BENEFITS OF SOLID WASTE MANAGEMENT FOR CLIMATE CHANGE MITIGATION

A CASE STUDY FROM GAZIPUR, BANGLADESH

Mirjam Grünholz

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People, we need to talk about trash!

We produce – for the sake of economic growth.
We don’t reuse – the reason for it is sloth.
We recycle – yes, like world champions do.
However, we don’t reduce – neither consumption, nor waste, nor shampoo.

Let’s stop talking trash – stop thinking about cash,
And start a serious conversation about real-world trash:

There are masks on the ground, in creeks and on trees,
Fighting for dominance with birds, turtles and bees.
Trash is burned by humankind – you have fancy incineration plants in mind?
But think of the people burning trash outside –
in backyards, on streets, or on tracks alike.

There are dump sites and landfills, there is litter in the streets,
and plastic bags, micro and nano – a huge mess of deceits.
Plastic floats around oceans in all forms and shapes and competes,
with seahorses and coral reefs, to be the ocean’s elites.

Out of sight does not mean out of mind, indeed,
If we don’t act now, we only get further behind; that’s guaranteed.
So, let’s stand together, here and now –
Let’s stand up and fight and say: PLASTIC CIAO!

Mirjam Grünholz, February 2022

Executive Summary

This MAS Development Policy Thesis evaluates the greenhouse gas (GHG) and black carbon emission reduction potential of solid waste management (SWM) in Gazipur City Corporation, Bangladesh. The thesis addresses the increasing waste generation in Bangladesh and its environmental impact when following a *linear economy of waste*. Based on a case study of a waste management project implemented by the Swiss Red Cross, the Bangladesh Red Crescent Society and the Gazipur City Corporation in Ward 49 of Gazipur City Corporation, three waste management scenarios are compared. Using a Life Cycle Assessment, the study evaluates the GHG and black carbon emissions associated with different waste management scenarios, including composting, recycling, open dumping, and waste incineration. It expands beyond previous analyses by considering not only CO_2 and methane emissions but also nitrous oxide and black carbon. Additionally, it explores the potential for energy recovery from waste incineration. The results show the immense benefits of treating waste in a *circular economy of waste* logic, with the BDRCS/SRC project emitting 58% less CO_2-eqivalent and 72% less black carbon compared to the business-as-usual scenario. The study emphasizes the importance of a holistic approach to SWM, considering local circumstances, political willingness, public awareness and the opportunity to develop market systems for individual material to maximize recovery. The findings may inform decision-making for SWM actors, such as actors of the Red Cross and Red Crescent Movement, local and national governments who consider in their strategy climate change mitigation and resilience building of urban communities to respond to multi-hazard risks and climate-induced phenomena. Ultimately, the results may positively impact the people of the Gazipur City Corporation, as they are the ones directly affected by unmanaged waste and its direct and indirect consequences.

1. Introduction

Everyone produces solid waste – and everyone is affected by it. In 2018, 2.01 billion tons of solid waste were generated worldwide, and are expected to increase to 3.40 billion tons by 2050. Over the same period, South Asian countries are expected to double their waste generation due to rapid population growth, increasing urbanization and rising GDP. Waste along the entire waste stream from transportation and operation to treatment and final disposal emits greenhouse gases (GHG), particularly methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O) and the short-lived climate pollutant black carbon (BC).

South Asia largely follows *a linear economy of waste* logic, pursuing a "take-make-consume-throw away" approach associated with a vast amount of GHG and black carbon emissions (Department of Environment, 2010). On average, 75 percent of the waste is openly dumped, the remaining 25 percent is disposed of on dumpsites, composted or recycled (Kaza et al., 2018). In contrast, a *circular economy of waste*, where a maximum of waste is composted and recycled, and a minimum is disposed of on a dumpsite, openly burned or illegally dumped, bears a vast potential to reduce GHG and black carbon and may even serve as a carbon sink.

Since 2016, the Bangladesh Red Crescent Society (BDRCS) and the Swiss Red Cross (SRC), in close collaboration with the Gazipur City Corporation, have jointly established a Solid Waste Management (SWM) in Ward 49 in Gazipur, Bangladesh. The system focuses on diverting a maximal amount of waste from final dumping by producing fertilizer from organic waste and selling recyclable waste. The system covers 8'485 households and 39'769 people. (K. Das et al., 2022). This project is expected to significantly contributes to GHG emission reduction and, ultimately, to climate change mitigation. However, the extent it benefits the climate remains unclear. Further, it remains open, how many tons of GHG and black carbon can be reduced if the introduced SWM system of Ward 49 is scaled up to the entire Gazipur City Corporation. The present analysis will, therefore, address the following research questions:

What is the greenhouse gas and black carbon emission reduction potential from Solid Waste Management in Gazipur City Corporation?

a) How many tons of GHG and black carbon emissions per capita are reduced under the SWM system in Ward 49 compared to the business-as-usual case of Gazipur City Corporation?
b) What is the potential of GHG and black carbon emission reduction for Gazipur City Corporation if the SWM System of Ward 49 is scaled up to the entire City Corporation?

A Life Cycle Assessment (LCA) will be conducted to answer the stated questions. A LCA has the advantage that it considers the potential environmental impact of products throughout its entire life cycle (ISO, 2006). A *LCA of waste* thus assesses the impact of solid waste from its generation, transportation, processing and recycling to its final disposal (Peiris & Dayarathne, 2022).

LCA on waste in Bangladesh are very rare and mainly focus on the treatment methods of composting and recycling, and the GHG emissions CO_2 and methane. The present analysis will overcome these shortcomings and not only consider methane and $CO_{2,}$ but also N_2O and the Short Lived Climate Pollutants black carbon, a pollutant with a warming impact up to 2100 times stronger than CO_2 (CCAC, 2024). Further, the study will go beyond composting and recycling and additionally consider emissions from uncollected waste that is openly dumped or illegally burned, as this share makes up around 50% of the waste in the country. Finally, as there is a growing interest in energy recovery from waste incineration in Bangladesh, the study will also consider a scenario where residual waste is not disposed of on a dumpsite, but waste is incinerated. For the LCA, a waste composition analysis at the MRF constructed under the BDRCS/SCR project was conducted. The data was complemented with project data from the BDRCS/SRC project and hearing data from the Gazipur City Corporation.

In the first part of the paper, the core concepts of waste and waste management will be introduced, followed by outlining the logic of a linear and circular economy of waste. This first part will be concluded by linking solid waste management and climate change. In the second part, the life cycle assessment will be explained and the tool to calculate the GHG and black carbon emissions will be presented. Subsequently, the case of Ward 49 in Gazipur City Corporation will be described, followed by the data sources used for the analysis. In the third part, the results will be presented. Finally, the results will be embedded in a broader discussion around SWM, and a set of policy recommendations will be presented.

