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Methane Gas Emission and its Management Practices from Solid Waste Stream, Case Study: Addis Ababa and its Surrounding Oromia Special Zone Towns

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Abstract

Waste disposal is one of the major contributors of greenhouse gas emissions worldwide, especially methane emission which was the largest contributor to global warming. This study aimed at assessing methane emission from solid waste disposal sites for the last five years (2013-2017), activities to reduce the emission level, and the existing legal instrument applied to reduce emission from the sector. An Intergovernmental Panel on Climate Change IPCC 2006 national greenhouse gas emission inventory model tire 2 with some default emission factor and country specific data was used to quantify emission. Identified result prevailed that the disposal sites of the study area emitted 4,848,147 tCO_2e methane for the last five years. The emission of methane showed a dramatic increase from 427,739 tCO_2e emission in 2013 to 1,510,191 tCO_2e in 2017. The activities that were applied to capture and utilize, and to reduce the emission was very poor. Similarly, the policies and proclamations of the country didn't give attention to emission reduction. Application of 3R strategy, reduction of disposing solid waste and revision of the existing legal instrument is necessary to reduce and control the emission.

Keywords: Emission; Landfill; Ipcc; Methane; Carbon dioxide; Global warming

Introduction

Currently, global climate change is the most important environmental problem facing mankind and it is caused by the release of anthropogenic greenhouse gases (GHG) into the Earth's atmosphere [1-3]. If the current GHG emission trends are continuing it is expected that the earth's surface temperature will increase substantially in the future and will lead to considerable changes in the global climate system, with far reaching consequences for humanity and the planet. Therefore, there has to be global effort and each country's participation to quantify, control, and reduce the emission of GHG from each sector that contributes to the emission. After pre-industrial era the emission of anthropogenic GHG has increased and now become higher than ever, it is basically because of economic and population growth factors [1]. Anthropogenic emission of GHG since the pre-industrial era increased the concentration of carbon dioxide and methane in the atmosphere between the years 1750-2011, general anthropogenic carbon dioxide emissions to the atmosphere were 2040 ± 310 $GtCO_2$. Out of this, 40% of emission remains in the atmosphere, the rest removed and stored on land (in plants and soils) and in the ocean [1]. Daniel and Perinaz [4], estimates that GHG emissions from post-consumer waste account almost 5% (1,460 $mtCO_2e$) of total global GHG emissions. United Nation Environmental Program (UNEP) also estimates the contribution of waste sector to the global GHG emission accounts 3-5% in 2005 [2]. The majority of these emissions (90%) consist of methane emitted from landfill sites [5,6]. Because of this emission contribution, municipal solid waste management has been emerged as a major concern of the global environmental problem [4]. The daily generation of solid waste in the Addis Ababa city is estimated to be 8,574 m^3/day and 3,129,510 m^3/annum [7]. The daily per capita solid waste generation also estimated to be 0.38 kg/capita/day. Other studies have estimated the per capita generation to be 3.5 kg/capita/day [7]. Data from the organization shows that, the contribution to the total generation of waste by the different sources is estimated to be around 76% from households, 6% from street sweeping, 9% from commercial facilities, 5% from industries, 3% from hotels, and 1% from hospital [8]. This can clearly indicate that, the generation of solid waste from households takes the major share of solid waste generated in the city. Out of the generated amount of solid per day in the study area only 74% waste is collected and dumped, 5% is recycled. The remaining 21% of the solid wastes is uncollected and dumped in unauthorized areas such as open fields, ditches, sewers, streets and many other available spaces in the city [9]. The total GHG emitted in Ethiopia in the year 2013 was estimated to be 146,160.43 Gg of carbon equivalent. Agriculture, forest and other land use was the major emitter of GHG followed by the energy sector and waste sector. Waste sector has a contribution of 5% emission in the 2013 inventory. Solid waste disposal and decomposition was the second contributor of methane emission in the country which emitted 25% of methane next to domestic livestock and other energy sector, which use fuel wood and wood waste in the residential and commercial institutions that contribute 26% emission each [10]. Ethiopia projected to limit its net emission from the business as usual (BAU) emission to 145 Mt CO_2e or lower by 2030, this plan include a reduction of 255 Mt CO_2e or 64% reduction from the BAU. Out of the total reduction, the building sector, which the solid waste is incorporated expected to contribute a 3% emission reduction which is 5 Mt CO_2e [11,12]. An activity to cut emission level of the waste stream is part of the global emission reduction strategy. Based on this quantification and accounting of the emission

