Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2022, 9(3):107-120

Research Article ISSN: 2394 - 658X

Assessment of GHG Reductions per Ton of Waste Diverted from Landfill to Composting Plant and Utilised in Agricultural Field for Okhla Composting Plant

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ABSTRACT

Climate change is likely to increase the incidences of epidemic and pandemics, which needs immediate attention for environmental safety, health security and social equity. In the coming decades, too, and the number of lives at risk due to climate change will also increase with time. The primary reason behind climate change is the increasing greenhouse gas emissions. After the Paris Climate Agreement 2015, all the party countries are focusing on reducing their emissions and taking other adaptation measures. Globally, the waste sector accounted for 5% of total global emissions and 12% of global methane emissions (Hoornweg and Bhada-Tata, 2012). In India, due to poor management of MSW and unscientific dumping of most of the solid waste leads to methane emissions from these landfills. The solid waste from Indian cities has a high fraction of compostable waste. Delhi generates more than 9000 tons per day of MSW, and more than 40% is compostable. The diversion of this compostable waste to composting plants can mitigate or reduce methane emissions from landfills, and other environmental benefits. In this Delhi-specific study, a life-cycle approach is used to quantify the reduction in GHG emissions per ton of waste from the Okhla landfill site Delhi to the Okhla composting plant and used in the agricultural field. The analysis shows that this process has a considerable potential to mitigate the emissions arising from the solid waste sector.

Key words: GHG Reductions, Waste, Agricultural Field,

INTRODUCTION

India's population is around 1.395 billion in 2021. While India's surface area is only 2.4% of the world's surface area, it shares a whopping 17.7% of its total population. Thus, there is considerable pressure on India's natural resources. The GHG emissions from India are the fourth largest globally after China, the USA and the EU. India is emitting around 3 Giga-tonnes CO2 equivalent yearly, which is a 363% rise from 1990, and these emissions are rising every year. Under Paris Agreement, Indiahas committed to reducing the GHG emissions intensity of its GDP by 33-35% belowthe levels of 2005 by 2030. The Climate Transparency report 2020 noted that India iswell on track to meet its commitments, but it is not on way to meet the long term target of 1.5˚C of the Paris Agreement. While India has taken many actions to reduce emissions in energy, transport, forest, waste and industry, it can still do more and be a 'Global Leader' in taking climate actions.

According to the World Bank (1994) municipal solid waste is defined to include refuse from households, hazardous solid waste from industrial and commercial establishments, and refuse from institutions, market waste, yard waste and street sweeping.

A combination of household waste and commercial refuse that is generated from the living population is usually considered as municipal solid waste (Rajkumar, Subramani & Elango 2010). MSW generally consists of biodegradable (paper, food waste, yard and garden waste), partially-biodegradable (like wood, sludge) and non-biodegradable fractions (metals, glass, dust, plastic (Jha *et al.*, 2011).

The end product of any consumption leads to waste generation. Waste managementis relatively easier for a smaller population (Himabandu *et al*., 2015). But as the population and urbanisation are increasing, the waste generation is increasing in thecities. The standard of living also decides consumption and increases the quantity of waste generated per capita (Gidde *et al*., 2008; Rathi 2007). As a by-product of urbanisation, the municipal solid waste that is generated over the world is expected to be 2.2 billion tonnes per year by 2025 (Hoornweg and Bhada-Tata, 2012). The huge quantities of waste generated and its management has become challenging environmental and health issues in front of governments and policy-makers (IPCC 2006). If managed improperly, the MSW release many toxic substances and gases in the atmosphere leading to the contamination of soil, air and water. These contaminants can enter the food chain and cause harmful effects on the ecosystem (Marshall &Farahbakhsh 2013).

India has rapidly urbanised, and the population living in the cities has grown significantly in India. Due to this, the quantity of waste that is generated in a city has also increased rapidly. It can be understood from the figures that in 1947 Indian cities were generating 48 million tons of waste, it then increased to 90 million tons in 2009, and by 2047, the quantity of waste generated is expected to increase to 300 million tons (TEDDY 2010; Sharholy *et al*., 2006).