2. Theory

The first section of this chapter is dedicated to introducing the core concepts of waste and solid waste management, and to introduce the 3R-strategy embedded in a more comprehensive waste hierarchy. In the second section, the logic of a “linear economy of waste” is introduced. The third section outlines the logic of a “circular economy of waste” and its benefits. In the last section, the link between solid waste management and climate change is presented.

2.1 Core concepts

Waste definitions are usually tied to the concept of disposal (European Union, 2008; OECD, 2022; UNEP, 2019). For instance, according to the Basel Convention, “‘wastes’ are substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law” (UNEP, 2019). Other publications specify *solid waste* as residential, commercial and institutional waste. Excluded are electronic, industrial, construction and demolition waste as well as medical and hazardous waste (Kaza et al., 2018). However, in a “resource efficient economy” (p. 8), as outlined in the *3R Strategy for Waste Management* by the Government of Bangladesh, waste only refers to residual materials that have no potential to be utilized again and thus have no economic value. A lot of materials conventionally disposed of are valuable resources which can be recycled or recovered and re-enter as a new ingredient into the economy (Department of Environment, 2010).

While solid waste is tied to disposal, *solid waste management (SWM)* focuses on the process of managing waste, from the collection of generated waste, its transportation, recovery and disposal of waste, the management of the disposal site and the monitoring of the process (European Union, 2008). However, to better understand the *dynamics of SWM*, one also needs to understand the economic development and population dynamics of a region, its institutional arrangements and policies, the financing and costs of the SWM system, and the formal operational model including citizen engagement as well as the role of the informal sector (Kaza et al., 2018).

To encourage communities and governments to minimize their waste, the 3R strategy proposes to reduce, reuse and recycle waste. The 3R are the basis of the *3R Strategy for Waste Management* in Bangladesh, one of the most comprehensive document on SWM in the country (Department of Environment, 2010). *Reducing* waste refers to using less and thereby lowering the amount of waste generated. *Reusing* means the repeated usage of items instead of throwing them away. *Recycling* is the process of using waste as a resource and turning it into new products. The 3R strategy is embedded in a broader *hierarchy of waste* defining different options of resource minimization from preventing waste (most favorable option) over waste minimization, reuse, recycle, energy recovery to disposal waste (least favorable option). In consequence, the fewer waste is produced, and the more waste is re-processed, the fewer resources are exploited and the smaller is the negative impact of waste on the environment, the climate and health (Department of Environment, 2010).

2.2 Linear economy of waste

In a *linear economic logic*, resources are extracted, used for production, consumed, and finally dumped, following a “take-make-consume-throw away" logic (Department of Environment, 2010; European Parliament, 2023). The same logic is applied for waste, following a generating-and-dumping logic.

In South Asia, waste **generation** ranges from 0.17 to 1.44 kg/capita/day with an average of 0.28 in Bangladesh. Urban waste generation is significantly higher than rural one. Households, shops and public institutions are the main producers of municipal solid waste (Kaza et al., 2018).

In the region, an average 77% of the waste in *urban* areas and 40% of the waste in rural areas is **collected** (Kaza et al., 2018). In contrast, in Bangladesh, only 45% of the waste in urban areas is collected, predominantly as mixed-waste (Department of Environment, 2010), whereas in rural areas, formalized waste collection is nearly inexistent. If waste is collected, door-to-door collection is the predominant collection method (as opposed to centralized drop-off points or combined models) (Kaza et al., 2018). Some cities have collection arrangements with private contractors for primary waste collection from the generation site to the transfer stations. Additionally, the informal sector plays a crucial role in collecting and recycling waste, which is oftentimes done by uneducated, ultra-poor women and children (Alam & Qiao, 2020; S. Islam, 2021). Secondary collection and transportation from the transfer station to the final dumpsite are usually done by private contractors, while the city corporation oversees the process (S. Islam, 2021).

As there are market incentives for many **recyclable** non-organic goods, the recycling of materials, sometimes done formally but more often informally, works quite well in Bangladesh (Matter et al., 2015). Also households sometimes collect valuables and sell them directly to scrap dealers to generate some additional income (Menikpura, 2013). However, organic waste recycling resulting in fertilizer or biogas is less present due to a lack of market incentives, policy enforcement, awareness and a large competition from chemical fertilizer and fossil fuel producers (Matter et al., 2015). Only a small fraction of the organic waste is composted privately (Tajkir-Uz-Zaman, 2023). Consequently, a large share of organic resources is dumped privately or on a dumpsite as mixed waste.

Much of the waste not collected is **illegally dumped**, which is the most common method of waste disposal in South Asia (Kaza et al., 2018). It is for instance buried in the soil or dumped in a hole in backyards, low lands or nearby ponds (Tajkir-Uz-Zaman, 2023). Around 3% of the waste is **openly burned** (B. Das et al., 2018; Tajkir-Uz-Zaman, 2023). Uncollected waste and leachate end up in water bodies and drainage systems, clogs water flows in drains, and pollutes groundwater, surface water, soil and the air (S. Islam, 2021). This bears negative consequences for human health and the environment, society and the economy (Kaza et al., 2018).

Collected waste is transported to **dumpsites** or sanitary landfills. In Bangladesh, only 9 out of 12 city corporations have designated dumpsites for municipal solid waste. However, none of these has any sanitary arrangements or collects landfill gas, but instead, waste is simply dumped open-air in a designated area (S. Islam, 2021)[1]. In Bangladesh with its dense population, land is very scarce and there is increasing opposition from local residents to construct new landfills, combined with the failure to obtain environmental clearance (S. Islam, 2021; Sang-Arun & Bengtsson, 2009). Further, waste management is expensive and requires political willingness, public awareness and community engagement, as well as technical and personal resources for waste operations and land for final disposal, which is often lacking (Sang-Arun, 2011)[2].

