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# Greenhouse gas footprint and the carbon flow associated with different solid waste management strategy for urban metabolism in Bangladesh

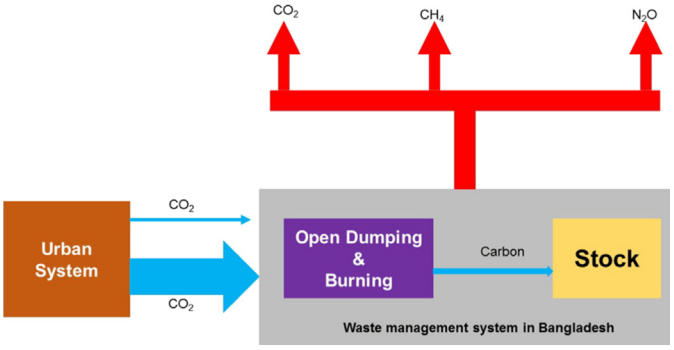
K M Nazmul Islam

*Institute of Forestry and Environmental Sciences, University of Chittagong, Chittagong 4331, Bangladesh*

## HIGHLIGHTS

- 420.88 kg $CO_2$ eq. emitted for the reference year 2015.
- 209.46 and 422.29 Gg carbon can be possible to send back to the studied urban systems.
- Waste management constraints and land scarcity problem demanding urgent initiation of waste to energy (WtE) strategy.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Greenhouse gas (GHG) emissions from municipal solid waste (MSW) and associated climate change consequences are gripping attention globally, while MSW management as a vital subsystem of urban metabolism significantly influences the urban carbon cycles. This study evaluates the GHG emissions and carbon flow of existing and proposed MSW management in Bangladesh through scenario analysis, including landfill with landfill gas (LFG) recovery, waste to energy (WtE), and material recovery facility (MRF). The analysis indicates that, scenario $H_2$ and $H_5$ emitted net GHGs −152.20 kg $CO_2$ eq. and −140.32 kg $CO_2$ eq., respectively, in comparison with 420.88 kg $CO_2$ eq. of scenario $H_1$ for managing per ton of wastes during the reference year 2015. The annual horizontal carbon flux of the waste input was 319 Gg and 158 Gg during 2015 in Dhaka and Chittagong, respectively. An integrated strategy of managing the wastes in the urban areas of Bangladesh involving WtE incineration plant and LFG recovery to generate electricity as well as MRF could reverse back 209.46 Gg carbon and 422.29 Gg carbon to the Chittagong and Dhaka urban system, respectively. This study provides valuable insights for the MSW policy framework and revamp of existing MSW management practices with regards to reduction of GHGs emissions from the waste sector in Bangladesh.



## 1. Introduction

Around the world human society with endures race for modernized urban life generating tremendous amount of by-products of urban lifestyle, popularly known as municipal solid waste (MSW). MSW generation rate is mounting even faster than that of urbanization (UN, 2003;

*E-mail address:* nazmul@ifescu.ac.bd.

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Hoornweg and Bhada, 2012). Global MSW generation was 1.3 billion tons/year in 2010, which is a twofold increase from 0.68 billion tons/year in 2000. It is projected to be 2.2 billion tons/year and 4.2 billion tons/year by 2025 and 2050, respectively (Hoornweg and Bhada, 2012). If not managed properly, this ever increasing waste load of urbanized world, will certainly have a negative impact on the possibility of sustainable life styles as well as on local land, air, and water quality, and consequently to human health (Scarlat et al., 2015). Rapid population growth and fast industrialization in response to the demand of national development and urbanization are already instigating severe MSW management problems in developing, and under developed countries like China, India, Malaysia, Thailand, and Bangladesh (Singh et al., 2011; Johari et al., 2012; Chiemchaisri and Visvanathan, 2008; Cheng and Hu, 2010).

Anthropogenic emissions of greenhouse gases (GHG) driven by global economic and population growth are currently the highest in history. Modern human civilization impact on the climate system of the earth is already concerning (Pachauri et al., 2014). Anthropogenic activities are increasing the concentration of GHG in our atmosphere and consequently increasing the global climate, which is a prime challenge for the survival of the earth (Stocker et al., 2013; Boldrin et al., 2009). Total annual GHG emissions (52 $GtCO_2$-eq./yr) during 2010 was observed due to increased contribution of $CH_4$ from MSW (Stocker et al., 2014). Globally, $CH_4$ generation from MSW landfills and open dumping grounds accounts for 11%; and <10% of this potential is currently captured and utilized (Themelis and Ulloa, 2007). So, in the contexts of climate change and global warming we should rethink our wastes management approach in the cities. In view of this urgency, the emerging field of research named urban metabolism became more popular to analyze the energy and material flows associated with the production and consumption activities in cities. The ultimate objective is to assess the flows of materials and energy to know the environmental stress from urban system.