The characteristics and quantity of waste differ for every city or place. The factors that influence waste characteristics are population, average income, social values and culture, climate and market for waste products (Late& Mule 2013; Yadav & Devi 2009). In the study (Neha, Yadav & Kumar 2015), which analysed the data by CPCBof 59 Indian cities, it was found that on a wet weight basis, the composition of waste was; organic fraction (40-60%), ash and fine earth (30-40%), paper (3-6%) and plastic, glass and metals (each less than 1%). The Indian waste collection sector is highly unorganised. Further, waste segregation is the biggest challenge for efficient SWM. The waste is collected in mixed form due to lack of awareness, proper education, and segregation techniques and infrastructure (Nandan *et al.*, 2017). Thewaste collection efficiency in Indian cities is also low at 70-80% (Saxena, Srivastava & Samaddar 2010).

To deal with such a huge amount of municipal solid waste, Indian cities lack the necessary resources and technical expertise for the scientific disposal of solid waste(Kausal, Varghese &Chabukdhara 2012). Various methods of solid waste management and treatment are used in Indian cities. These include anaerobic digestion/ biomethanation, composting, vermicomposting, refuse-derived fuel, landfilling and material recovery facility. Among these, composting and landfilling are the most popular techniques for SW M in India. Other techniques and waste management through them are at the nascent stage in India. Only 6-7% of the total waste collected is composted, and the remaining waste is sent to landfills (Annepu 2012). Although this waste management scenario is changing with time as cities are incorporating different techniques to manage their waste other than just dumping thewhole waste into the landfills.

The landfills are constructed to keep the waste and its toxic effects away from the people and environment (Narayana 2009). But due to the unscientific and improper engineering technique, these landfills now have become a threat to human life and the environment in India. When waste in the landfill is subjected to biological and physicochemical changes, highly contaminated wastewater is formed that is called leachate. The percolation of leachate to the underground water and sometimes its disposal in water bodies leads to contamination of water resources (Kanmani & Gandhimathi 2013). The different type of waste that reaches to landfills without proper segregation in India contains various toxic substances. These toxic substances come from pharmaceutical companies, e-waste, hospitals, industries etc.These toxic substances are recalcitrant to a great extent and are harmful to both humans and the environment (Swati, Vijay & Ghosh 2018). Further, the anaerobic decomposition of waste in landfills produces methane and carbon dioxide, and both are greenhouse gases. Globally, 818 million $MTCO_2E$ of methane emissions (13% of total methane emissions) come from landfills (Rachel *et al.*, 2007). The methane generated at the landfills has a high fuel value, and it can be used to generate electricity if it is tapped from the gas tapping systems of landfills (Kumar & Sharma 2014). But Indian landfills lack this kind of system, which is why the methane is unabatedly released into the atmosphere. Methane's global warming potential is 21, which means it is 21 times more potent than carbon dioxide as a greenhouse gas that causes global warming and climate change.

As solid waste generated in India contains a high fraction of compostable matter, composting this organic waste can reduce the methane emissions from landfills. Composting is a biological process that uses natural aerobic processes to increase the decomposition rate of organic materials (Saheri *et al.,* 2012). It converts the initialorganic matter into an organic-rich soil amendment known as compost. The application of compost in agriculture has numerous benefits like reduced soil erosion, increased porosity, decreased density, increased soil carbon content, the addition of secondary and micro-nutrients to the soil, increased crop productivity etc.(Cogger 2005; ROU 2006; Shiralipour, McConnell & Smith 1992).

The available Indian literature has many studies on the potential of methane, which is generated in the landfills, to generate electricity. While discussing the greenhouse gas benefits of composting the MSW, the available literature in India quantifies only the reduced methane emissions from the landfills. But as discussed, the application of compost to the agricultural fields has greenhouse gas benefits and with other co-benefits. These greenhouse gas reduction benefits must be quantified to estimate the total reduction of GHG if organic waste is diverted from landfills to composting plant and then used the compost is used in agriculture. This study is an attempt to quantify these GHG benefits using a life-cycle approach.

METHODOLOGY

We took landfilling as the baseline scenario to calculate the reduction in GHG emissions by diverting the organic waste to compost and utilising the compost appropriately. For this, the Okhla composting plant and Okhla landfill site were selected to apply the life-cycle approach to calculate the GHG emission reductions. The life-cycle stages were used to quantify different emissions and emission reductions in making compost and using it as an agricultural amendment. In the first part, all the emissions released from composting and making compost were taken into account. In the second part, all the reduction in emissions associated with using the compost in agriculture and emissions that can be avoided from landfills were taken into account. The factors affecting the composting emissions and reduction in emissions are discussed below in detail.

