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Short communication

Greenhouse Gas Emission Due to Plastic Waste Recycling in the Chittagong City Corporation

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Life cycle assessment (LCA) is known as a "cradle to grave" analysis. It specifies the environmental impacts through every stage of its life from obtaining the raw material for making the product to its disposal [1]. It is a technique for assessing the potential environmental impacts associated with a product [2]. It is a valuable tool to document the environmental concerns that help in the decision making process towards environmental sustainability [3].

Municipal Solid Waste (MSW) generation is one of the most severe problems in Bangladesh [4]. Total solid waste generation was 7690 tons per day at the six major cities of Bangladesh, namely, Dhaka, Chittagong, Khulna, Rajshahi, Barisal, and Sylhet in 2005 with a 0.41 kg/person/day waste generation rate [5]. Among different kinds of municipal solid waste, plastic wastes comprise 5% of total waste in the Chittagong City Corporation (CCC). In the CCC, plastic waste generation was 37 tons/day in 2005 [5]. Various processes involved in municipal solid waste management are responsible for the emission of greenhouse gases (GHG), including CO_2, CH_4, NO_2, HFCs, PFCs, and SF_6 to the atmosphere [6]. Recycling is a solution to reducing the environmental impacts of municipal solid waste management, which minimizes oil usage, GHGs emissions, and quantities of wastes requiring disposal [7]. Recycling of plastic wastes is prevalent in Brazil, Thailand, Botswana, Turkey, and India [8, 9]. Informal sectors in Bangladesh recycle about 4-15% of total solid waste [10]. Dhaka city recycles 66% of total plastic wastes each year [11]. Recycled solid waste is estimated at 8.25% of complete solid waste in Rajshahi city [12]. The studies revealed that the MSW management was responsible for the greenhouse gas emission [13-15]. Some life cycle assessment studies were relevant to plastic materials. It was found that GHG emissions were1480 tons of CO_2-eq and 1340 tons of CO_2-eq for manufacturing of Polyethylene (PE) and Polypropylene (PP) plastic pellets, respectively [1]. For the treatment of high-density polyethylene (HD-PE) boxes, emitted GHG from electricity was 94-358 kg CO_2-eq/ton of treated waste. For the production of 1 ton of virgin HD-PE granulates, the GHG emissions were 1082-1626 kg CO_2-eq [16]. Recycling of 1 kg pet flakes requires 42-55 MJ energy for plastic packaging recycling [17]. GHG emission from expanded polystyrene mold production was 7.36 kg CO_2-eq per kg of mold [18].

The literature review found the studies on MSW generation, and management [5, 11, 19-21], on recycling of solid waste [5, 7, 8, 10, 12, 17, 22-27], on GHG emissions from their management and treatment [6, 28-33], and on the GHG emission from plastic material production and recycling of plastic waste [1, 16-18, 34, 35]. All the above studies adopted the life cycle approach to understanding the environmental impacts. However, no study was found in the CCC, even in other places of Bangladesh concerning the life cycle assessment of plastic waste recycling. So, this study attempted to find out GHGs emissions from the recycling of plastic wastes in the CCC. The outputs of this study will become a baseline for future studies. The study will be useful for understanding greenhouse gas emission from the plastic waste recycling.

The geographic scope of this study was the CCC area (Figure 1). The study was performed from March 2016 to September 2016.