2.3 Circular economy of waste

In a *circular economy*, the aim is to reduce waste to a minimum by valuing a maximum of materials in a product through reusing, repairing, refurbishing or recycling them (European Parliament, 2023). Circular economy is based on three principles:

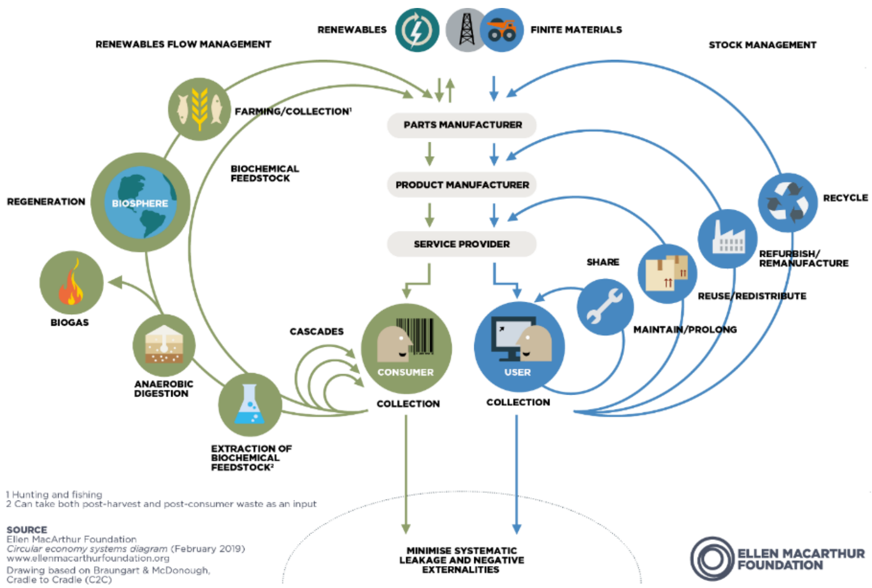
The first principle aims at *eliminating waste and pollution*. This requires action from the producer side through the design choice of products (Ellen MacArthur Foundation, 2023) and extended producer responsibility (EPR) (Bourguignon, 2016). It involves stringent policies and enforcement (Bourguignon, 2016; Department of Environment, 2010; S. Islam, 2021). And it gives an important role to communities, households and public institutions like schools to act as a driver of change,

[1] To my knowledge, the landfill in the Rohingya refugee camp in Cox's Bazar is the only landfill in Bangladesh with full sanitary arrangements. Further, JICA is working on upgrading the Matuail dumpsite in Dhaka South City Corporation under the New Clean Dhaka Master Plan (2018-2032). However, as of now, they still suffer from poor landfill management and unregular coverage of waste with soil due a lack of equipment and manpower (Chandan, 2021; Dhaka North City Corporation, 2019; Nahar, 2022).

[2] In the Business Model Analysis which I conducted during my JPO with Swiss Red Cross, I assessed the sustainability, effectiveness and efficiency of the Solid Waste Management System in Palongkhali Union, a community located around the Kutupalong Refugee camp, in the Ukhiya Upazila in the Cox's Bazar district. Interviews with the WASH Sector lead from UNICEF, the Chairman from Palongkhali Union, and the Management of Swiss Red Cross and the Bangladesh Red Crescent Society revealed that final dumping was the biggest barrier to environmental sustainability. Challenges were land scarcity as well as political barriers to receive the permission for land use from higher-level government bodies combined with a lack of technical knowledge on how to construct sanitary landfills.

follow the waste hierarchy, reduce waste at the source or participate in public cleaning activities (Chinasho, 2015; Mertenat & Zurbrügg, 2023; Miao et al., 2017)

The second principle aims at *circulating products and materials at their highest value* and keeping material in use as products or raw materials for other produce. Ther are two cycles in this process, the biological cycle and the technical cycle. In the former, biodegradable materials are composted or anaerobically digested resulting in nutritious fertilizer that can be used to enhance soil quality and replacing chemical fertilizer. In the latter, products can be shared, reused through resale, repaired, or refurbished and components can be remanufactured or recycled (Ellen MacArthur Foundation, 2023). Household and public institutions can significantly contribute by segregating waste, compost organic material and using the fertilizer to improve soil quality in their community (Chinasho, 2015). With 57% of the waste being organic, composting bears a great potential in South Asia, also given the vast amount of inexpensive labor force which can be mobilized to establish composting systems. This is facilitated, though, if waste is segregated at the source and stable markets for products of organic waste are established (Hettiarachchi et al., 2018). Sources segregation has the additional advantage that communities can store and sell recyclables at home to generate some additional income (Chinasho, 2015).



Graphic 1: Circular economy system diagram (Ellen MacArthur Foundation, 2023)

The third principle aims at *regenerating nature*. By moving from "take-make-consume-throw away" to a circular economy, nature can be regenerated. Biological materials are returned back to the earth, and non-organic materials are not depleted and lost, but stay in the cycle (Ellen MacArthur Foundation, 2023). In consequence, local economies can be strengthened through hiring waste collectors, building composting facilities and fostering the recycling industry (Chinasho, 2015; Menikpura, 2013). Jobs created and revenues generated along the waste stream result in increased well-being of the local community. Resources, and if technology allows for it, energy and heat from waste, can be recovered. And the improved management of waste reduces waste disposal on dumpsites, increasing their lifetime and reducing negative impacts on water, soil and air quality. Ultimately, a holistic waste management focusing on circular economy significantly reduces greenhouse gas (GHG) emissions (Menikpura, 2013; Sang-arun, 2012).

2.4 Solid waste and climate change

Waste management emits greenhouse gas throughout the entire waste flow. Direct emissions are emitted by treating waste and final disposal. Indirect emissions result from the transportation and operation of waste. Managing waste emits methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O) and black carbon[3] (BC), which all significantly contributing to global climate change.

Globally, the waste sector accounts for 20% of anthropogenic methane emissions (12% from solid waste, 8% from wastewater) and is the third largest emitter after the agricultural and energy sectors (UNEP, 2022). Open dumping of waste emits methane. Carbon dioxide and nitrous oxide are emitted while transporting waste and handling it with fossil-fuel based machinery. Openly burning waste and handling waste with old machinery emits black carbon (IGES, 2018). Methane and black carbon are Short Lived Climate Pollutants (SLCP), agents with a short life span in the atmosphere of a few days to a few decades, and a warming influence on the climate (IGES, 2018).

Indirect emissions are produced during waste **transportation** and **operations on the dumpsite.** Fossil fuel and grid electricity emit significant amounts of CO_2 and BC. The emissions depends on the amount and type of fossil fuel used and the age of the trucks (IGES, 2018). The other emissions discussed below are *direct* emissions.