Composting Emissions

This comprises emissions from 3 important factors. The first factor is the emissionsarising out of the transportation of feedstock to the composting units (ET). Second factor is the emissions arising out of energy and other inputs to run the composting units (EP). Third factor is the fugitive emissions arising due to the anaerobic decomposition of feedstock (EF). Each factor is important to be considered as theseemissions are significant enough to detract from the overall emission reductions arising out of compost use. During the composting process and then after the application of compost in the field releases biogenic CO2 in the atmosphere. Thesebiogenic CO_2 emissions are not considered GHG under the *Inventory of U.S.*

Greenhouse Gas Emissions and Sinks. So, these biogenic CO_2 emissions are not considered while calculating the composting emissions (USA, California Environmental Protection Agency, Air Resources Board, 2014). Hence, the followingequation represents the total emissions (Etotal) arising out of composting:

$$\mathbf{Etotal = ET + EP + EF} \quad (1)$$

Each of the values is to be taken in MTCO2E/ton of feedstock.

Transportation Emissions

The transportation emissions occur when diesel is burnt used in vehicles to transportthe feedstock to the composting plant and then transport the compost to the application sites. The average incremental distance travelled by the trucks to transport the feedstock to the Okhla Compost Plant. Then transportation of compost to the warehouses was monitored by IL&FS Environmental Infrastructure and Services Limited (IEISL). This data is available on the Clean Development Mechanism (CDM) site of UNFCCC for different periods. We have taken the data from 4 monitoring reports published for the period of 22/06/2011 to 31/12/2015.

The transportation emissions arising out of composting and its application are compared to the transportation emissions of the baseline scenario of landfilling. Any significant net emissions were taken into account while calculating ET.

Process Emissions

The process emissions include the emissions arising while making compost at the compost plant. Both factors the electricity that is required to run the compost plantand the diesel that is used to turn and manage the compost pile, generate GHG emissions. We have used the data of total electricity consumption and the grid emissions related to the electricity consumption from the monitoring reports of the Okhla Compost Plant. Also, the on-site fuel (diesel) consumption and emissions related to it were also taken from the same report for process emissions calculationsof process emissions. [1, 2, 3 & 4]

Although there is a particular amount of process emissions in landfills, they are notconsidered for the calculations due to the paucity of relevant data.

Fugitive Emissions

Methane (CH_4) and Nitrous oxide (N_2O) are released during the composting process as the microbial activity turns waste into different compounds (Beck-Friis *et al.*, 2000). These emissions comprise fugitive emissions. These emissions depend on the local factors such as type of feedstock, type of supporting material (e.g. wood chips or peat), frequency of turning, climate, aeration, and size of compost piles (USA. US Environmental Protection Agency, Office of Resource Conservation and Recovery, 2019, p.4-1—4-8). Nitrous oxide is generated due to nitrification or de- nitrification, and methane is generated in the anaerobic pockets of the compost piles.The amount of emissions of CH_4 and N_2O are very low, but the Global Warming Potential (GWP) of these gases (GWP of CH_4 and N_2O is 25 and 298, respectively) is very high when compared to the GWP of CO_2 (Solomon *et al.*, 2007).

The fugitive emissions data is taken from the IPCC Guidelines for NationalGreenhouse Gas Inventories, 2007.

Compost Emission Reductions

The total emission reduction benefits from composting and using it in agriculture areexpressed in Metric Tonnes of CO2 equivalent per ton of feedstock. It is the sum of different factors. First factor is the avoided emissions that would have arisen when the organic waste is dumped in landfills (ALF). Other factors include the emissions reduced due to reduced soil erosion (RE), the emission reduction due to reduced fertilisers use (RF) and herbicide use (RH). Hence it gives us the following equation tofor total emission reductions:

$$\mathbf{Rtotal = ALF + ((RE + RF + RH) \times CF)} \quad (2)$$

Here, CF is the conversion factor to convert the values of reduction benefits from $MTCO_2E$ per ton of compost to $MTCO_2E$ per ton of feedstock.

In the Okhla Compost Plant monitoring reports, only the avoided emissions from landfills are considered to calculate reduction benefits. But the agronomic use of compost has the added benefits of reducing emissions due to reduced soil erosionand reduced water use in the field. The GHG emission reduction benefits several other benefits of compost application to the soil, such as increased crop yields, increased biomass activity below ground, etc. But more research is needed to quantify the GHG emission benefits of compost application to the soil.