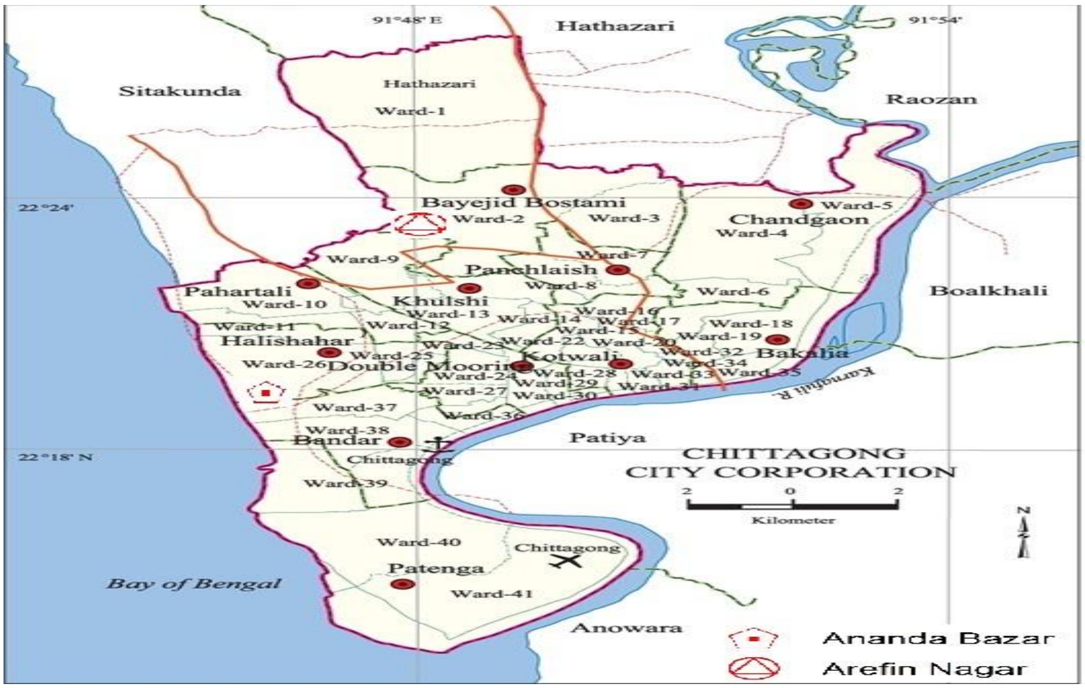

Figure 1: Chittagong city corporation as a study area for greenhouse gas emission due to plastic waste recycling.

Chittagong is the second-largest city in Bangladesh. It is also the commercial capital of the country. It lies in the southeastern part of Bangladesh between 22°14′ and 22°30′ north latitudes and between 91°45′ and 91°53′ east longitudes on the banks of the Karnaphuli river [36]. She covers a total area of 157 km^2. The population census in 2011 found that the total population of Chittagong city is 25,92,439, with a density 16,513 per km^2 in total 5,58,097 households. The CCC consists of 41 wards, including two zones. These are the North and South zone. Out of 41 wards, 24 are conservancy, and 17 are non-conservancy wards. At the very beginning, Chittagong town started to grow as a small municipality in 1863 inhabited by 25,000 people only. In 1864, the British government declared it as Chittagong Municipality. It upgraded to Chittagong Municipal Corporation (CMC) in 1982 and finally to Chittagong City Corporation (CCC) in 1990.

A large number of economic and industrial activities is extended in the CCC because of the presence of the Chittagong port. And, hence, the contribution of this city to the country's national economy is much higher than the other cities in Bangladesh. There are some industrial belts, including many medium and heavy industries located at Fouzdarhat, Kalurghat, Baizid Bostami, and Potenga industrial area. The city's GDP was $16 billion in 2005, with an annual growth rate of about 6.3%, and it was estimated that in 2020, the GDP of Chittagong would be $39 billion [37]. Since this city has a vast population and carries out dense commercial activities, the generation of solid wastes is also increasing rapidly. It was estimated that the total average waste generation was 1300-1356 tons/day including per capita waste generation of 0.48 kg/day in the CCC [11].