Composting emits GHG from the degradation of organic waste and GHG and BC if fossil fuel is used to operate the compost. More specifically, in deeper layers of a composting pile, CH_4 is produced due to anaerobic degradation of organic waste. IPCC recommends using emission factors of 4 kg CH_4/ton of organic waste (wet basis). In smaller concentrations, N_2O is produced with a recommended emission factor of 0.3 kg N_2O/ton (wet basis). As CO_2 emissions from composting have biogenic origins, they are not accounted for in the GHG emission calculations (IGES, 2018; IPCC, 2006). Yet, composting not only emits GHG, but it can also serve as a carbon sink. Fertilizer from organic waste contains nitrogen (N), phosphorous (P_2O_5) and potassium (K_2O) and can replace conventional fertilizer. Additionally, composting organic material reduces

[3] Black carbon is a component of fine particulate air pollution. It is very effective at absorbing light, thus has a great impact on warming the atmosphere. It has an average atmospheric lifetime of 4-12 days. Depending on the source, black carbon has a warming impact between 500-2100 times stronger than CO_2 (CCAC, 2024; IGES, 2018).

the amount of waste on dumpsites and openly dumped and prevents methane from being produced. Thus, composting organic material can result in net negative GHG emissions if GHG avoidance is larger than the fossil fuel-based GHG (Menikpura & Sang-Arun, 2013).

Recycling also has the potential to serve as a carbon sink and thereby contributes to climate change mitigation despite producing GHG and BC emissions. The primary emission is CO_2, which results from direct fossil fuel consumption and the indirect usage of grid electricity used for pre-processing, sorting, transportation, and the recycling process itself. In contrast, materials recovered through recycling can replace virgin materials and thereby avoid GHG and BC emissions that would otherwise be produced through the extraction and processing of virgin materials. Material recovery avoids large amounts of CO_2, but emission and saving potentials depend on the material. Aluminium, steel, glass and plastic have negative net emissions. Recycling paper emits more CO2 than producing virgin paper (Zurbrügg et al., 2018a). However, as paper is the only degradable fraction among the recyclables, emissions from paper not ending up on the dumpsite can additionally avoided CH_4 (Menikpura & Sang-Arun, 2013)[4].

Open-air **dumpsites** are the most common way of disposing of collected waste in Bangladesh, emitting vast amounts of GHG and black carbon (Kaza et al., 2018). The anaerobic decomposition of waste in open dumpsites generates landfill gas (LFG), containing approximately 60% CH_4 and 40% CO_2. The CO_2 part is biogenic and thus not considered (Conestoga-Rovers & Associates, 2010). The methane part of the LFG contributes to global warming. CH_4 emission quantities depend on the dumpsite's waste composition, volume, temperature and age, with increasing methane emissions resulting from higher shares of organic waste, moisture and deeper dumpsites as compared to shallow ones (Menikpura & Sang-Arun, 2013; Zhang et al., 2019). Emission quantification for black carbon resulting from operational activities on the dumpsite is not available yet (IGES, 2018).

In the urban areas of Bangladesh, around 55% of the generated waste is neither collected for recycling nor for dumping on a designated dumpsite (Department of Environment, 2010). Instead, vast quantities of the waste are illegally dumped. **Openly dumping** waste emits CH_4 comparable to a shallow and unmanaged dumpsite. Additionally, approximately 3% of the total waste generated is openly burned (B. Das et al., 2018; Tajkir-Uz-Zaman, 2023). **Open burning** affects the climate similarly like incineration, however, due to the inefficiency in combustion, the oxidation

[44] For detailed numbers on emissions and avoidance potential for each material, see the Emission Quantification Tool estimating CH_4, CO_2 and N_2O and black carbon emissions from the waste sector and later applied in this paper (IGES, 2018).

factor for open burning is at 58%. It results in fossil fuel-based CO_2 emissions and 0.65 kg of black carbon/ton of waste, affecting the climate and public health (IGES, 2018).

Incineration of waste has the potential to reduce its quantity by 75% to 90% (Lam et al., 2010). Installing incinerators with integrated waste-to-energy facilities is of great interest in Bangladesh to minimize waste, reduce land pressure, generate electricity and gain financial benefits (Rahman & Alam, 2020). GHG and BC emissions largely depend on the composition and moisture content of waste to be incinerated.

CO_2 from fossil-fuel-based products such as plastics, rubber or certain textiles are climate-relevant. Biogenic CO_2 from burning biomass such as paper, food and wood is not considered for GHG emission estimations. CH_4 and N_2O emissions depend on the type of incinerator, the type and amount of fossil fuel and electricity used to run the incinerator. Black carbon emissions from incineration are 0.322 kg/ton of waste. In return, incinerating waste can eliminate CH_4 emissions of waste otherwise disposed of on a dumpsite.[5].

In conclusion, inadequate SWM causes significant amounts of GHG such as CH_4, CO_2, N_2O and black carbon. In return, effective SWM bears a vast potential to reduce emissions and may even serve as a carbon sink.

3. Methods and Data

3.1 Life Cycle Assessment

Life cycle assessment (LCA) is one technique to identify the potential environmental impact of products throughout their life cycle, from acquiring raw materials, production, use, end-of-life treatment, recycling to final disposal (ISO, 2006). *LCA of waste* assesses the impact of solid waste from its generation, transportation, processing and recycling to its final disposal (Peiris & Dayarathne, 2022). LCA assists decision-making by identifying and quantifying the environmental impacts of a product throughout its life cycle and comparing appropriate technologies to manage waste (Laurent et al., 2014). The most commonly used metric to quantify the impact of SWM on climate change is Global Warming Potential (GWP) (Yadav & Samadder, 2018).

GWP is a metric used to compare the contribution of different substances in the atmosphere to global warming, relative to CO2. The IPCC recommends using GWP over the time horizon of 100

[5] An alternative to composting is **anaerobic digestion (AD)**, which has a large potential in South Asia. It is cost-effective and has a high energy-recovery potential by converting organic materials into biogas and then then heat or electricity with limited environmental impact (N. Menikpura & Sang-Arun, 2013). AD is not common in the study area, so it is not further discussed here.

years (GWP100). For all except BC, these values have officially been determined. BC will thus be considered separately. The present analysis uses GWP100 as shown in Table 1 (IGES, 2018; IPCC, 2013):

Table 1: Global warming potential of different substances over the time horizon of 20 and 100 years as compared to CO_2.

Type of Gas	GWP20	GWP100
CO_2	1	1
CH_4- biogenic	84	28
CH_4-fossil	85	30
N_2O	264	265
BC	2100	590

LCA on SWM has primarily been conducted in Europe, with a growing number being conducted in Asia (Laurent et al., 2014; Yadav & Samadder, 2018). Many LCA focus on a particular type of waste, such as paper, plastic or bio-waste. Only a few cover multiple SWM options (Yadav & Samadder, 2018). As it is of utmost importance for LCA to consider local conditions, such as waste composition, location, societal, geographical and cultural contexts, LCA of SWM can be regarded as a tool to determine "context-specific waste hierarchies" (Laurent et al., 2014, p. 580).