Net Avoided Emissions from the Landfill

When waste is disposed in landfills, the anaerobic decomposition of the organic waste takes place. This results in the generation of significant quantities of methane,a greenhouse gas. After undergoing a brief aerobic decomposition, the compostable part of the waste in the landfills undergoes anaerobic decomposition. This anaerobic decomposition produces landfill gas (LFG). LFG consists of almost equal quantitiesof methane and biogenic carbondioxide. The landfill methane must be oxidised andor captured and destroyed by a gas collection system. Else, this methane will be released into the atmosphere and add to concentrations of GHGs.

At Okhla landfill, managed by MCD follows the practice of controlled MSW practice without any methane recovery system. The monitoring report of the Okhla Compost plant has calculated the baseline methane emissions arising out of the Okhla landfill.The total methane generated at the landfill was calculated using the multi-phase model, the First Order Decay (FOD) Model of the IPCC Guidelines.

Decreased Soil Erosion

When compost is applied to the soil, the available literature tells that this decreases the density of the soil. This happens because of the porosity of the soil increases. The increased porosity and surface area increase the soil's water-holding capacity compared to the unadjusted soil. This is why compost is also used as an erosion control device along highways, construction sites, and agricultural fields (Barker 1997; Bresson *et al.*, 2001; Faucette *et al.*, 2004). The decay pattern of compost wastaken similar to that of carbon for erosion control because it is also related to the carbon content, density and water retention in the amended soil.

As there is a dearth of studies in this field in India, we have used the data from similar studies conducted in California. The study was carried out by the University ofCalifornia-Riverside (Crohn 2010). They conducted the study at two sites: a construction site and a site damaged by fire. An average erosion value of the construction site and site damaged by fire were used for the calculations. The soil benefit was the difference between the erosion of control and the experimental site. The results were extrapolated to a hectare patch of soil and converted to the unit soilsaved per ton of compost application.

Reduced Fertilizer Use

The application of compost to the soil does not provide nitrogen (N), potassium (K)and phosphorus instantly to the growing plants. A study shows that nitrogen from compost is available for use ten years (Naeini & Cook 2000; Smiciklas, Walker & Kelley 2008). This means that the compost application to the soil does not completely alleviate the use of chemical fertilizers (Montemurro *et al.*, 2006). For this method, a decay rate of 38% of nitrogen was used over a period of 10 years. The decay of potassium and phosphorus was assumed to be similar to that of nitrogen.
The 10-year decay curve was applied to N, P and K from the compost of California, as similar studies are still needed in India. When compost is applied to the soil, it will reduce the application of chemical fertilizers. This, in turn, will lead to savings in emissions due to the production of these fertilizers. N, P and K have emission factorsof 8.9, 1.8 and 0.96 kg CO2E/kg, respectively (Boldrin*et al.,* 2009; Wood & Cowie 2004).

Reduced Herbicide Use

The growth of weeds in undesired areas of a field can be hindered by the applying of compost to the soil. This is possible as compost forms crust over the top of the soil, making weeds penetrate the soil (Roe, Stoffella & Bryan 1993). But some studies show that the benefits of compost application to the soil last only for a year (Brown & Tworkoski 2004). Still, for this period, herbicide use can be reduced.
There are not enough studies in India of reduced herbicide use after compost application to soil. So, the California based data was used for the calculations. Roe,Stoffella & Bryan (1993) had studied the reduced herbicide use. Later, as the emission factor data was not available for herbicides, it was assumed equivalent to the pesticide's emission factor and multiplied by the reduced herbicide use data of the mentioned study.[7]

Compost Emission Reduction Factor (CERF)

The CERF of compost production and its application is the difference between totalemission benefits (RTotal) and total emissions (ETotal). Both the values are to be expressed in MTCO2E/ton of feedstock.

CERF = RTotal − ETotal **(3)**

RESULTS

This section deals with the calculations of different emission factors and emission reduction factors related to the compost production at the Okhla Composting plant and then its application to the non-amended agricultural fields. Hence, determining the CERF for use and ultimately using it to calculate total GHG emission reductions by diverting the compostable waste to make compost and use it in agricultural fields.

COMPOSTING EMISSIONS

Composting emissions comprise of three factors as discussed in the previous section: Emissions from increased transportation of waste to composting plant and tothe agricultural fields (ET), process emissions (EP) and fugitive emissions during the compost production (EF). The net emissions were calculated by comparing the emissions in compost production and application to the baseline scenario of landfilling in the case of transportation emissions and fugitive emissions, but the datato compare process emissions was lacking.