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level of the waste stream, measuring of activities performed to reduce the emission level and assessing the suitability of legal instruments of emission reduction is the first step to meet the global GHG emission reduction strategy. Several studies conducted on the contribution of waste sector to GHG emission. The IPCC in its 2006 revision has prepared a separate guidelines volume to quantify the GHGs from both solid and liquid waste sector using the regional based activity data and emission factors. The application of these regionally based activity and emission factor over estimate or under estimate the real emission faces of countries. So, country or very specific area related studies on waste generation rate, characterization, type of waste management and also real physical condition of a given area is essential to at least to draw a better emission scenarios. In this research paper a specific area based activity data, scientifically proved emission factors related to other similar environment and locally practicing waste management system were used to estimate the emission of GHG from Addis Ababa and its surrounding Oromia special towns. The study provides a comparative result to study other cities and Towns that are used to generate a national communication report for IPCC every two years. Hence, it becomes novel to initiate a benchmarking experiences of locally found data and emission factors to generate a greenhouse gas of a given built environment.

Materials and Methods

Site overview

The study comprised Addis Ababa and the surrounding Oromia special zone towns namely Sebeta, Burayu, Gelan, Dukem, Sululta, and Legedadi Legetafo. Addis Ababa is the capital city of Ethiopia, located almost at the center of the country. The city is located between 8°22'N and 9°30'57"N latitudes and 38°24'East and 39°21'E longitudes. The city is divided into 10 sub-cities and 116 weredas for administrative purpose. Similarly, the surrounding Oromia special zone is located in the central highlands of Ethiopia, in Oromia Regional state surrounding the capital city of Addis Ababa. Geographically, the zone lies between 8034'-9032' north latitude and 38025'-39008' east longitude. This zone has a spatial coverage of 497,846 hectares. Since location-wise it is found surrounding the capital city of Addis Ababa, highways or outlets connecting the capital with all the regions pass through this zone (Figure 1) [12,13].

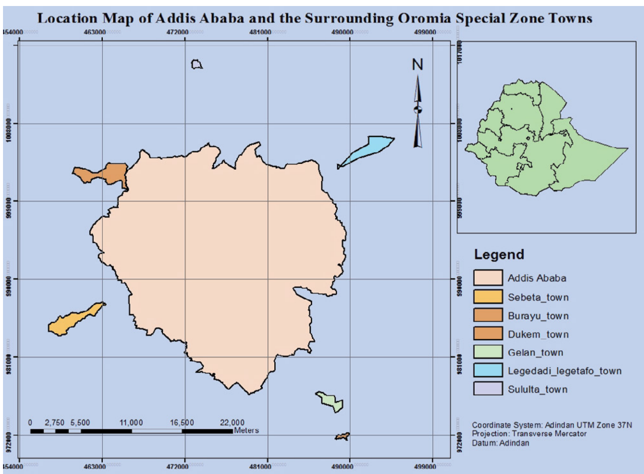

Figure 1: Location map of Addis Ababa and surrounding Oromia special zone towns.

Required data

Solid waste generation data, waste composition data and waste characterization data were gathered from secondary data basically, from official report and documents of cleansing management offices of the study area and from conducted researches. Report and documented information were obtained to evaluate the emission reduction activities. Additionally, secondary document was used to investigate the policy and legal framework applied to reduce emission. Primary data were used to evaluate the emission reduction activity performed in the sector and in some extent, the availability and application of emission reduction policy and legal framework were studied by information gathered through primary data.

Model for emission estimation

The IPCC national greenhouse gas emission inventory guideline outlines two methods to estimate CH_4 emissions from solid waste disposal sites, the default method (Tier 1), and the FOD method (Tier 2). The main difference between the two methods is that the default method based on the assumption of all potential CH_4 is released in the year the waste disposed on the other hand the FOD method is a time dependent method that better reflect the true pattern of degradation process over time [14-16]. Tier 2 of the IPCC models with country specific data, computed emission parameter and some IPCC default values or parameters were used.