LCA on SWM in Bangladesh are very limited. A study from Chittagong City Corporation compares composting, recycling and landfilling, using CO_2-equivalent as a metric (Miah & Siddik, 2018). An LCA from Khulna compares the same three treatment options but compares different scenarios varying the waste fractions per option, using methane as a metric (M. S. Islam et al., 2017). Another study from Khulna concentrates exclusively on market food waste and compares the methane and CO_2 emissions of different treatment methods (Alim Al Razi et al., 2013). These studies display one of the main challenges of LCA: comparability. Despite the different metrics, waste fractions and waste treatment foci, they all favor composting and recycling over other methods, as they emit the least amount of GHG.

Nonetheless, these studies display several shortcomings: While the studies only consider methane, CO_2 or overall CO_2- equivalent, they neglect to specify other GHG emissions like N_2O and Short Lived Climate Pollutants such as black carbon with a warming impact up to 2100 times stronger than CO_2 (CCAC, 2024). Further, the studies neglect emissions from uncollected or burned waste, which makes up for around half of the waste in Bangladesh (Kaza et al., 2018). Finally, none of the studies considers Waste-to-Energy technologies, a technology of growing interest in Bangladesh. The study at hand will overcome these shortcomings.

3.2 GHG calculation tool

To conduct the present LCA, the *Estimation Quantification Tool (EQT) for Estimating Short Lived Climate Pollutants (SLCPs) and Other Greenhouse Gasses (GHGs) from the Waste Sector* (Version II) developed by the Institute for Global Environmental Strategies (IGES) is used. The tool supports assessing GHG and SLCP emissions associated with SWM from actual and projected waste-related emissions. It includes emissions and saving potentials throughout the lifecycle of waste management, including waste collection, transportation and multiple waste treatment and disposal approaches, such as composting, anaerobic digestion (AD) and recycling, incineration (with and without energy recovery), mechanical biological treatment (MBT), landfilling/dumping of wastes, landfill fires, open dumping of waste and open burning. Net emissions are calculated as: Total GHG/SLCP emissions from treatment technologies minus GHG/SLCP avoidance via resource recovery. The estimated emissions are disaggregated into the pollutants methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O) and black carbon (BC). The output of the tool is a scenario-wise overview of CH_4, CO_2 and N_2O and a summary of GHG displayed in CO2-eq. BC is displayed separately. Ultimately, the tool allows for calculating and comparing different waste treatment scenarios while accounting for country/location-specific features, such as the economic level and the climatic zone (IGES, 2018).

3.2 Case

Gazipur City Corporation (GCC) is the third largest city in Bangladesh with 2’674’697 inhabitants (Bangladesh Bureau of Statistics, 2022). Ershadnogor, today Ward 49 of GCC, was originally a settlement of floating people from Dhaka who settled there in 1974, shortly after the Liberation War. The informal settlement was partly formalized under the National Housing Authority of President Hosain Mohammad Ershad in 1988. New houses were constructed in blocks 1, 2 and 3. After Ershad's resignation, the housing program was stopped. Consequently, these blocks have more organized housing and roads than the other blocks (K. Das et al., 2022).

In 2016, the Bangladesh Red Crescent Society (BDRCS) and the Swiss Red Cross (SRC) started a SWM project in Ershadnogor in close collaboration with the GCC, covering 316 households in block 6. A Material Recovery Facility (MRF) was built, and a SWM system focusing on composting and recycling was established. The goal was to establish an integrated and scalable SWM system by leveraging economies of scale. After a successful pilot, the second phase started in 2019, covering blocks 3, 5 and 6 (out of 8 blocks) with approximately 3’300 households and 12’000 inhabitants. By 2023, the SWM system covered all 8 blocks with 8’485 households and 39’769 people. (K. Das et al., 2022).

The households in Ward 49 are encouraged to segregate their waste into organic and non-organic waste. They are incentivized to pay a monthly collection fee of 50 BDT if they properly segregate their waste. Otherwise, they pay 100 BDT. They are encouraged to sell their recyclables to the scrap shops attached to the MRF or rarely sell them directly to floating scrap sellers to generate some additional income. The remaining waste is collected from each household by waste collectors and transported by tricycle to the MRF. On the way, waste collectors can remove valuable materials and individually sell them to generate some extra income. The remaining recyclables are transported to the MRF and given to the scrap shops associated with the MRF for sale. The organic material is composted, resulting in nutritious fertilizer that is subsequently packed and sold for agriculture and gardening. The residual waste, which can neither be recycled nor composted, is transported to the nearby dumpsite (K. Das et al., 2022).

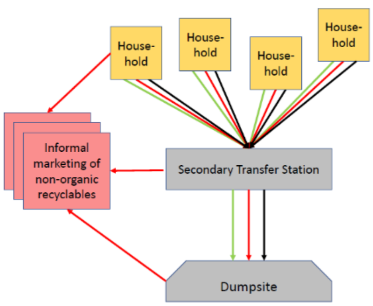
In the following, the GHG and black carbon emissions of three scenarios will be compared. This comparison will serve to show the emission reduction potential of different SWM approaches. Afterwards, their feasibility and scale-up potential will be discussed.

1. Business-as-usual scenario in Gazipur City Corporation (excluding Ward 49)
2. BRDCS/SRC project in Ward 49
3. Modiefied BRDCS/SRC project in Ward 49

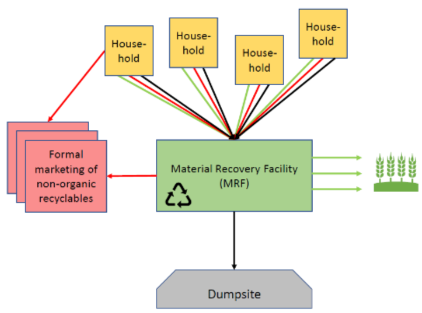
The **business-as-usual scenario** represents the predominant waste process in the GCC. Waste collectors hired by the City Corporation manually collect approximately half of the waste and bring it to one of the 19 Secondary Transfer Stations (STS). From there, private contractors transport the waste to the dumpsite. As the City Corporation lacks the capacity, human resources and machinery to collect all the waste, the other half is openly dumped and ends up in water bodies or streets, and around 3% is openly burned. Waste that can be recycled is removed throughout the process, either by the households, the waste collectors, or the informal waste pickers on the dumpsite (K. Das et al., 2022; Hassan, 2023; Tajkir-Uz-Zaman, 2023).