Transportation emissions

The monitoring report which IEISL prepares for the Okhla compost plant has assessed the incremental distance travelled by vehicles to transport the feedstock tothe composting plant by visiting the compost plant and landfill site. It was found out that the distance from the waste source to the landfill site is more than the distance to the compost plant. The monitoring report has mentioned extra kilometres travelled by vehicles to transport the feedstock to the compost plant are to be taken as zero.S o, the emissions related to this are also zero. But after the compost is ready, the vehicles need to transport the compost to different locations. The emissions associated with this activity are calculated below:

Table -1 Incremental Transport emissions per ton of feedstock (due to transport ofcompost)

Parameter	Unit	Value	Value	Value	Value
		applied 22/06/2011-21/06/2012	applied 22/06/2012-31/12/2013	applied 01/01/2014-21/06/2014	applied 01/10/2014-31/12/2015
Quantity ofCompost produced	T	6,553.31[1]	7,926.62[2]	1,887.76[3]	9,052.1[4]
Quantity ofFeedstock used	T	59,248.63[1]	42,174.74[2]	7,613.42[3]	61,951.72[4]
Emission fromincremental transportation of compost	$MTCO_2$	76.20[1]	88.78[2]	21.67[3]	95.78[4]
IncrementalTransport emissions	**$MTCO_2/T$**	**0.001286**	**0.002105**	**0.002846**	**0.001546**
per ton of feedstock (due to transport of compost)					

The data of emissions from transport and quantity of feedstock was taken from the monitoring reports of the composting plant of Okhla. The values were then calculatedof incremental transport emissions per ton of feedstock. The average for the considered period came out to be 0.00184084MTCO2/ton of feedstock. This is equivalent to 0.00184084 MTCO2E/ton of feedstock.

PROCESS EMISSIONS

Composting process is completed using various inputs, and these inputs are responsible for GHG emissions. For the calculations of process emissions, emissions from the electricity consumption at the Okhla composting plant and emissions from the on-site fuel consumption to move and turn the compost. Theseemissions are calculated (Table 2).

Table -2 Process emissions per ton of feedstock

Parameter	Unit	Value	Value	Value	Value
		applied 22/06/2011-21/06/2012	applied 22/06/2012-31/12/2013	applied 01/01/2014-21/06/2014	applied 01/10/2014-31/12/2015
Quantity of Compost produced	T	6,553.31[1]	7,926.62[2]	1,887.76[3]	9,052.1[4]
Quantity of Feedstock used	T	59,248.63[1]	42,174.74[2]	7,613.42[3]	61,951.72[4]
Emissions from electricityuse	$MTCO_2$	135.86[1]	277.99[2]	123.34[3]	379.87[4]
Emissions from on-sitefuel consumption	$MTCO_2$	190.67[1]	177.62[2]	42.62[3]	173.36[4]
Total process emissions	**$MTCO_2$**	**326.53**	**455.61**	**165.96**	**553.23**
Process emissions per ton of feedstock	**$MTCO_2$ /T**	**0.005511**	**0.0108029**	**0.021798**	**0.00893**

The data of the emissions from electricity use and on-site fuel consumption was taken from the monitoring reports of the composting plant of Okhla. The values were then calculated of incremental transport emissions per ton of feedstock. The average for the considered period came out to be 0.010328 MTCO2/ton of feedstock. This is equivalent to 0.010328 MTCO2E/ton of feedstock.

Fugitive Emissions

The *IPCC Guidelines for National Greenhouse Gas Inventories, 2006* in its chapter on *Biological treatment of Solid Waste* has provided the default factors for CH_4 and N_2O emissions from composting. It reports that CH_4 emissions are 4 g CH_4/kg of wet-waste treated, and N_2O emissions from the composting plant during compost production are 0.3 g N_2O/kg of wet waste treated. These values were then converted to theMTCO2E/ton of feedstock using the Greenhouse Gas Equivalencies Calculator available online at the United States Environmental Protection Agency. This resulted in 0.1 $MTCO_2E$/ton of feedstock and 0.089 $MTCO_2E$/ton of feedstock fugitive emissions of CH_4 and N_2O, respectively, arising during the composting process.

Summary of Emissions

The following table 3 summarises the total emissions (ETotal) from the compostproduction and its application to the field.