Degradable organic carbon

Degradableorganic content of the waste was computed for each type of the waste by using equation (1) below

$$DOC = (0.4 * A) + (0.17 * \mathrm{B}) + (0.15 * \mathrm{C}) + (0.3 * D) .... equation 1$$

A=Fraction of MSW that is paper and textiles

B=Fraction of MSW that is garden waste, park waste or other non-food organic putrescibles

C=Fraction of MSW that is food waste

D=Fraction of MSW that is wood or straw

Methane generation potential

The methane generation potential of the waste that was necessary parameter for emission quantification was computed by using equation (2)

$$Lo_{(x)} = \left[MCF_{(X)} * DOC_{(x)} * DOCF * F * 16/12 \left({}^{GgCH_4}\!/\!{}_{Ggwaste} \right) \right] .... eq2$$

MCF (x) = Methane correction factor in year x (fraction)

DOC (x) = Degradable organic carbon (DOC) in year x (fraction) (Gg C/Gg waste)

DOCF= Fraction of DOC dissimilated

F = Fraction by volume of CH_4 in LFG

16/12 = Conversion from C to CH_4

Generation of CH_4

$$CH_4 generatedinyeart \left({}^{Gg}\!/\!{}_{yr} \right) = \sum_x \left[\left(A * k * MSW_T(x) * MSW_F(x) * L_0(x) \right) * e^{-k(t-x)} \right] ... \mathrm{eq}\,3$$

Where:

t = year of inventory

x = years for which input data should be added

A = (1 – e–k) / k; normalization factor which corrects the summation

k = Methane generation rate constant (1/yr)

MSWT(x) = Total municipal solid waste (MSW) generated in year x (Gg/yr)

MSWF(x) = Fraction of MSW disposed at SWDS in year x

L0(x) = Methane generation potential

Emission of CH_4

$$CH_4\, emitted\, in\, year\,(Gg/yr) = \left[CH_4\, generated\, in\, year\, t - R_{(t)}\right] * (1-OX) .....eq4$$

Where:

R(t) = Recovered CH_4 in inventory year t (Gg/yr)

OX = Oxidation factor (fraction)

Results and Discussion

Identification of degradable organic carbon and methane generation potential

The amount of degradable organic carbon for each waste type was computed based on equation number (1). A characterization study conducted by IGNIS (2014) [17] was used to quantify the DOC value. Under the study a value of 63%, 6%, 4%, 3% were indentified for food waste, paper waste, textile waste and wood or straw waste respectively. The DOC value computed and used in the study for each waste type was listed in Table 1 below.

In addition to degradable organic carbon (DOC) value, methane generation potential (Lo) value of the waste also computed and used in the study. Equation (2) was used to compute methane generation potential Table 2. The computed methane generation potential is become 0.028153 and it was computed as follows:

$$Lo = 0.6*0.1408*0.50*0.50*1.333 Lo = 0.028153$$

A value of 0.6 that was provided for uncategorized solid waste disposal sites in IPCC 2006 guideline were used for methane correction factor as the disposal sites of the study area was not categorized under any type of disposal site. For the other emission parameters IPCC default values were used.

Waste type	Fraction	Value
Food waste	0.63	0.094
Paper	0.06	0.023
Textile	0.04	0.016
Garden waste or park waste	0	0
Wood or straw	0.03	0.008
DOC	0.1408	

Table 1: Value of degradable organic carbon used in the study.

Parameters	Value
Methane correction factor (MCF)	0.6
Degradable organic carbon (DOC)	0.1408
Fraction of DOC dissimilated (DOCf)	0.5
Fraction of methane in developed gas (F)	0.5
Conversion factor C to CH_4	1.333
Methane generation potential (Lo)	0.02815

Table 2: Value of methane generation potential.

Amount of solid waste generated and disposed

A total of 27,357,338 m^3 solid wastes were generated and 19,697,283 m^3 of solid waste were disposed in the disposal sites of Addis Ababa and surrounding Oromia special zone towns for the last five years. The generation as well as the disposal of solid waste in the study area has been increasing over time, the generation of solid waste increased from 3,010,317 m^3 in 2013 to 12,457,369 m^3 in 2017. Similarly, the disposed solid waste amount also increased from 2,167,428 m^3 in 2013 to 8,969,306 m^3 in 2017.

The rate of increase also changed rapidly from time to time, it was low at the beginning of the study year. The rate of change from 2013 to 2014 was 2.48% it becomes 36.15% in year 2014 to 2015 and become 170.57% at the end of the study year from 2016 to 2017 (Figure 2).

This amount of solid waste that were generated and disposed in the study area increased at a dramatic rate and reached 27,357,338 m^3 of solid waste generation and 19,697,283 m^3 of disposal in the year 2017. The major reason associated with the dramatic increase in the generation of solid waste in the study area was rapid population growth, rapid urbanization and the increase in the per capita income of the residence, which contribute to the per capita waste generation of the city and towns of the study area [18].

