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Life Cycle Assessment Modelling of Greenhouse Gas Emissions from Existing and Proposed Municipal Solid Waste Management System of Lahore, Pakistan

Adila Batool Syeda [1,*], Anwar Jadoon [2] and Mahuammad Nawaz Chaudhry [2]

[1] Department of Space Science, Punjab University, Lahore 54590, Pakistan
[2] College of Earth and Environmental Sciences, University of the Punjab, Lahore 54590, Pakistan; aaajadoon@gmail.com (A.J.); muhammadnawazchaudhry@yahoo.com (M.N.C.)
* Correspondence: Aadila.spsc@pu.edu.pk; Tel.: +92-42-9230370 or +92-0331-4591316

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Abstract: Open Dumping of indiscriminate municipal solid waste (MSW) remarkably contributes to global warming (GW). Life Cycle Assessment modelling may be a useful tool for assessing the best waste management option regarding GW potential. The current study evaluates the contribution of an existing MSW management (MSWM) system to greenhouse gases in Gulberg Town, Lahore, Pakistan. This research also presents a comparison of scenarios with different waste management options. Life Cycle Assessment methodology has been used to conduct the study. EASETECH has been used for modelling. The short-term scenarios (STSs) have been developed to promote the thinking of integration of treatment technologies in the current waste management system within a few months. The results show that the major contribution to the total emissions comes from the anaerobic digestion of organic material from open waste dumps. Currently, recycling is the best treatment option for reducing the CO_2-eq values in the study area. It was clarified that recycling is the best option for reducing the CO_2-eq values, whereas biogasification comes in second in terms of savings and reduction. The integration of recycling and biogasification techniques would be a good solution.

Keywords: municipal solid waste; global warming; refused derived fuel; recycling; biogasification; CO_2 equivalent; EASETECH

1. Introduction

Pakistan is facing very serious environmental problems due to poor municipal solid waste management systems (MSWMSs). Waste management is an essential component of overall environment planning [1–4]. The emission of greenhouse gases and associated global warming is one of those problems. Global warming is one of today's most politically important global environmental issues. It has been shown by the Intergovernmental Panel on Climate Change (IPCC) that the release of certain compounds known as greenhouse gasses (GHGs) can lead to an increase in the global average temperature, as well as climate change at a regional level [5]. According to [6,7], the waste management sector contributes 5% to global greenhouse gases emission. There are many studies which have investigated the waste management system and the emission of greenhouse gases [8–13]. A study was conducted by [14,15] to quantify carbon emission and emission reductions related to waste management activities. Authors in [16,17] worked on the quantification of methane emissions from waste disposal sites. Some researchers discussed the use of Life Cycle Assessment (LCA)/Life Cycle Inventory (LCI) methodology for the evaluation of greenhouse gas emissions from waste management [18–22].

The current study presents and evaluates the global warming potential of the current waste management system of Gulberg Town, Lahore, Pakistan (Figure 1). Gulberg Town is one of the nine towns in Lahore city, with a population of 851,709. It comprises 15 administrative units which are called union councils.

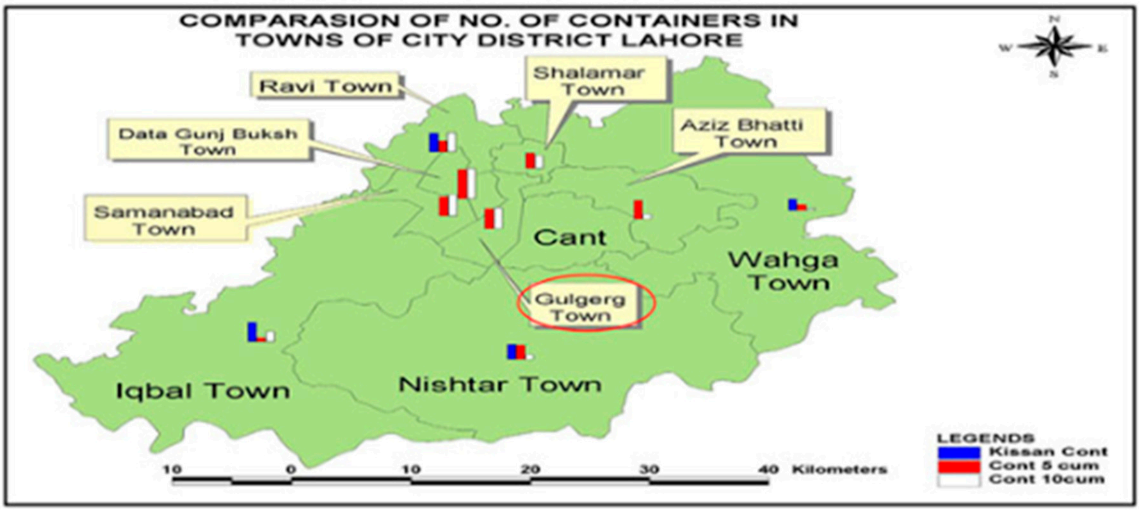

Figure 1. Map of the study area (Source: [23]).

