., Firouzkouhi, H., Chow, J. C., Watson, J. G., Ho, S. S. H., Carter, W., & De Vos, A. S. M. (2023). Chemically speciated air pollutant emissions from open burning of household solid waste from South Africa. *Atmospheric Chemistry and Physics, 23*(24), 15,375–15,393. https://doi.org/10.5194/acp-23-15375-2023

Wang, X., Padgett, J. M., Powell, J. S., & Barlaz, M. A. (2013). Decomposition of forest products buried in landfills. *Waste Management, 33*(6), 1299–1308. https://doi.org/10.1016/j.wasman.2013.07.009

Waste Concern. (2021). *22-Bangladesh-Waste-Database_2 (1)*. https://wasteconcern.org/wp-content/uploads/2024/02/22-Bangladesh-Waste-Database_2.pdf

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., & Weidema, B. (2016). The ecoinvent database version 3 (part I): Overview and methodology. *The International Journal of Life Cycle Assessment*, 21(9), 1218–1230. https://doi.org/10.1007/s11367-016-1087-8

Wu, H., Duan, H., Wang, J. *et al.* Quantification of carbon emission of construction waste by using streamlined LCA: a case study of Shenzhen, China. *Journal of Material Cycles and Waste Management* **17**, 637–645 (2015). https://doi.org/10.1007/s10163-015-0404-9

Ximenes, F. A., Kathuria, A., & Barlaz, M. A., et al. (2018). Carbon dynamics of paper, engineered wood products and bamboo in landfills: Evidence from reactor studies. *Carbon Balance and Management, 13*, 27. https://doi.org/10.1186/s13021-018-0115-3

Yadav, P., & Samadder, S. R. (2018). Environmental impact assessment of municipal solid waste management options using life cycle assessment: a case study. *Environmental Science and Pollution Research*, *25*(1), 838–854. https://doi.org/10.1007/s11356-017-0439-7

Zhao, W., der Voet, E. van, Zhang, Y., & Huppes, G. (2009). Life cycle assessment of municipal solid waste management with regard to greenhouse gas emissions: Case study of Tianjin, China. *Science of The Total Environment*, *407*(5), 1517–1526. https://doi.org/10.1016/j.scitotenv.2008.11.007