The study selected the CCC purposively as a study area to research the generation of plastic waste, 37 tons/day [5]. It had a questionnaire survey to fulfill the objectives of the study. It included the personal interviews of the people related to the recycling process of plastic waste in the city. The study collected primary data from 25 waste depots and 19 plastic waste processing industries. Surveyed waste depots and processing industries were in Muradpur, Solosohor, Korbanigonj, G.E.C, Newmarket, Bakalia, Halisohor, and Dewanhat area. The data on plastic waste collection, energy consumption in the form of electricity for storage were collected from the waste depots. Processing industries reported fuel consumption (diesel) for waste transportation to the processing industry and energy consumption (electricity) for processing them. The data analysis was performed with Microsoft Excel 2010.

LCA, an evaluation tool, calculated the environmental impacts of plastic waste recycling in the CCC. LCA was comprised of four significant stages: goal and scope definition, life cycle inventory, life cycle impact analysis, and interpretation of the results.

This study aimed to evaluate the GHG emissions from the plastic waste recycling process in the CCC area from a life cycle perspective. Environmental impacts considered energy consumption in the form of fuel and electricity. The study considered collection, storing, transportation, separation, and processing under the components of the recycling process.

The functional unit selected for quantification of greenhouse gas emission was kg CO_2-eq/ton of plastic waste.
The system boundary started with the collection of plastic wastes. The boundary ended at the processing industry, which treated the collected plastic wastes into plastic flakes. This system boundary considered only energy inputs such as electricity and fuel (Figure 2).

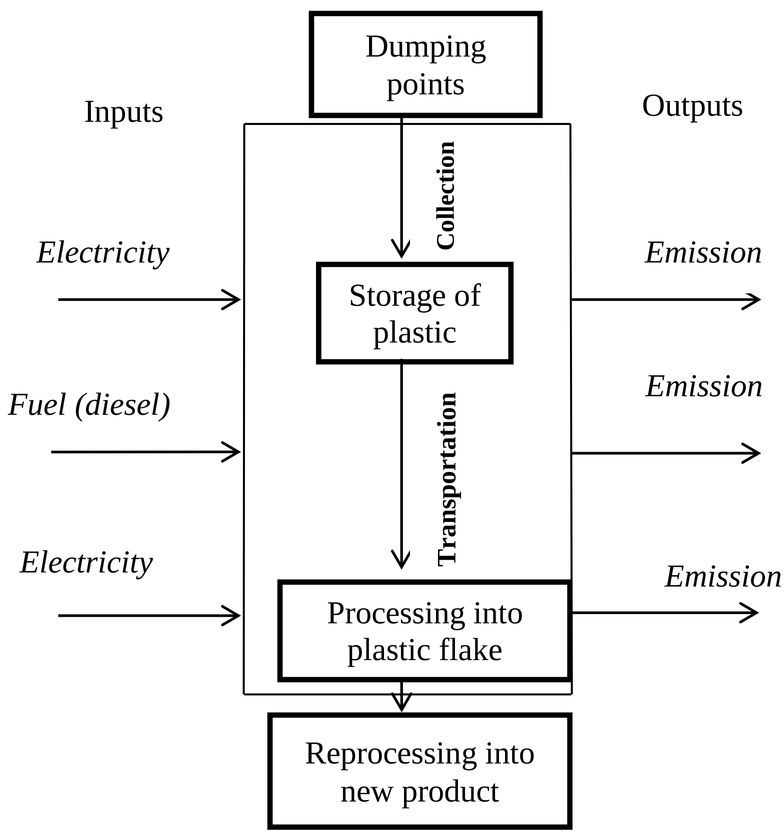

Figure 2: The system boundary of the LCA study of plastic waste recycling in the Chittagong City Corporation.