2. Materials and Methods

Life Cycle Assessment methodology has been used to assess the global warming potential (GWP) associated with the municipal solid waste management (MSWM) system of Gulberg Town, Lahore, Pakistan. The LCA modelling was guided and controlled by the Intergovernmental Panel on Climate Change (IPCC) [24,25]. The GWPs were calculated using a timeline of 100 years using the IPCC guidelines. The emission of greenhouse gasses is regulated by the Kyoto Protocol [26] under the Climate Convention [27].

The functional unit for this LCA study was the amount of MSW generated in Gulberg Town, Lahore. The EASETECH model developed by the Technical University of Denmark [28] has been used to conduct this LCA study. Scenario S0 represents the existing situation and acts as a baseline scenario. The poor MSW management condition of the study area requires quick actions to reduce its environmental impacts. Therefore, three other scenarios have been developed on a short-term basis to improve the current situation and to promote the thinking of integration of treatment technologies in the sector of waste management. The proposed options can be incorporated with the current waste management system within a few months. In short-term scenario (STS) 1, it was assumed that all waste arising is sent to a material recovery facility (MRF) at a 10 km average distance from collection points. The rate of recycling is the same as in the existing scenario (i.e., 17.94%). Residual waste (12.08%) (mostly kitchen and yard waste) is sent to a compost plant with improved quality of compost, and remaining waste is sent to a dump site with a clay cover. STS 2 was just like STS 1, and the only change introduced was that residual waste (12.08%) (mostly kitchen and yard waste) is sent to a biogasification plant with digestate that is used on land for soil conditioning, and the remaining waste goes to a dump site with a clay cover. STS 3 is like STS 2, except remaining waste is sent as refuse-derived fuel (RDF) to a cement plant for energy recovery.

The system boundaries include all components of the waste management system from collection and transportation to its final disposal. Figure 2 shows the system boundaries for the study. Storage of waste in domestic as well as in commercial containers is not included. Collection of waste is assumed to be the transportation of waste from MRF to the treatment plant or disposal site. Primary collection of waste is carried out by the private sweepers with donkey carts or handcarts.

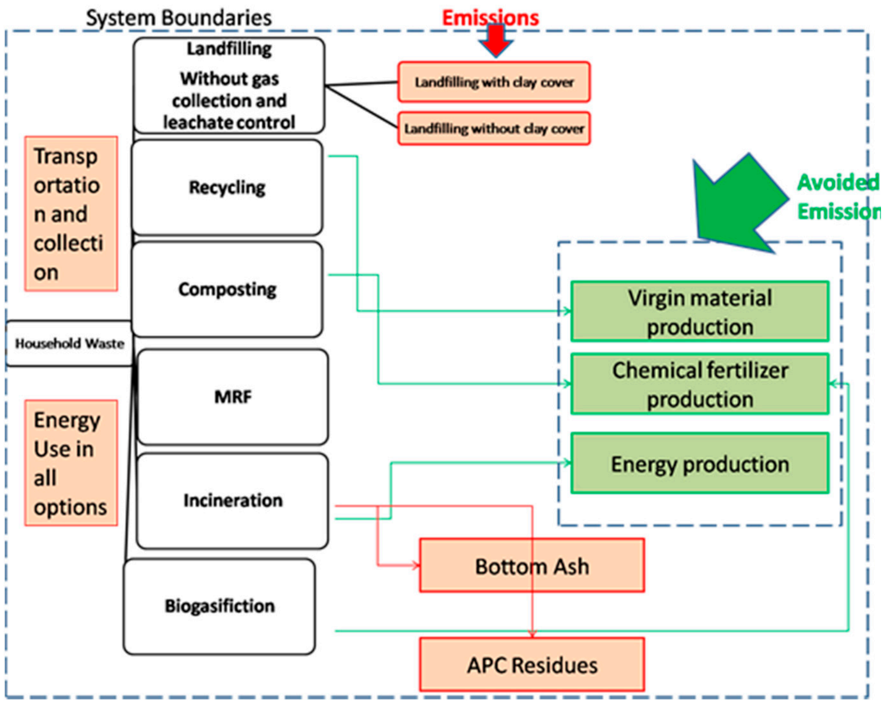

Figure 2. System boundaries for the study. MRF: material recovery facility.