In the **BRDCS/SRC project in Ward 49**, waste collectors hired under the project manually collect waste from the households and transport it to the MRF constructed under the project. During collection, waste is already partly segregated, and collectors pick out the recyclable materials for later sale. At the MRF, organic material is composted. The fertilizer produced is sold to the community for agriculture and gardening. The residual waste is transported by truck to the dumpsite (K. Das et al., 2022; Hassan, 2023). In this scenario, no burning and open dumping is assumed to happen since all the waste is collected (B. Das et al., 2018).

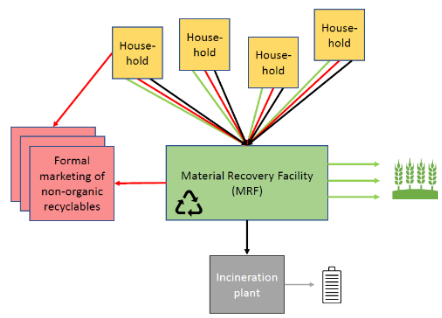
In the third scenario, the **BRDCS/SRC project in Ward 49 is modified**, assuming that all the collected residual waste is incinerated in a nearby **Waste-to-Energy (WtE)** plant instead of disposed of on the dumpsite, while the rest is composted and recycled. This scenario was added since there is a growing interest in WtE in Bangladesh. For instance, in the Kalita area of GCC, a 42.5 MW WtE power plant has been announced to be constructed, for which the GCC is supposed to supply 2500-3000 tons of waste per day. However, the process is currently on halt because the sponsoring company is under investigation for fraud allegations (Energy Transition Bangladesh, 2022). This scenario serves to assess the effect of an SWM system, with and without energy recovery from incineration, on climate change. It will also be necessary to highlight some major challenges regarding incineration plants with WtE systems in a low-income country context.



Scenario 1: Business-as-usual scenario (green: organic, red: non-organic, black: residual waste)



Scenario 2: BDRCS/SRC project in Ward 49 (green: organic, red: non-organic, black: residual waste)



Scenario 3: Modified BDRCS/SRC project (green: organic, red: non-organic, black: residual waste, grey: energy)

3.3 Data

To calculate the emissions from the different scenarios, the *weight* and *waste composition* of waste composted, recycled, disposed of on the dumpsite, openly dumped, openly burned and incinerated had to be measured or estimated.

To ensure comparability of the scenarios, the BDRCS/SRC-project served as a starting point. The waste composition assessed in this project was used to simulate the business-as-usual scenario and the modified BDRCS/SRC-project with incineration and WtE. In doing so, counterfactuals are simulated showing what would have happened if there had been no BDRCS/SRC-project in place (business-as-usual) and what would happen if the residual waste under the BDRCS/SRC-project was incinerated with or without energy recovery (modified BDRCS/SRC-project).

The BDRCS/SRC team greatly supported the data collection.

A **waste composition study** was conducted at the MRF over the period of 5 days. Two tricycles filled with collected waste were randomly chosen per day. The waste was segregated according to predefined categories. The resulting waste composition contained 56% organic waste, 14% plastics, 11% textiles, 11% hazardous waste, 3% glass, 1% paper, 1% leather and rubber, 1% metal, and 2% other waste.

The **BDRCS/SRC project monitoring data** over 11 months showed that, on average, 64 tons of waste arrived at the MRF per month. 32 tons were composted (50%), 1 ton was recycled (1.5%), and 31 tons (48.5%) of mixed residual waste were transported to the nearby dumpsite. 75% of the composted waste was sold or distributed to the community[6].

Project monitoring data further shows that small drum trucks (3 tons) are usually used to transport the residual waste to the dumpsite. Due to the high volume of rejects with low weight, a smaller quantity than 3 tons can be transported per trip. The distance between the MRF and the dumpsite is 16km (one way). 54 trips are conducted per month.

Hearing data from the Gazipur City Corporation reveals that monthly, 432 liter of diesel fuel is used to transport the residual waste to the dumpsite and to operate the machinery on the dumpsite. As there is no accurate data on how much diesel is used for the two sets of activities, the number is spilt in half, 216 liters for transportation, 216 liters for dumpsite management.

This data above was used to calculate the emissions from the BDRCS/SRC-project. the same waste composition and fuel data was used to estimate the business-as-usual scenario, adjusting the waste fractions. In this scenario, the City Corporation only has the capacity to collect half of the generated waste which is all disposed of on the dumpsite (32 tons/month). 1 ton/month is recycled, but here informally instead of formally. The other half is openly dumped (29 tons/month) or openly burned (2 tons/month). No waste is composted. For the modified BDRCS/SRC-project, composting activities remain the same as in the BDRCS/SRC (32 tons/month) and 1 ton/month ton is recycled. However, instead of dumping the residual waste, it is assumed to be incinerated in the nearby incinerator with energy recovery (31 tons/month).

[6] For simplicity reasons it is assumed that 100% of the waste is collected. However, as of March 2024, only 5'571 of the 8'485 households (39'769 people) of Ward 49 were registered to the waste collection service. The reader might still be confused about the low waste generation per capita in this scenario, as the average waste generation per capita in Bangladesh is with 0.28 kg/capita/day much higher (Kaza et al., 2018). Reasons for this are that some waste is already diverted by the households for recycling and may not arrive at the MRF, where waste for this study was weighted. Additionally, Ward 49 is an informal settlement, and people are economically very poor, resulting in less waste per capita. As the waste production is low, people may not give waste to the collectors daily but keep it at home for several days. All of this, however, does not diminish the importance of waste management in this area.

Table 2 shows the waste shares per waste processing method for all three scenarios:

Table 2: Share of waste per treatment method for different SWM scenarios in Ward 49 in Gazipur City Corporation.

Waste process (tons/months)	**Scenario 1: Business-as-usual (BAU)**	**Scenario 2: BRDCS/SRC-project**	**Scenario 3: Modified BRDCS/SRC-project**
Composting	0	32	32
Recycled	1	1	1
Openly dumped	29	0	0
Openly burned	2	0	0
Dumped on dumpsite	32	31	0
Incinerated + 20% electricity recovered	0	0	31
Total	**64**	**64**	**64**

4. Results

The study has shown the significant benefits SWM on GHG emission reduction when following a circular economy of waste, where all the waste is collected, a maximum of waste is composted and recycled, and open burning and illegal dumping are avoided. This is in comparison to following a linear logic, as done in the business-as-usual scenario, where only half of the waste is officially collected, no waste is composted, recycling happens informally, and the other half of the waste is illegally dumped or openly burned.

The *Estimation Quantification Tool (EQT)* allowed for estimating different scenarios and combinations of waste treatment and serves as a great tool to estimate GHG emission reduction potentials of different waste scenarios compared to the business-as-usual. All the detailed results can be found in the Appendix.