Amount of methane generated and emitted

As discussed in different literatures and global environmental publication methane emission from solid waste management was highly linked with landfilling of municipal solid waste. Methane emitted from landfills was estimated to account from 3% to 19% of anthropogenic emission source globally [19-21]. For the last five years out of the total generated and disposed solid waste in the study area, 4,848,147 tCO_2e were emitted to the atmosphere. Identified result showed that 1,510,191 tCO_2e, were emitted in 2017. The annual emission showed that about 1,244,809 tCO_2e, 938,867 tCO_2e, and 726,541 tCO_2e were emitted in the years 2016, 2015, and 2014 respectively. Similarly, in 2013 around 427,739 tCO_2e were emitted from solid waste disposal sites of Addis Ababa and the surrounding Oromia special zone towns.

About 4,679,729 tCO_2e were emitted from Addis Ababa city for the last five years. The highest emission of methane was recorded in the year 2017 when 1,454,704 tCO_2e were emitted and the lowest emission was in 2013 when 414,585 tCO_2e were emitted. Methane emission in the other years 2014, 2015 and 2016 were 702,461 tCO_2e, 905,465 tCO_2e and 1,202,514 tCO_2e respectively (Figure 3a). From

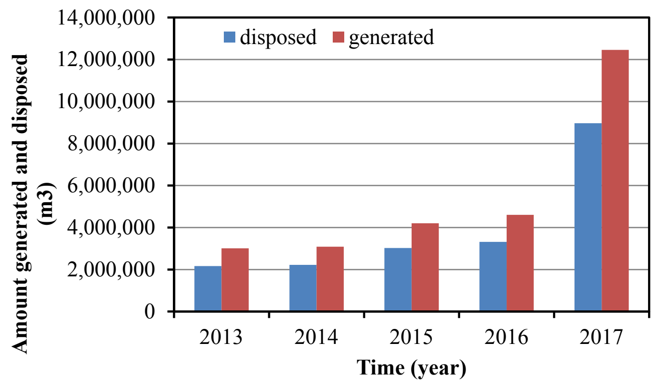

Figure 2: Total amount of solid waste generated and disposed in M3 (2013-2017).

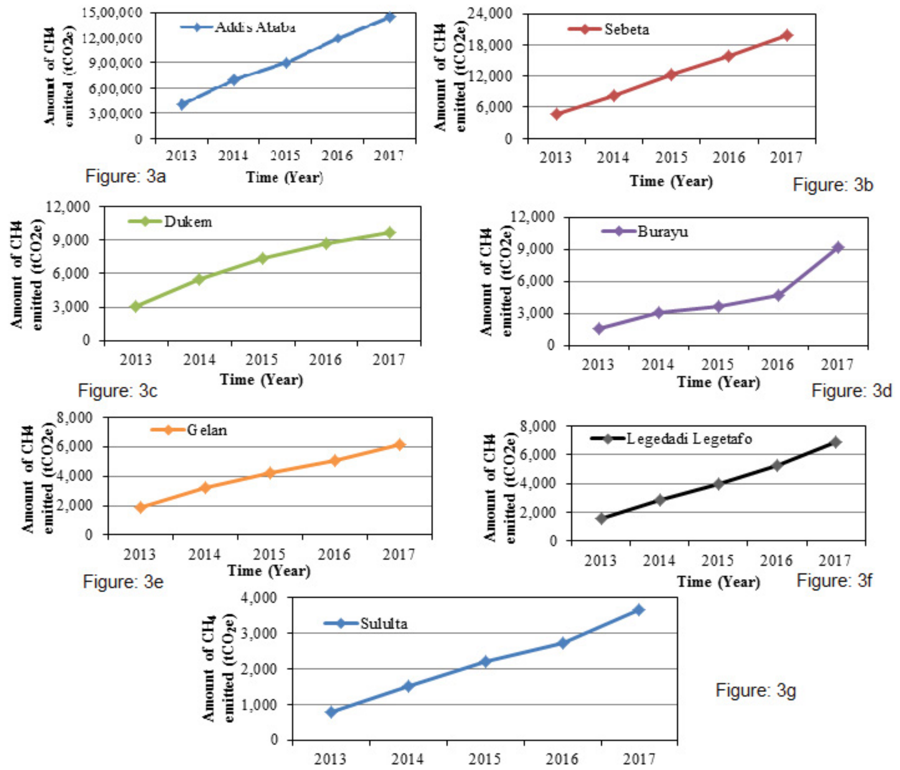

Figure 3: Amount of methane emitted from each city and towns of the study area (tCO_2e).