Low-carbon city development significantly relies on urban communities. Studying the carbon metabolism of urban communities will assist exploring the metabolic behavior and structure, as well as interactions among communities and households with urban environment to identify the intrinsic drivers of carbon emissions (Lu et al., 2015a). A number of studies recently conducted on urban metabolism were focusing on carbon metabolism and energy metabolism. The study of urban metabolisms basically deals with analyzing the elementary flows in social systems, which facilitates sustainability assessment of cities and identification of appropriate measures in relation to material consumption and waste recycling (Chen and Chen, 2015). The research conducted so far within the research arena of urban metabolism deals with energy metabolisms of urban agglomerations or cities (Zheng et al., 2016; Chen and Chen, 2016a; Shahrokni et al., 2015; Chen et al., 2015; Chen, 2015; Chen and Chen, 2014; Chen and Chen, 2012), carbon metabolisms in urban communities (Lu et al., 2015a; Lu and Chen, 2015), carbon metabolisms of energy consumption (Yang et al., 2015), carbon metabolisms of municipal solid waste management system (Zhou et al., 2015), food-sourced nutrient metabolisms in cities (Lin et al., 2016), inter-regional carbon metabolisms (Chen and Chen, 2016b), methodological insight into urban metabolisms and the nexus (Chen and Chen, 2015), and carbon metabolisms at the eco-industrial parks (Lu et al., 2015b). Most of the mentioned studies, viewed the studied carbon and energy metabolism framework for designing circular economy at the city, urban, regional and sometimes at the industrial conglomerate.

Production, consumption and dumping are the common practices in a typical linear economy, from which the world is trying to move to the practice of circular economy (CE). CE is a simple and convincing strategy, targeting to reduce both virgin materials input and wastes output through closing economic and ecological resource flow loops (Haas et al., 2015). Good examples of turning our society towards zero waste and circular economy principle is the adoption of reduce, reuse, recycle, materials recovery and finally waste-to-energy (WtE) strategy by managing and using MSW in the city. WtE is a very promising alternative energy option for the future, because 10% of global annual electricity need equivalent to $71.81 \times 10^{15}$ kWh can be satisfied from the 2.3 billion tons of MSW from the urbanized human society by 2025 (WEC, 2013). WtE identified as one of eight technologies likely to make a meaningful contribution to a future low-carbon energy system, by the World Economic Forum in its 2009 report, "Green Investing: Towards a Clean Energy Infrastructure" (Greenwood, 2009). The two most common practices for WtE are electricity production through mixed waste incineration and landfill gas (LFG) recovery system (Tan et al., 2014). Besides, materials recovery facility (MRF) provide an option to recover the materials like aluminium, iron, copper, paper, plastic from the waste stream. Unfortunately, fast population growth and ongoing economic development cause a tremendous generation of solid waste, and are blamed for significant environmental glitches in the urban areas of Bangladesh (Bhuiyan, 2010; Ahsan et al., 2014; Afroz et al., 2011a). Bangladesh has enjoyed a tremendous growth in its economy over the last few years, which is causing a great influx of village workforce to cities (BDNews24, 2015). Hence, these two factors, i.e. population and economy growth should be constructively transformed, because they are the major drivers of sustainable waste management in Asia (Johari et al., 2012; Agamuthu et al., 2009). In Bangladesh, sustainable MSW management is still a dilemma in spite of a continuous government effort (Bhuiyan, 2010; Ahsan et al., 2014). A number of studies have been conducted in Bangladesh covering a number of aspects related with MSW management issues, such as-characterization and factor of the MSW generation (Afroz et al., 2011a; Alamgir and Ahsan, 2007a; Salam et al., 2012; Sujauddin et al., 2008; Yousuf and Rahman, 2007), disposal status and management problems (Bhuiyan, 2010; Hai and Ali, 2005; Chowdhury et al., 2013; Ahsan and Zaman, 2014; Matter et al., 2013; Hasan et al., 2009; Sufian and Bala, 2007), people's willingness to pay for different waste management options (Afroz et al., 2009; Afroz et al., 2011b), composting aspects (Alamgir and Ahsan, 2007a; Zurbrügg et al., 2005; Rahman et al., 2006), and recycling aspects (Matter et al., 2013; Alamgir and Ahsan, 2007b). A few studies have been conducted to estimate electricity generation potential (Alam and Boie, 2001; Sufian and Bala, 2006), but none of the studies is conducted to comprehensively assess the GHG footprint and the carbon flow of different MSW management options from urban metabolism and low carbon city development perspectives in Bangladesh.

This study conducted a comprehensive assessment of GHG emissions of the total waste generated, and existing management practices along with several waste management scenarios in the urban areas of Bangladesh. Waste management scenarios were developed combining WtE incineration plant, landfill with LFG recovery and MRF. The results of this study could serve as a practical guideline in the waste management system in Bangladesh, as well as for the evaluation of waste management policy frameworks in relation to GHG mitigation and carbon flow from the waste stream in the urban areas of Bangladesh. This article is an attempt of evaluating the carbon metabolism of MSW management systems to develop circular economy perspectives for waste management as well as low carbon cities in Bangladesh. Most of the data in this study is locally relevant to Bangladesh, and collected from field work, relevant authorities or scientific literature on waste management in Bangladesh.

## 2. Methodology

This study evaluated the GHG emissions and carbon flow of existing and proposed solid waste management strategies in the urban areas of Bangladesh. GHG emissions were evaluated from five waste management scenarios including landfilling, waste to energy, and material recovery at the national level using the total waste generation from 514 urban areas (12 city-corporations, 298 municipalities, 218 other urban centers). The carbon flows of existing and proposed MSW management strategies were modeled at the city level using the annual urban waste generation data (2001 to 2015) for two cities of Bangladesh, namely Dhaka (the capital of Bangladesh) and Chittagong (the commercial

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