Transportation of plastic wastes for recycling consumes fossil fuel. Through this fossil fuel combustion, greenhouse gases were emitted into the atmosphere. In the CCC, vehicles used for transportation of plastic wastes used diesel as fuel. Combustion of diesel released CH_4, N_2O, and CO_2. Here, the emission of CH_4 and N_2O was negligible. So, in this study, CO_2 was considered as the main component of greenhouse gas emission from this transportation. The study calculated total GHG emission from transportation by using the following equation [38]:

$$\text{Emissions}_T = \frac{\textit{Fuel (units)}}{\textit{Wastes (tons)}} \times \text{Energy (MJ/unit)} \times \text{EF (kg } CO_2\text{-eq/MJ)}$$

Here,

Emissions $_T$ = Emissions from transportation (kg CO_2-eq/ ton of waste transported)

Fuel (units) = Total amount of diesel consumption per month, (Diesel in liters)

Waste (tons) = Total amount of transported per month

Energy (MJ/unit) = Energy content of the fossil fuel (e.g. diesel: 36.42 MJ/L)

EF = GHG emission factor of the fuel (e.g. diesel: 0.074 kg CO_2-eq/MJ)

Furthermore, monthly GHG emission from transportation was estimated as follows:

Monthly GHG emission (kg CO_2-eq/month) = GHG emissions/ton × tons of waste transported per month

Bangladesh produces electricity mainly from natural gas, coal, heavy furnace oil, high-speed diesel, and hydropower. A little electricity also flows from gas-based power plants in Tripura, India.

By using the following equation, the study calculated GHG emission using table 1.

Emissions = [Percentage of electricity from coal (2.03%) × total electricity (kWh) × 3.26 Kg CO_2-eq/kWh] + [Percentage of electricity from natural gas (61.82%) × total electricity (kWh) × 0.185 Kg CO_2-eq/kWh] + [Percentage of electricity from heavy Furness oil (21.68%) × total electricity (kWh) × 2.96Kg CO_2-eq/kWh] + [Percentage of electricity from high speed diesel (7.75%) × total electricity (kWh) × 0.733Kg CO_2-eq/kWh] + [Percentage of electricity from hydropower (1.86%) × total electricity (kWh) × 0.0236 Kg CO_2-eq/kWh] + [Percentage of electricity imported from India (4.86%) × total electricity (kWh) × 0.185 Kg CO_2-eq/kWh]

In the CCC, plastic wastes generally originated from residential, industrial, commercial, and institutional areas. These wastes appeared in pet bottles, cans, jugs, bowls, plastic polythene, gallons, hanger, electrical products, electric boards, and buckets. Before reaching the recycling industries, most of these wastes reached waste depots locally known as *Vangari*. The figure 3 shows the supply chain of plastic wastes.

Table 1: Sources of the generated electricity to the national grid in Bangladesh.

Fuel type	**Capacity (MW)**	**Percentage (%)**	**Emission factor**	**Emission factor unit**	**Source**
Natural gas	7628.00	61.82	0.185	kg CO_2-eq/kWh	[39]
Coal	250.00	2.03	3.26	kg CO_2-eq/kWh	[39]
Heavy furnace oil	2675.00	21.68	2.96	kg CO_2-eq/kWh	[40]
High-speed diesel	956.00	7.75	0.733	kg CO_2-eq/kWh	[41]
Hydroelectricity	230.00	1.86	0.236	kg CO_2-eq/kWh	[41]
Imported from India	600.00	4.86	0.185	kg CO_2-eq/kWh	[39]
Total	12339.00	100			[42]

The sources of the plastic wastes were households, local markets, and rail/bus stations. Mainly, *Tokai* (street-urchin) collected plastic wastes from dumping sites of different places and households and then they were reported to sell the wastes to waste depots. From these waste depots, waste plastics were bought by the processing industries that cut/crushed plastic products into flakes. Infrequently, the processing industries also were reported to collect plastic wastes directly from the households, *Tokai* (street-urchin), local market, industrial areas, and bus/railway stations.