Table -3 Summary of total emissions (ETotal) from the production of compost and its application to the field

Type of Emissions	**Emissions ($MTCO_2E$/per ton of feedstock)**
Emissions from incremental transport (ET)	0.001841
Process emissions (EP)	0.010328
Fugitive methane emissions (EF)	0.1
Fugitive Nitrous oxide emissions (EF)	0.089
Total emissions (ETotal)	**0.201169**

Compost Use Emission Reductions

Landfilling is a widespread practice of solid waste management in India. Due to mismanagement of these landfills without proper scientific techniques results in a large amount of methane emissions from these landfills. When the compostable part of the waste is diverted to the composting plants, composting these GHG emissions from the landfills can be avoided. Further, the application of this compost to agricultural fields has added benefits. The emission benefits arising out of reduced fertilizer use, reduced soil erosion, and reduced herbicide use were considered for this study.

Net Avoided Emissions from Landfill

Okhla landfill does not have any system to capture the methane generated due to the anaerobic decomposition of compostable waste at the site. So, almost all the methane that is generated from the landfill is released into the atmosphere adding to the GHG concentrations in the atmosphere. These emissions are estimated in the monitoring reports by IEISL for the Okhla composting plant. The reports have used the First Order Decay (FOD) method for these estimations.

Using the total baseline methane emissions data in $MTCO_2E$ and total feedstock used to make compost, baseline emissions per ton of feedstock were calculated for each mentioned period in the table. Then, the average baseline emissions per ton of feedstock were calculated for the considered time period, which turned out to be 1.05448 $MTCO_2E$/ton of feedstock.

Table -4 Baseline emissions per ton of feedstock

Parameter	**Unit**	**Value**	**Value**	**Value**	**Value**
		applied 22/06/2011- 21/06/2012	applied 22/06/2012- 31/12/2013	Applied 01/01/2014- 21/06/2014	Applied 01/10/2014- 31/12/2015
Quantity of Compost produced	T	6,553.31[1]	7,926.62[2]	1,887.76[3]	9,052.1[4]

Avoided waste deposition, processed for composting	T	59,248.63[1]	42,174.74[2]	7,613.42[3]	61,951.72[4]
Emissionsfrom (A): wood and wood products	MTCO$_2$E	657[1]	1217.23[2]	635.57[3]	1660.35[4]
Emissions from (B): pulp. paperand cardboard	MTCO$_2$E	750[1]	1420.51[2]	763.94[3]	2334.31[4]
Emissions from (C): food and food waste	MTCO$_2$E	22,534[1]	38915.47[2]	18,818.81[3]	59,633.64[4]
Emissionsfrom (D): textiles	MTCO$_2$E	561[1]	799.57[2]	565.99[3]	1518.56[4]
Emissions from (E): garden, yardand park waste	MTCO$_2$E	2607[1]	3447.27[2]	2,294.63[3]	5716.65[4]
Total baselinemethane emissions	**MTCO2E**	**27108.66**	**45800.07**	**23,078.94**	**70863.52**
Baseline emissions per ton offeedstock	**MTCO2E/T**	**0.45754**	**1.08596**	**3.03135**	**1.14385**

Decreased Soil Erosion

The carbon content and water retention rate is directly linked to the decreased soil erosion due to compost application to the soil. As this type of studies is still needed in India, the data for this factor was taken from few California based studies. The twostudies Bresson *et al*., 2001 and Faucette *et al.*, 2004 have stimulated single rain events and reported a range of 33-64 lbs/ton of compost applied to reduce soil erosion over a year. But these studies only considered single rainfall events. Crohn (2010) has considered multiple rainfall events and used the compost at two sites: fireaffected site and construction site. It reported reduced soil erosion of 91 and 328 lbs/tons of compost applied for one year. This results in reduced soil erosion of 1750and 6300 lbs/ton of compost for 30 years.

The emission factor (calculated in Table 3) was 0.2 MTCO$_2$E/ton of feedstock whenone ton of eroded soil is replaced with compost. When this emission factor is multiplied with the range of soil saved from erosion it gives the range of emission savings, which is 0.175-0.63 MTCO$_2$E/ton of compost. The average emission savings due to decreased soil erosion are 0.4025 MTCO$_2$E/ton of compost.

Reduced Fertilizer Use

The use of fertilizers in agricultural fields has many negative impacts in the long run.It contributes to soil pollution and water pollution. Montemurro *et al.*, (2006) has observed that adding compost to the soil can reduce the requirement of fertilizers.

The studies related to the quantification of reduced fertilizeruse after compost applications were missing in the context of available Indian literature. A study by California Air Resource Board has reported fertilizer benefits from compost application at an average of 0.26 MTCO$_2$E/ton of compost with a range of 0.1-0.32 MTCO$_2$E/ton of compost over a period of 10 years. These values were consistent with similar studies from other regions (Boldrin *et al.*, 2009; Favoino & Hogg 2008; Blengini 2008).