As far as MRF is concerned, it is considered to be just like a transfer station. Energy consumption is related to the conveyor belt system and the office electricity.

No construction and maintenance of the treatment or disposal system was included. In the case of landfilling, carbon sequestration was taken into account. The biogenic carbon that enters the landfill is considered as sequestered carbon and it gives savings to global warming (savings are indicated by a negative sign). The system is credited for this sequestrated carbon, with a characterization factor of 44/12 kg CO_2-eq/kg C [28]; this is a value used by EASETECH.

The data used in EASETECH has been collected through questionnaire survey. A number of field visits have been carried out for the primary and secondary data collection.

3. Results and Discussion

According to questionnaire and field survey, it was found that two treatment technologies exist in the study area: recycling (17.94%) and composting (12.08%). The 1.64% of the remaining waste has been reused, and 68.34% was openly dumped (without clay cover). The EASETECH landfill module gives the options of landfill gas collection and leachate collection. In order to represent the true picture of study area it was assumed that generated landfill gas went to the atmosphere and all leachate to groundwater. The generation and composition of waste has been analyzed as shown in Figure 3. The calculated amount of MSW generated in study area was 283,387 tons/year.

The major contribution to global warming in the study area comes from the dumping of waste (i.e., 146%). These contributions mainly consist of the continuous release of CH_4, CO_2 and N_2O to the atmosphere. Only CO_2 from fossil fuel is considered for the estimation of GHG emissions with CH_4 and N_2O, because CO_2 from the decomposition of waste is biogenic in origin and therefore cannot add to the overall GHG emissions. Methane-oxidizing bacteria are responsible for the release of N_2O to the atmosphere [29,30]. Therefore, N_2O may also be generated and emitted from landfill sites, not only due to the process of nitrification and denitrification, but also from CH_4-related phenomena. The process of disposal is not organized in the study area. Waste is dumped anywhere on the ground. There are no proper cells and lifts as in proper sanitary landfills. Different stages of microbial activity are running at the same time. So, a continuous emission of greenhouse gases was found at the dumpsite.

Recycling contribution was −50%. A closer look reveals that the recycling of paper gives the maximum savings with 30%, while 10% savings come from recycling of metal. The contribution of the recycling of plastics is approximately 8%.

Composting is also in practice in the study area. Composting gives 3% to the net emission of greenhouse gases. Currently, it does not give any savings to GWP because of the poor maintenance and improper management system of the compost plant. The waste that is used for composting is not properly segregated. The compost that is being prepared in the existing compost plant is just the stabilization of organic waste and not a proper compost. It was found during the field survey that farmers were not ready to use this type of compost.

Collection and transportation of waste is another source of GHG. The combustion of fuel is the major environmental load from waste collection and transportation. The comparison between the STSs is shown in Figure 4. STS 3 gives the maximum while STS 2 gives the minimum value of GWP in terms of CO_2-eq.

It was also observed that the collection and transportation of waste does matter, but the main problematic region is the use of RDF and dumping of waste without landfill gas collection and a leachate control system (Figure 5). The high moisture content (i.e., 75%) and lower heating value (i.e., 4.7374 GJ/ton waste) is the major problem with the RDF technology. The residual waste contains many inert materials, such as glass, soil, concrete etc., which lowers its value.

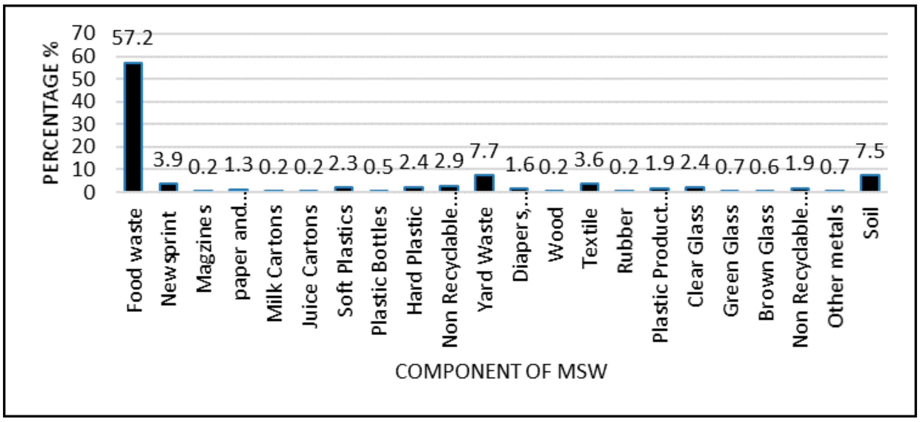

Figure 3. Generation and composition of municipal solid waste (MSW) of the study area.