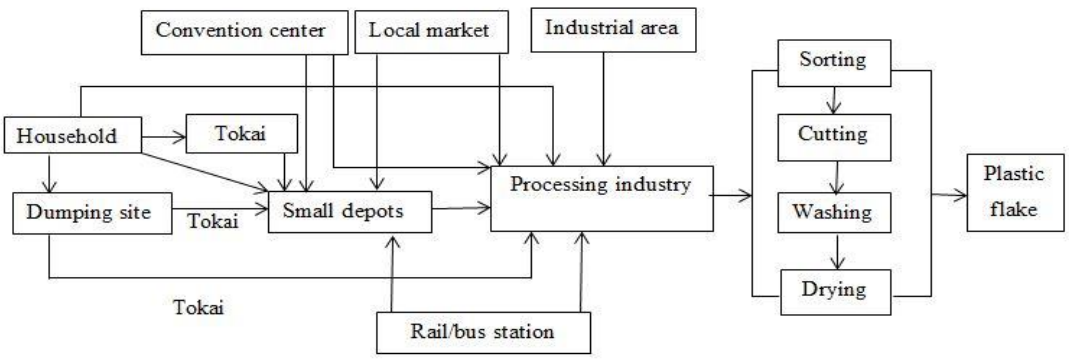

Figure 3: The supply chain of plastic wastes in Chittagong City Corporation.

The household was the largest source of waste plastic in this sector. The waste depot collected 37.44% of their plastic wastes from the household. They also collected 28.73%, 17.79%, and 16.04% plastic wastes from *Tokai*, bus/railway station, and local market, respectively.

The processing industries collected significant quantities of plastic wastes, 36.79%, from the waste depot, followed by *Tokai*, 20.74%. Other sources such as bus/railway station, local market, industrial area, and household contributed 13.83%, 11.36%, 11.11%, and 6.17%, respectively, of the processing industries' total collection.

The defined system boundary identified three stages as a source of GHG emission. These were storage, transportation, and recycling of plastic wastes. In the waste depots, plastic wastes were stored initially for recycling purposes. The waste depots did not perform any processing activities except storing the waste. Storage and maintenance activities of the wastes used electricity until the wastes go for the processing industries. In the waste depot, the average energy consumption in the form of electricity was 80.21 kWh/ton of wastes.

For transportation, the processing industries used diesel as fuel. A total of 12 of the surveyed processing industries were found using fuel-based vehicles for transporting the wastes. Other industries used manually driven vehicles like a van for transportation. The processing industries required 226 liters of diesel per month for transportation of these plastic wastes.

In the processing (plastic recycling) industries, plastic wastes were cut into plastic flakes using cutting machines. These machines ran by electricity. So converting plastic wastes into plastic flakes was another major source of GHG emission in the plastic recycling process in Chittagong city. Average electricity consumption in this stage for processing of plastic was 54.84 kWh/ton of wastes.

In the waste depot, GHG emitted due to the use of electricity. This electricity consumption was only for the storage and maintenance of plastic wastes before selling it to the processing industries. The figure 4 shows the average requirement of energy and emission of GHG in the waste depot. The required electricity in the waste depot for 1 ton of plastic waste was about 80.21±7.20 kWh. The quantity of emitted GHG from this stage was 71.27±6.39 kg CO_2-eq/ton.

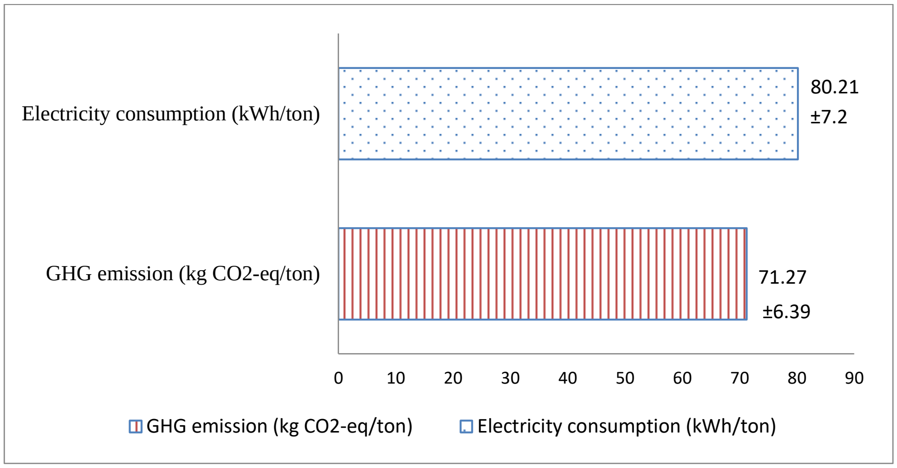

Figure 4: The average consumption of electricity and GHG emissions in the plastic waste depots in Chittagong City Corporation.