Reduced Herbicide Use

Roe *et al.* (1993) compared the effectiveness of glyphosate spray and compost inthe bell pepper field. It reported that compost is as effective as an herbicide.

Glyphosate is a popular herbicide that is also used in large quantities in India. So, assuming 100% replacement of herbicide with compost, the value of herbicide reduction was multiplied by the emission factor related to the herbicide production. This gave a very uncertain value of <0.001 MTCO$_2$E/ton of compost because of the large amount of compost that is needed to meet the benefits arising out of herbicideuse in agricultural fields. Hence, its contribution to the emission reductions is negligible and taken as zero for the calculations of CERF.

Conversion Factor

As the values of emission reductions by reduced soil erosion and reduced fertilizer use are in $MTCO_2E$/ton of compost, these needed to be converted into the unit of $MTCO_2E$/ton of feedstock for the calculations of CERF. The conversion factor wascalculated from the available data of the Okhla composting plant for the consideredperiod.

Table -5 Calculations for Conversion factor CF

Parameter	Unit	Value	Value	Value	Value
		applied 22/06/2011-21/06/2012	applied 22/06/2012-31/12/2013	Applied 01/01/2014-21/06/2014	Applied 01/10/2014-31/12/2015
Quantity of Compost produced	T	6,553.31[1]	7,926.62[2]	1,887.76[3]	9,052.1[4]
Avoided wastedeposition, processed for composting	T	59,248.63[1]	42,174.74[2]	7,613.42[3]	61,951.72[4]
Conversion factor	**Unit-less**	**0.111**	**0.188**	**0.248**	**0.147**

Taking the average of conversion factor over the given period of time gives its valueas 0.165.

Summary of Composting Benefits (RTOTAL)

Table -6 Summary of emission reductions

Type of emission reductions	Emission reductions		
	$MTCO_2E$/perton of compost	**Conversion factor (CF)**	**$MTCO_2E$/perton of feedstock**
Emissions avoided from the landfill	---	---	1.05448
Reduced emissions from Decreased Soil Erosion	0.4025	0.165	0.066
Reduced emissions from Decreased Fertilizer Use	0.26	0.165	0.043
Reduced emissions from Decreased Herbicide Use	0.00	0.165	0.000
Total emission reductions ($MTCO_2E$/Ton of feedstock)	1.16348		

Compost Emission Reduction Factor

According to equation (3), the compost emission reduction for the Okhla compostingplant, Delhi is calculated as follows,

CERF = RTotal − ETotal

= 1.16348 -0.201169

= 0.962311 ~ **0.96$MTCO_2E$/ton of feedstock**

The capacity of Okhla’s compost plant is to process 200 tons of MSW per day andtherefore 73,000 tons of MSW per year.

Total avoided emissions per year = 73,000 x 0.96= **70,080MTCO$_2$E**

DISCUSSION

The Okhla composting plant is registered as a Clean Development Mechanism project, and due to this UNFCCC/Kyoto protocol requirements are applied to its management. Further, this plant generates carbon credits that are sold to the Annex I countries of UNFCCC. The emission benefits, as reported in the monitoring reports prepared by IEISL consider only the avoided methane emission from landfills due to diversion of compostable waste to the composting plant. But the application of compost to agricultural fields results in additional greenhouse gas reductions. This study quantifies the GHG reductions if one ton of waste is diverted to the composting plant and then the compost is applied to the agricultural field.

The CERF came out to be 0.96 MTCO2E/ton of feedstock. This means that the Okhla composting plant, which has a capacity of composting approximately 73,000 tons of MSW per year, can save 70,080 MTCO$_2$E emissions. The monitoring reports of the Okhla composting plants have reported about 34,000 MTCO$_2$E emission reductions per year.

According to the Ministry of Housing and Urban Affairs, India has 685 centralised composting plants to process 1,88,00,000 tons of waste per year. If the CERF is used to estimate the emission reductions, approximately 1,80,48,000MTCO$_2$E emissions can be reduced only by using the existing composting facilities efficiently. The GHG Platform India has reported that total GHG emissions from MSW disposal in India in 2015 were 1,16,69,533 MTCO$_2$E. This implies that, over a long period, the benefits of composting and using compost in the agricultural field are enormous in terms of mitigating the GHG emissions from India's MSW sector. Over the decades, India can also achieve carbon neutrality or, say, carbon negativity.