Table 3 shows the yearly emissions of CO_2-equivalent, the aggregation of CH_4, CO_2 and N_2O, in tons and the yearly black carbon emissions in kg for each of the three scenarios.

Table 3: Aggregated annual GHG emissions (CH4, CO2 and N2O) and black carbon emissions from different SWM scenarios for Ward 49 in Gazipur City Corporation.

Emissions/year *(for Ward 49)*	**Scenario 1: Business-as-usual**	**Scenario 2: BRDCS/SRC-project**	**Scenario 3: Modified BRDCS/SRC-project**
CO_2-equivalent	594 tons	248 tons	232 tons
Black carbon	29 kg	8 kg	12 kg

These results show that through the BDRCS/SRC-project, yearly GHG emissions could be reduced by 58%, from 594 tons of CO2-equivalent to 248 tons, while Black carbon emissions could be reduced by 72%, from annual 29 kg down to 8kg. In scenario 3, where residual waste is incinerated and electricity is recovered, GHG emissions are even lower. Black carbon emissions are 12kg, slightly higher compared to scenario 2, where residual waste is disposed of on the dumpsite. However, if no electricity is recovered in scenario 3 (scenario not shown here), GHG emissions are 437 tons of CO2-eq, almost twice as high, while BC emissions remain unchanged.

The emission reduction potential per household is shown in Table 4.

Table 4: Aggregated annual GHG emissions (CH4, CO2 and N2O) and black carbon emissions from different SWM scenarios per household of Ward 49 in Gazipur City Corporation.

Emissions per Household/year *(for Ward 49)*	**Scenario 1: Business-as-usual**	**Scenario 2: BRDCS/SRC-project**	**Scenario 3: Modified BRDCS/SRC-project**
CO_2-equivalent	70 kg	29 kg	27 kg
Black carbon	3.4 g	0.9 g	1.4 g

The results until here have shown the emissions for Ward 49 of Gazipur City Corporation under different scenarios. In the next step, the results will be scaled up to the entire Gazipur City Corporation. One should be aware that the following GHG and black carbon emissions estimates are very likely lower than the actual emissions. The reason is that Ward 49 is an informal settlement, and waste generation in other parts of the City is higher since income levels and living standards are also higher there. The resulting annual (minimal) emissions for Gazipur City Corporation are shown in Table 5:

Table 5: Aggregated annual GHG emissions (CH4, CO2 and N2O) and black carbon emissions from different SWM scenarios for the entire Gazipur City Corporation.

Emissions/year *(for the entire Gazipur City Corporation)*	**Scenario 1: Business-as-usual**	**Scenario 2: BRDCS/SRC-project**	**Scenario 3: Modified BRDCS/SRC-project**
CO_2-equivalent	39’949 tons	16’679 tons	15’603 tons
Black carbon	1’950 kg	538 kg	807 kg

From a climate perspective, these results provide clear evidence for the emission reduction potential of an SWM system that follows a circular economy of waste management where composting and recycling are maximized. Considering the climate implications from net GHG emissions, Scenario 3 with composting, recycling and waste incineration seems to be the best option for Gazipur, but only if electricity is recovered from the waste incineration. Regarding Black carbon emissions, the BDRCS/SRC project with composting, recycling and residual waste disposal on the dumpsite appears to be the most climate-friendly option.

As Scenario 3 builds on Scenario 2, Scenario 2 should be pursued and scaled up by maximizing composting and recycling. This is the precondition for any further expansion of the project, such as waste incineration and energy recovery.

5. Discussion and Policy Recommendations

An SWM system built upon a circular economy of waste that maximizes composting and recycling and minimizes waste dumping or incineration not only benefits the climate but also public health, the local economy, and the environment. Less waste in an area leads to higher social prestige, a cleaner environment and less smell, less pressure on already scarce land, formal jobs and income along the value chain of waste, reduced water logging of drains and channels, a reduction of vector and water-borne diseases, and ultimately increased land fertility due to organic fertilizer produced from compost (Rimi Abubakar et al., 2022).

Nonetheless, technology can only unfold its full potential if local circumstances are sufficiently considered, political willingness and public awareness are present, and when there are investments in the establishment of markets. Thus, to make a technology work, it needs to be embedded in a well-functioning system:

Composting is a great and simple technology and a perfect method for an SWM system. Optimizing composting requires the households' awareness to segregate waste into organic and non-organic waste (Miao et al., 2017). It needs an efficient system of (door-to-door) waste collectors and composting facilities and knowledge of how to run such as system (Matter et al., 2015). It requires political oversight over the entire waste management process that is well coordinated and enforced (S. Islam, 2021). And it needs market incentives and awareness in the community to mainstream compost fertilizer use instead of chemical fertilizer (Matter et al., 2015).

Bangladesh has a well-established recycling sector all along the waste stream (Matter et al. 2015). However, recycling is mainly done informally by economically poor and low-educated people. They are often socially stigmatized and face significant occupational risks. One option to upgrade the informal sector is to integrate informal collectors into the city's waste management plan, integrate them into the collection system, let them collect waste at the source, allow them to sell the collected recyclables to generate additional income and guarantee them access to waste (Zurbrügg et al., 2018b).

Incinerating waste is only effectively reducing GHG emissions if the waste composition is considered, moisture content is low, sufficient waste is delivered to the incinerator to run efficiently, and energy is recovered. It requires, once more, source segregation of waste and a well-functioning system with sufficient human resources and machinery to ensure regular waste supply. Finally, it requires the incinerator to be handled professionally, which requires skill and training; and to recover electricity, for the incinerator to be connected to the electricity grid.

The analysis at hand shows clearly the benefits of effective SWM on climate change mitigation. To conclude this thesis, a list of recommendations for the Gazipur City Corporation (GCC) and national and international actors like BDRCS and the SRC are provided:

- It is strongly recommended that all actors think of waste as a system that affects us all, not as individual components. Waste management is an opportunity, economically, socially, and environmentally.
- It is strongly recommended that source segregation, composting, and recycling be scaled up immediately in the entire GCC. In the medium run, the system can also be connected to the planned incinerator, but only non-compostable and non-recyclable waste should be incinerated. Yet, from a climate perspective, incineration only reduces GHG emissions if energy is recovered by connecting the incinerator to the electricity grid.
- BRDCS and SRC are strongly encouraged to share their SWM experiences with a broader public (e.g. internally, with other Red Cross partners, NGOs working on WASH, waste and climate, the UN, agencies such as JICA and SDC, local governments, Ward members, the City Corporation,…), e.g. by providing training modules, workshops or a waste manual.
- The City corporation is advised to establish a bylaw for the entire City Corporation on handling municipal solid waste. BDRCS/SRC may support this process based on their experiences from Ward 49. The City Corporation supported by BDRCS/SRC may further engage in a broader policy dialogue and advocate for national-level SWM.
- A business model for the entire Gazipur City Corporation should outline revenue from composting and recyclable sales, ensuring cost-effectiveness. Ward 49 may act as a viable role model case for urban Bangladesh, once the upfront costs are covered. Further, exploring carbon credits is advisable, as vast amounts of carbon emissions are avoided through an improved SWM system.
- Volunteers are one of the key resource of the Red Cross Red Crescent Movement. It is strongly recommended to mobilize them for awareness-raising on the benefits of SWM including, waste segregation, and the benefits of compost fertilizer.
- International organizations may invest upfront to build MRFs incl. composting centers all over the city, upgrade Secondary Transfer Stations or construct a new sanitary landfill. The City Corporation should provide the land and be actively involved.