The figure 5 shows the monthly emission of greenhouse gas from waste depots. The average consumption of electricity was 21.56±2.75 kWh per month. So the emission of GHG from the storage of plastic waste in one month was 19.16±2.44 kg CO_2-eq.

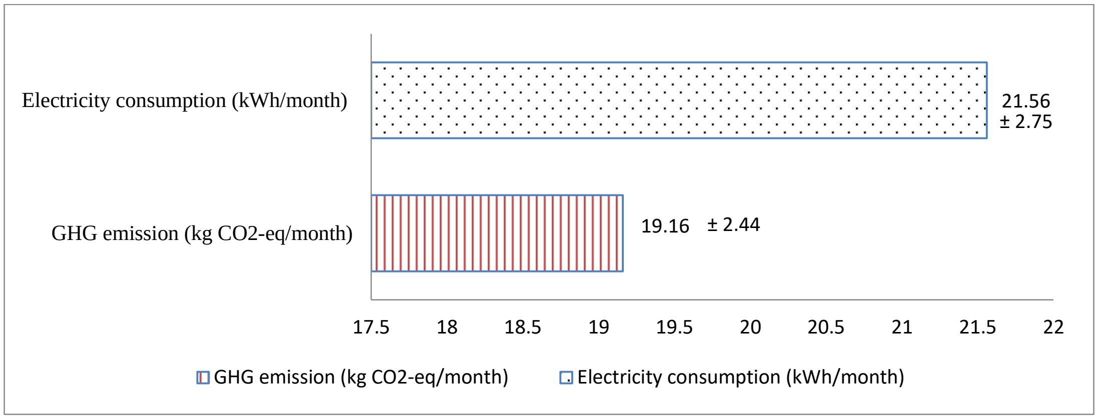

Figure 5: Average monthly electricity consumption and emission of GHG in the plastic waste depots in Chittagong City Corporation.

From the life cycle inventory, it was found that the plastic processing (plastic recycling) industries required machines for converting plastic wastes into plastic flakes in the processing industries. These machines ran by electricity. So, this was another primary source of GHG emission within the defined system boundary.

The figure 6 shows the average consumption of electricity and GHG emissions in the processing (plastic recycling) industries. Here, the average consumption of energy in the form of electricity was 54.84±14.84 kWh/ton. Greenhouse gas emission from the consumption of energy was 48.73±12.73 kg CO_2-eq/ton of waste plastic processing.