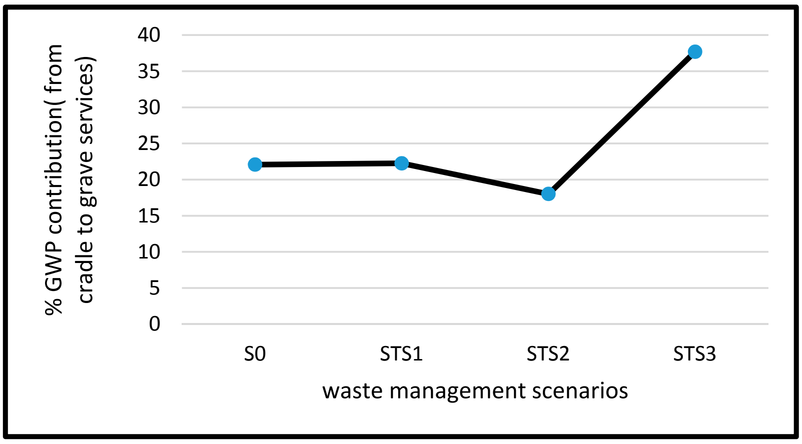

Figure 4. Comparison of existing and short-term scenarios (STSs) for global warming potential (GWP) contribution from cradle to grave services.

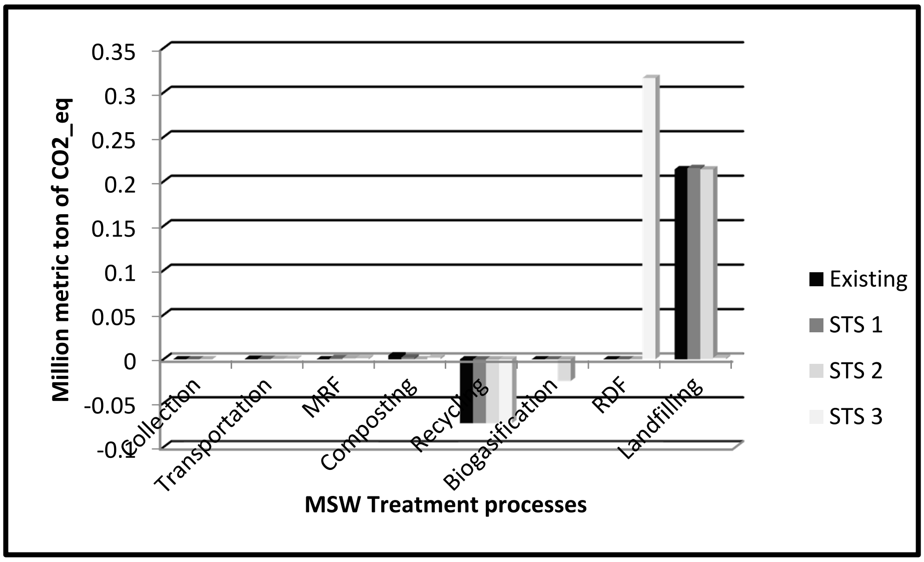

Figure 5. Comparison between MSW management processes for GWP.

The changes made to the existing scenario were (1) introduction of a material recovery facility (MRF); (2) better quality of compost production compared to the existing scenario; and (3) a clay cover over the dumpsite, and significantly respond to the GWP. The fuel consumption in the process of collection was decreased with the reduction in the amount of waste to the dumping site, and consequently decreases in GHG emission (i.e., 0.0002%) were found. The increase in GHG emission was found due to the energy consumption in the form of electricity at MRF and energy consumption in the form of fuel consumption due to the external clay movement to the landfill site for covering the dump. The electricity was produced mainly by using thermal power plants (gas (25.7%), coal (0.2%), oil (38.5%)), whereas other sources of electricity generation include hydro power plants (30.7%) and nuclear (4.9%) [31]. By improving the quality of compost, it was found that the value of global warming decreased by 53% of composting in the existing scenario. Overall, global warming was decreased by 1.58% in STS1 as compared with the baseline scenario.