Sebeta town about 60,969 tCO_2e was emitted for the last five years. The highest emission was recorded in the year 2017 when 19,879.23 tCO_2e were emitted. On the other hand, the lowest emissions were recorded in 2013 when 4,683.63 tCO_2e emitted. On the other years, which were 2014, 2015 and 2016 about 8,220, 12,280, and 15,905 tCO_2e methane were emitted respectively (Figure 3b). Dukem town accounts for the emission of 34,385.82 tCO_2e methane for the last five years. In the years 2013, 2014, 2015 and 2016, the emission of methane was 3,067, 5,503, 7,347, and 8,733 tCO_2e respectively. Finally, at the end of the study year 2017 the methane emission of the town was 9733.50 tCO_2e (Figure 3c). Burayu town was accounted for the emission of 22,086 tCO_2e for the last five years. In 2017 about 9,176.00 tCO_2e methane was emitted. On the other hand, in the year 2013 about 1,586.00 tCO_2e methane was emitted. Methane emissions in the other years of the study period were 3,044, 3,591, and 4,689 tCO_2e in 2014, 2015, and 2016 respectively (Figure 3d). About 20,503 tCO_2e were also be emitted from Legedadi Legetafo town for the last five years. In the town 6,914 tCO_2e methane was emitted in 2017 and it was the highest emission of the study period. On the other hand, 1,532 tCO_2e were emitted at the beginning of the study period 2013 and it's been the lowest of emission of the period (Figure 3e). Similarly, about 20,490.33 tCO_2e were emitted for the last five years from Gelan town. The highest and lowest emissions were recorded in 2017 and 2013 when 6,174 tCO_2e and 1,842 tCO_2e were emitted. The other years of the study period that were 2014, 2015 and 2016 accounted for the emission of 3,223, 4,198 and 5,051 tCO_2e respectively (Figure 3f).

About 10,905 tCO_2e were emitted in the last five years from Sululta town. The annual distribution of emission was similar to the other towns, in 2017 about 3,672 tCO_2e and in 2013 about 793 tCO_2e were emitted. About 1,504, 2,194, and 2,739 tCO_2e were emitted in the other years of the study period, which were 2014, 2015, and 2016 respectively (Figure 3g). The major city that much of the emission of methane in the study area attributed to being Addis Ababa city, which emitted a total of 4,679,729 tCO_2e for the last five years. Solid waste disposal of the city emitted 96.53% of the total emission that quantified in the study area. Solid waste disposal site of the Addis Ababa has a huge share even from the county's disposal site methane emission. Methane emissions from Addis Ababa City solid waste disposal site account for 18% of the total emissions from Ethiopia's urban centers, 20 percent of the total emissions of the waste sector and 2 percent of the country's total emissions [11]. Methane emission of Addis Ababa and the surrounding Oromia special zone towns' disposal sites confirm with other similar studies. The total emission of Addis Ababa and surrounding Oromia special zone towns were 0.93 tCO_2e/tonnes of waste. Under the study conducted by Friedrich [22], concluded a generalized GHG emission scenario under different landfill sites. Based on the study sanitary landfill with no LFG capturing mechanism has the highest emission which was 1.2 tCO_2e/tonnes of waste, it was followed by open dumping which has an emission of 0.74 tCO_2e/tonne of waste. The conclusion provided on the study conducted by Manfredi [23] fell under the same rage, it was concluded that open dumping emitted around 1 tCO_2e/tonnes of waste, whereas sanitary landfill with energy recovery emitted 0.07-0.3 tCO_2e/tonnes of waste.

Emission change over time

Methane emission of all the towns of the Oromia special zone (SOSZT) and Addis Ababa city showed an incremental change over time for the last five years. In some towns, the increment was very sharp and in some, it showed a steady increase over time. In towns like Sebeta and Addis Ababa city the emission of methane showed a very sharp and dramatic increase over time, on the other hand, the emission in Sululta town showed a steady increase as it increased from 793 tCO_2e in 2013 to 3,672.27 tCO_2e in 2017. The increase in methane emission in Legedadi Legetafo town and Gelan town was almost steady that showed a constant increase year to year. In contrast, the emission increase in Burayu town was different from the other as it showed a stable increase from 2013-2016 and showed a sharp increase from 2016-2017 (Figure 3). The high increase in the generation and disposal of solid waste contributes for the increase in the emission of CH_4.