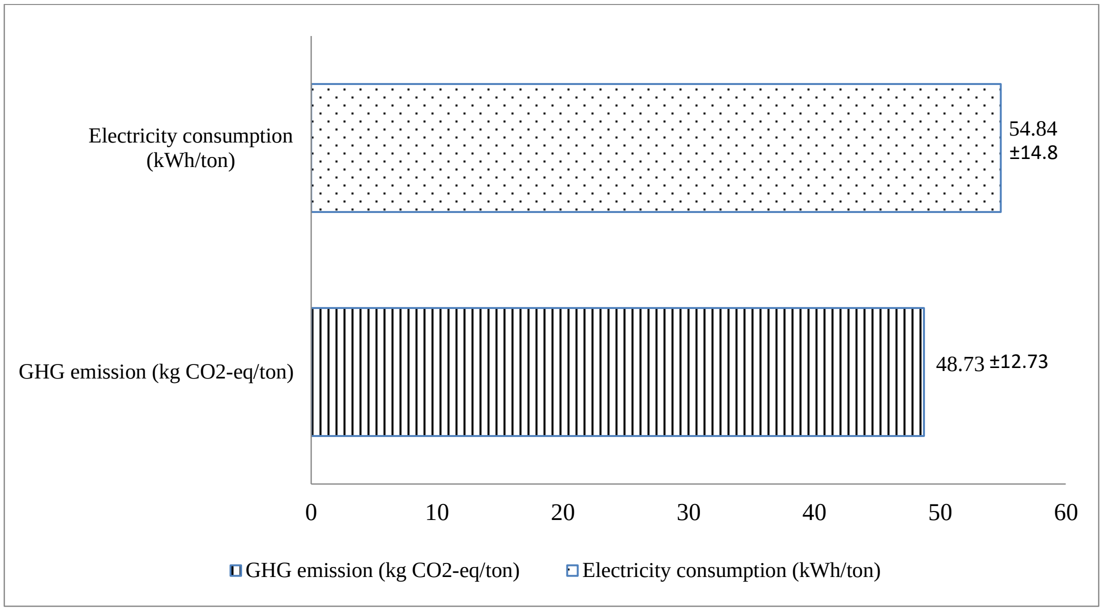

Figure 6: The average consumption of electricity and GHG emissions in processing (plastic recycling) industries in Chittagong City Corporation.

The average monthly electricity consumption was 827.61±17.36 kWh for the processing of plastic wastes in the processing industries. The emission from the processing industries was calculated at 735.34±15.17 kg CO_2-eq/month. The figure 7 shows the monthly electricity consumption and the emission of GHG.

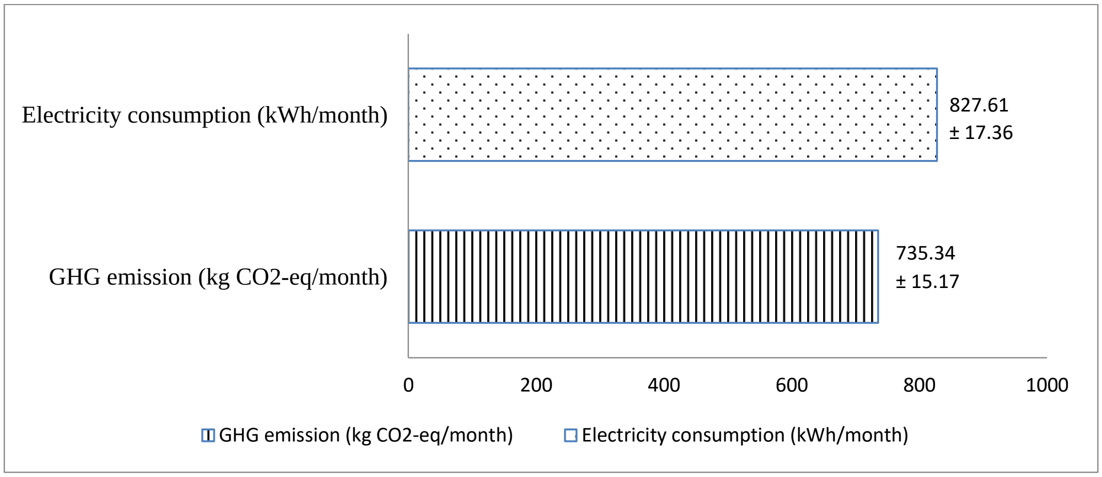

Figure 7: Average monthly electricity consumption and emission of GHG in the processing (plastic recycling) industries in Chittagong City Corporation.

The surveyed processing industries, 12 in numbers, were found to use fuel-based vehicles for transporting the plastic wastes from the waste depots to the processing industries. They generally used small trucks for transporting the wastes, which used diesel as fuel.