The application of compost in agricultural fields has added benefits too. It increases the water retention capacity of the soil. According to World Resource Institute's report, India ranked 13th in the most water-stressed country and more than 50% of water in India is used in the agriculture sector. The use of compost in the agricultural field can, to some extent, help India in reducing the usage of water in the agriculture sector. Also, the reduced water consumption will have an added benefit of reducing emissions related to electricity used to run pumps for extra water for irrigation.

MSW is one of the major challenges that are faced by Indian cities. In Delhi, and other Indian cities, dumping of waste in the landfills is a common practice to manage the MSW (Sharma & Chandel 2017). Delhi generated around 9000 tonnes of waste per day in 2017 (Kumar 2017), and most of the waste is dumped into landfills. These landfills have already exceeded their capacity way back in 2008. Other Indian cities face a similar scenario. According to the report of MoHUA, 80% of the waste generated in cities is dumped into landfills. Dumping of waste in landfill has created soil, air and water pollution and many human health risks (Narayana 2009). So, diverting waste from landfills to produce compost can reduce the burden of already burgeoning landfills of Delhi and other Indian cities. Also, this will have added health and environmental benefits.

Food security and proper nutrition is also a major challenge in India. With increasing population and urbanisation, the land for crop production is decreasing day by day. Further, around 37% of the land is degraded in India (Radda, Kumar & Pathak 2021). The benefits of compost use and fertilizers have resulted in increased crop productivity and soil health (Aktar *et al.*, 2018; Kavitha & Subramanian 2007; Jahiruddin *et al.*, 2012). It implies that compost can be a factor in ensuring Sustainable Development Goals 2, 3 and 15.

The estimated potential of compost production in India is 4.3 million tons every year, but due to improper management of MSW and production of compost which does not meet the quality standards, the vast potential of producing compost and its utilisation in agriculture goes unutilised. A study (Saha, Panwar & Singh 2010) has reported that out of 35 samples tested for quality standards from 29 cities of India, only 2 samples were of a quality that can be marketed and 3 samples that fell under the restricted use marketing index. All the other samples were unfit for marketing.

Therefore, there is a need to improve the quality of compost that is produced from MSW in India and create its demand in the market to utilise the end-user benefits of compost efficiently.

This study has some limitations too. The data for fugitive emissions reduced emissions from fertilizer use and herbicide use, and benefits arising from reduced soil erosion was taken from different studies conducted in the USA or well-reputed sources of information like IPCC and USEPA. Further, decreased soil erosion and water use results were extrapolated to the macro scale from laboratory-scale experiments. This extrapolation of results may skew the results to some extent. The data of reduced herbicide use and related benefits from decreased production of herbicides was not available. That is why the associated data of pesticides was usedto quantify the emission benefits from reduced herbicide use.

More long-term research in Indian scenarios is needed to quantify the factors of emission reductions. The actual compost emission reduction factor for the waste diverted from landfills to agricultural fields in India can be calculated with more precision. Also, compost production has to be made efficient and produce compost that consumers can use without any hesitation.

CONCLUSION

Greenhouse gas emissions and climate change induced by them are among the most severe threats faced by humanity. Every country is developing policies and frameworks to reduce their emissions to meet their targets of the Paris Agreement. The EU, Japan and 111 countries have pledged carbon neutrality by 2050, and China has pledged to do the same by 2060. India is also planning to reduce its emissions according to its Paris Agreement targets. The waste sector contributes 4%of the total emissions in India out of which around 12% of emissions are due to the solid waste disposal. Being a developing country, more than 50% of MSW in India comprises compostable matter. The mismanagement of this waste and unscientific dumping in landfills emits methane due to the anaerobic decomposition of organic matter. In this context, calculating the CERF for diverting the compostable waste to composting plants and utilising it in the agricultural field is an important constituent.

The CERF value that came out for this study is 0.96 $MTCO_2E$/ton of feedstock for Okhla's composting plant. Suppose the values are extrapolated to calculate the emissions reductions from utilising the installed central composting plants at full capacity to produce compost and use the compost in the agricultural field. In that case, it shows considerable potential to mitigate the emissions from India's solid waste sector. These values are expected to provide a way forward to future researchin this field. Using values in the Indian scenario in the future to calculate CERF will help quantify the emission reduction benefits more accurately. This can turn out a major step in making the solid waste sector of India carbon neutral. Once the central and state governments have the exact value of benefits provided by the efficient production of compost and its utilisation in agriculture, they can be motivated to streamline the solid waste management in India and utilise this waste to generatethe discussed benefits arising from its efficient management.

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