Activities applied to reduce the emission

The finding prevailed that the activities that was undertaken so far to reduce the emission of GHG from solid waste management stream in the study area was very poor, even the attention given to reduction of emission was non-existent almost in all city and towns. The only city that can be identified for its initiation of emission reduction activity was Addis Ababa city, which installed methane capturing and flaring instrument in Reppi solid waste disposal site. However, the findings exposed the non-functionality of the facility. Similarly, the application of composting in the study area was insignificant to consider it as one of waste management options. As the waste generated and disposed in the study area meanly constituted with organic waste, which was suitable for composting, a further collaborative effort is necessary to make it practicable rather than a pilot project. The recycling level of all the cities and towns of the study area was very low. In all cases, the real amount of solid waste that was recycled was not properly quantified. Like other developing countries the existing low level of recycling was also facilitated by the informal sector and inclined to some solid waste types, particularly plastic waste. In numerous literatures, different solid waste management options and LFG management options are suggested that have a potential for greenhouse emission saving from the sector. The major options that can reduce GHG emission from solid waste management stream include solid waste minimization, reusing, recycling, composting, LFG capturing and flaring, and LFG capturing and energy production [24-26]. Other studies also suggested the use of LFG collection and utilization for GHG reduction in relation to technological use as the highest overall GHG reduction can be achieved through the introduction of LFG collection and utilization system in the municipality waste management system [22,6]. The study conducted by Friedrich identified that the diverting of waste from landfill having LFG utilization system to a new one without an LFG system causes an increase in the emission of GHG by 294,670 tCO_2eq.

Existing legal framework related to GHG emission and management

National up to regional documents, including the constitution of the country was reviewed to identify and assess the legal framework that existed in relation to emission of GHG, its management practices and reduction measures as a whole and particularly from the solid waste management stream. The major policy instruments of the country FDRE constitution and environmental policy of the country doesn't have specific articles regarding GHG emission and its management options. As a general document, a detail provision of each and every specific issue was not expected from the constitution. Based on this binding principle its provision under article 44.1 and 44.4 right to live in clean and healthy environment and the state obligation of allocating resources to provide health, education and other social services to citizens can be used as a base for other policies and proclamation to provide a specific concern GHG emission [27]. The environmental policy of the country that puts its base on the constitution of the country lacked special concern for GHG emission in general and solid waste management in particular. One thing that can be reflected as a good start in the policy was its provision regarding the application of 3Rs in the solid waste management hierarchy and construction of sanitary landfill in different towns [28]. The other sector specific proclamation, solid waste management proclamation No 513/2007 also lacked specific concern towards GHG emission in the sector [29]. There were also no provisions of legal instruments that aimed at controlling or prohibiting the disposal of biodegradable waste into disposal sites. The only document that provides a detail analysis and provision for GHG emission and reduction was CRGE strategy of the country. It analyzed and estimates the generation of GHG emission from each sector and propose possible reduction strategies for limiting the country emission to the present level in 2030. The problem that can be associated with the implementation of the strategy was that it was not properly cascaded to the ground level professionals who worked on the day-to-day solid waste management activities. Many countries, especially developed countries provide regulation regarding the type of waste that can be disposed into the landfills. In European countries, the disposal of biodegradable waste by landfilling is totally prohibited, and composting was instead used as an alternative technology for biodegradable waste. The emission of GHG particularly methane from landfill sites also regulated and controlled by laws, the owners of Landfills expected to control methane emission from the landfill and regular inspection are conducted [30]. But in our country case there were no provisions of legal instruments that aimed at controlling the disposal of biodegradable waste into disposal sites.

Conclusion

A huge amount of CH_4 was emitted from Addis Ababa and the surrounding Oromia special zone towns for the last five years. The generation of CH_4 in the solid waste disposal site was highly dependent on the amount of solid waste that was disposed at the site. From the study area a total of 4,848,147 tCO_2e methane was emitted for the last five years. The annual emission of CH_4 showed a very sharp increment year to year correlating with the sharp increase of solid waste disposal in the study area. The activities, that were applied to manage and reduce the emission of CH_4 in the study area was very poor. The option that has a potential of GHG reduction in the waste sector was not practiced well. This low level of 3Rs strategy implementation restricts resource recovery and contributes for GHG emission in the study area. Similarly, legal instruments operated in the country, particularly in the study area didn't provide a necessary focus for emission management and reduction. Environmental policy of the country and solid waste management proclamation doesn't provide any provision regarding emission management. The CRGE strategy that provides a full coverage of GHG emission also lacked grass root level implementation.

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