It was found that 185 tons of plastic wastes were transported monthly by using fuel-dependent vehicles. Based on the results from the inventory, the figure 8 shows the consumption of fuel and GHG emissions from transportation.

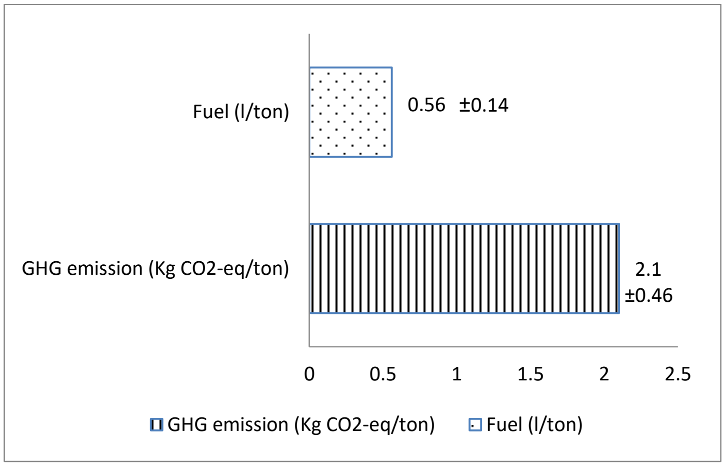

Figure 8: The average consumption of fuel (diesel) and GHG emissions in the transportation of plastic wastes for recycling in Chittagong City Corporation.

Transportation required about 0.56±0.14 liter diesel for transporting 1 ton of plastic wastes. Direct greenhouse gas emission from the waste transportation in the CCC was about 2.1±0.46 kg CO_2-eq/ton of the transported wastes. Monthly GHG emission was found 388.5 kg CO_2-eq from the transportation of 185 tons of plastic wastes.

The overall emission within the system boundary is in the figure 9. In the waste depot, the emission was 71.27 kg CO_2-eq/ton of stored wastes. Whereas, in the processing (plastic recycling) industries, the emission was less than the waste depot. Total emission from transportation and energy consumption was 50.83 kg CO_2-eq/ton of processed waste. Here, 2.1 kg CO_2-eq emitted from the transportation of 1 ton plastic wastes, and 48.73 kg CO_2-eq was emitted from the processing of 1ton plastic wastes.

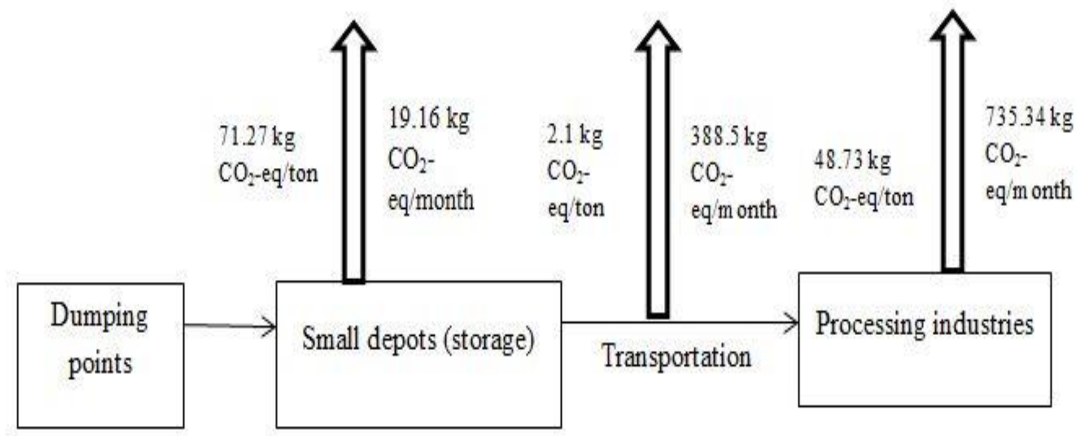

Figure 9: Overall emission of greenhouse gas within the defined system boundary for plastic waste recycling in Chittagong City Corporation.

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