It was found that the main problem is the handling of the organic portion of household waste. So, we compare the techniques of composting with biogasification. Portable biogas plants are easily available on the market, so it would be a good option for organic waste handling. There was no change in the results of MRF, transportation and dumping of waste; the values were the same as in the existing scenario or STS 0. It was found that biogasification gave more savings towards GHG emissions. It saved the GHGs through the biogasification process, by replacing the burning of fossil fuel in electricity generation and by the use of digestate on the ground as soil conditioner. When compared with the composting process, the biogasification process gives 371% reduction in GW in the form of CO_2-eq. Further reduction was found by the use of digestate in fields or gardens (i.e., 7%). It also reduced the amount from the landfilling process by 0.03%, and an overall decrease of 18.5% was found from STS 1. Short-term scenario 3 represents results from the use of RDF in cement factories and the use of compost just as in STS 1 but with improved quality. It is assumed in this scenario that all the residual waste which was going to dump site will be used in the cement plant as a substitution for coal. This scenario is same as STS 0, the only difference is of dumping. This scenario gives 70% more CO_2-eq as compared to the existing scenario, with improved quality of compost (Table 1). The negative numbers in Table 1 mean that the specific treatments (e.g., biogasification and recycling) in STS 2 replace more polluting processes, meaning that the scenario gives a saving of environmental emissions. The calorific value of the residual waste calculated by the model is 4.7473 GJ/ton. The value of GW increased due to two processes: (1) the increased distance to the cement plant (i.e., approximately 300 km compared to just 50 km to dumpsite), and (2) the poor quality of RDF (i.e., calorific value).

Table 1. Life Cycle Inventory for GWP.

Substance Name	S0	STS 1	STS 2	STS 3
Carbon Dioxide (CO_2—Biological with impact)		−352,093		−352,093
Carbon Sequestered	−54,572,532	−53,068,261	−53,068,261	
HCFC 21 (Dichlorofluoromethane)	75,627	75,627	75,184	444
1,1,1-Trichloroethane	693	682	681	659
Hydrocarbons (HC)	−176,051	−176,262	−180,207	−176,631
Carbon Monoxide (CO)	−264,323	−264,692	−270,280	−270,923
Carbon Dioxide (CO_2—Fossil)	−58,836,893	−58,965,960	−80,709,327	258,009,697
Methane (CH_4)	250,206,040	250,332,345	246,710,315	−9,675,849
Nitrous Oxide (Laughing Gas) (N_2O)	952,067	921,994	−2,031,752	1,659,785
Dichloromethane (Methylene chloride)	15,005	15,005	14,917	88
CFC 11 (Trichlorofluoromethane)	1,380,497	1,380,497	1,372,399	8098
CFC 12 (Dichlorodifluoromethane)	6,362,288	6,362,288	6,324,968	37,320
HFC 134a (Tetrafluoroethane)	3	3	3	3
HCFC 22 (Chlorodifluoromethane)	663,239	663,239	659,348	3890
Carbon tetrachloride	1621	1621	1611	10
CFC 113 (Trichlorotrifluoroethane)	180,065	180,065	179,009	1056
Halon (1301)	−744	−870	−870	−744
Total	145,986,601	147,105,226	119,077,738	249,244,808

This value cannot compensate or be the substitute for coal used in the RDF plant, so high emission was found. The field survey for compost reveals that farmers were not willing to use the compost as a substitute for chemical fertilizer. In addition, the process of composting that is being used in the study area was not appropriate, affecting its quality. Composting can be a good treatment, but only if the product is useful and substitutes in part for chemical fertilizer, otherwise it is a large source of greenhouse gases

4. Conclusions

The current MSWM system contributes to global warming at rate of 0.17 metric tons/person/year. Life Cycle Assessment methodology has been used to conduct the study. The processes considered for LCA of existing waste management system were collection of waste, transportation of waste, composting, and finally dumping of waste directly on the ground without any leachate collection and gas collection systems. The scenarios were developed to get the best scenario with the smallest change in the current waste management system in a shorter time period.

The process of open dumping without landfill gas collection and leachate collection system contributes to global warming the most. Recycling and biogasification are the most favorable processes regarding greenhouse gases emission, whereas composting and the use of waste as RDF in cement plants would not be a good option regarding GWP.

The analysis and comparison of STS show that the integration of waste management options results in more savings from greenhouse gases emissions.

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Author Contributions: Adila Batool and Myhammad Nawaz Chaudhry conceived and design the experiments; Anwar Jadoon performed the experiments. Adila Batool and Muhammad Nawaz Chaudhry analyzed the data; Anwar jadoon contributed materials; Adila Batool wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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