All these recommendations will not change the system in one day. But they can contribute to making SWM in GCC more climate-friendly, more environmentally friendly, more inclusive, and healthier.

6. Conclusion

In this study, the GHG and black carbon emission reduction potential from SWM in Gazipur City Corporation was assessed. Three scenarios were compared: Scenario 1 represents the business-as-usual in Gazipur, where half of the waste is collected and disposed of on the nearby dumpsite, a small amount is recycled, and the remaining waste is illegally dumped or openly burned. The second scenario considered the SWM system in Ward 49 as BDRCS/SRC have introduced it together with with the City Corporation: 50% of the waste is composed, a small portion recycled, and the residual waste disposed of on the dumpsite. As the interest in waste-to-energy solutions in Bangladesh is increasing, the third scenario builds upon scenario 2, but with the incineration of residual waste instead of dumping, comparing emissions when energy is recovered or not.

The results show that the BDRCS/SRC project emits 58% less CO_2-eq than the business-as-usual scenario, with the former emitting 594 and the latter 248 tons per year. Black carbon emissions were even reduced by 72%, from 29kg to 8kg per year. Emissions from the modified BDRCS/SRC scenario where waste is incinerated instead of disposed of on the dumpsite varies, depending on whether electricity is recovered from the incinerated waste or not. Emission for the entire GCC are estimated to be 40'042 tons of CO2-eq in the business-as-usual scenario, compared to the BDRCS/SRC project, which only emits 16'679 tons yearly. 1'950 kg of black carbon is emitted in the former compared to 538 kg in the latter case.

From a climate perspective, these results provide clear evidence for the emission reduction potential of an SWM system that follows a *circular economy of waste* management where composting and recycling are maximized. However, it also becomes clear that one must consider more than just the technological possibilities of solid waste management. Rather, SWM must be regarded holistically, considering local circumstances, political willingness, public awareness and the opportunity to develop market systems for individual material to maximize recovery.

IFRC has identified climate and environmental crises as one of the most pressing challenges in the upcoming years, including mitigation and adaptation (IFRC, 2018). BDRCS emphasizes in their current Strategic Plan the resilience building of urban communities to respond to multi-hazard risks and climate-induced phenomena (BDRCS, 2021). And SRC has defined Disaster Risk and Climate Change as thematic priority in their strategy 2025-2028. The findings of this study may thus serve them and other SWM actors as well as the GCC and the government of Bangladesh in their future decision-making and to attract funds for waste-related projects. Finally, the results may benefit the people of Gazipur, as they are the ones directly affected by unmanaged waste and its direct and indirect consequences.

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Appendix

Summary of results of the GHG emission calculation tool.

Description	Technology	Unit	BAU				Scenario 1				Scenario 2			
			CH_4	BC	CO_2	N_2O	CH_4	BC	CO_2	N_2O	CH_4	BC	CO_2	N_2O
Waste collection and transportation by the city	Transportation	**kg /tonne** (unit ' kg ' used here to show the magnitude of small amount of emissions)	0.001	0.015	19.944	0.001	0.001	0.007	9.703	0.001	0.001	0.007	9.703	0.001
Treatment for separated waste	Composting						4.000	0.000	-2.220	0.293	4.000	0.000	-2.220	0.293
	Anaerobic digestion													
	Recycling		-0.007	-0.014	-834.039	-0.002	-0.007	-0.014	-834.039	-0.002	-0.007	-0.014	-834.039	-0.002
Treatment for mixed waste	MBT													
	Incineration										0.188	0.322	429.099	0.068
	Landfilling		37.251	0.006	19.944	0.000	17.108	0.007	20.644	0.000				
	Open burning/ landfill fire													
Uncollected waste	Open burning/ scattered dumping		16.512	0.039	17.008									
GHGs/SLCPs emission per tonne of generated waste:		**kg/tonne**	**26.340**	**0.037**	**25.984**	**0.001**	**9.807**	**0.010**	**5.866**	**0.147**	**2.086**	**0.154**	**192.249**	**0.178**
BC emissions from yearly generated waste:		**Tonnes**	**0.029**				**0.008**				**0.120**			
Climate impact from GHGs emissions from yearly generated waste:		**Tonnes of CO2-eq**	**593.809**				**248.326**				**231.533**			

Some impressions of the waste management in Gazipur

Business-as-usual in Gazipur City Corporation

Photo taken by Md. Kamrul Hasasn, Urban Manager, BDRCS

Waste in streets of Ward 55

Secondary Transfer Station

Open dumping of collected waste…

…and water logging

A visit to the top of the approx. 50m high dumpsite in Gazipur City

Photo taken by Mirjam Grünholz

The dumpsite of Gazipur

Where we met waste pickers…

…and cows

SWM system in Ward 49 - SRC/BDRCS project

Photo taken by Mirjam Grünholz

Waste collectors collect waste…

… and bring it to the MRF.

Recyclables are diverted during collection…

… and sold in the scrap shop

Organic waste is composted…

…and fertilizer is produced.

For a clean and healthy
Ward 49 of Gazipur City Corporation, Bangladesh!

Declaration of originality

The signed declaration of originality is a component of every semester paper, Bachelor’s thesis, Master’s thesis and any other degree paper undertaken during the course of studies, including the respective electronic versions.

Lecturers may also require a declaration of originality for other written papers compiled for their courses. I hereby confirm that I am the sole author of the written work here enclosed. I have compiled it in my own words. Parts excepted are corrections of form and content by the supervisor. Contributions from artificial intelligence-based (AI) tools are described in annex 1 of this work. All contributions from artificial intelligence-based tools have been reviewed and edited as necessary. I take full responsibility for the content of the work.

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