TECHNIUM
Romanian Journal of Applied Sciences and Technology
ISSN: 2668-778X

vol. 16 / 2023

The 7th International Conference on Science Technology

organized by
Faculty of Social Science and
Law Universitas Negeri Manado and
Consortium of International Conference
on Science and Technology

The Innovation Breakthrough in Digital and Disruptive Era

PLUS COMMUNICATION

International Communication & PR

Technium: Romanian Journal of Applied Sciences and Technology
Vol. 16, 388-392, October, 2023
ISSN: 2668-778X
www.techniumscience.com

Environmental Impact Analysis of Methane Gas from Landfill using LCA in Klotok landfill, Kediri, East Java

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Abstract. The effective management of municipal solid waste is a persistent challenge within emerging nations. The observed phenomenon can be attributed to a multitude of reasons, encompassing swift economic growth, urban population development, garbage output, the substantial costs associated with waste treatment, and the design and functionality of containment systems. Methane, being the second most significant greenhouse gas following carbon dioxide, is prominently emitted into the environment by municipal solid waste dumps. This study use the IPCC model to assess the methane emissions generated by landfills. Additionally, Simapro 9.5 software is utilised in conjunction with the ReCiPe 2016 Midpoint approach to evaluate the corresponding environmental consequences. The Klotok landfill was found to generate the maximum quantity of methane, specifically 3.518 Mg CO2 eq, as determined by the composition analysis of paper waste. Additionally, the largest environmental impact was observed in the category of human toxicity carcinogenicity, as indicated by the life cycle assessment (LCA) analysis with a value of 3733.057.

1 Background

The management of municipal solid waste is still a challenge in developing countries. This is due to several factors, including rapid economic expansion and an expanding population in urban centers, waste generation, high expenses connected with management, and the structure of containment systems [1]. Recycling, composting, and incineration in recent years have made increasingly significant contributions to the management of solid waste, yet, landfilling continues to be a prevalent method of garbage disposal globally [2]. Even though burying waste in landfills is a slightly effective method for managing waste, there is a significant risk that the environment may be harmed due to this practice [3]. In order to precisely express what occurs in an environment with complex environmental interactions, a model is required [4] The time that waste is stored in landfills and the presence of landfill gas (also known as LFG) contribute to the complexity of life-cycle modeling for landfills [5].

1.1 Methane Landfill Emission

The emissions from landfills take place over a long period and at variable rates of pollutant release, depending on the conditions present within the dump. Changes in the behavior of a landfill may occur due to water and air getting into the landfill body, the loss of materials, or internal chemical interactions [6]. Therefore, in general, a landfill can be considered an open system with fluctuating chemical, physical, and biological conditions [7]. These conditions are what determine the emission characteristics of a landfill. The processes of substance release are distinctively different for inorganic waste deposits (such as slag landfills) and organic waste landfills (such as municipal solid waste landfills) [8].

The second most important greenhouse gas after carbon dioxide is methane, and municipal solid waste dumps are substantial contributors to its presence in the atmosphere [9]. Significant methane emissions from landfills contribute to global climate change and the development of ozone caused by the augmentation of radical chains that occur in atmospheric reactions of volatile organic compounds and nitrogen oxides [10]. This results from methane emissions, which make the chain lengths of radicals in the environment longer [11]. The amount of organic waste subjected to anaerobic microbial decomposition in a landfill determines the quantity of methane released by the landfill [12] [13]. The microbial decomposition of organic waste in anaerobic conditions produces landfill gas, mainly made from carbon dioxide (40–45% by vol.) and methane (50–60% by vol.). Landfill gas is formed when microbes decompose organic matter [14]. When municipal solid waste (MSW) gets treated in landfills, the organic components face anaerobic degradation facilitated by methanogens, resulting in the emission of methane into the atmosphere. Once the waste is deposited in a landfill, it conducts anaerobic decomposition, resulting in the

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Technium: Romanian Journal of Applied Sciences and Technology
Vol. 16, 388-392, October, 2023
ISSN: 2668-778X
www.techniumscience.com

generation of a relatively small amount of methane gas. In the majority of circumstances, anaerobic conditions often present during a period of less than one year, increasing the activity of methanogens in decomposing waste materials and releasing methane as a byproduct [8].

1.2 Life Cycle Assessment (LCA)

The life-cycle assessment, often known as LCA, is a method that is applied to determine how much waste management scenarios and processes, such as landfills, affect the environment and how much resources they require (United States Environmental Protection Agency (USEPA), 2020). A life cycle assessment (LCA) is defined by the ISO standard 14040/44 as a collection and evaluation of the inputs and outputs as well as the potential environmental implications that a product system may have throughout its life cycle. In light of this description, it should come as no surprise that an effect assessment is an essential component of an LCA.

Life Cycle Inventories of waste landfilling, typically documented as part of published research or made available in standard databases, usually involve contain CH_4 direct emissions [15]. LCA is now being utilized in several nations to assess various treatment options and solid waste management techniques of specific waste fractions [16].

1.3 Study Area

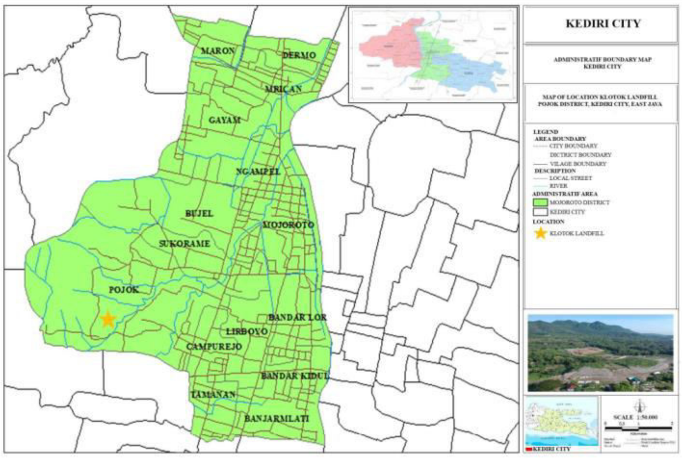
Klotok landfill is a sanitary landfill in Pojok Village, Kediri Regency, East Java, Indonesia. This landfill has a service area that covers the entire area of the city of Kediri [17].

This research uses LCA to examine three scenarios for the Klotok Landfill case study: the first scenario is a landfill, the second combines with composting, and the third scenario does not use any processing (open dumping). The second scenario represents the actual condition of Klotok Landfill. However, the result obtained can be considered reliable for other cities in developing nations, particularly in South East Asia, with a similar MSW composition and solid waste management practices. This is especially true for cities in developing countries in Southeast Asia.

Although a significant number of life cycle analysis studies have evaluated the treatment of biowaste, there is yet to be one that provides a complete LCA of the influence of CH_4 emissions from various waste management systems and the effect that it caused on treatment of biowaste and its management strategies. This study evaluates biowaste treatment's many potential outcomes by merging on-site mobile CH_4 emissions with an LCA model rather than relying on default emission rates. Additionally, the study emphasizes the energy value that can be obtained from waste treatment.

TPA Klotok uses the controlled landfill method to process waste. Klotok Landfill case study waste treatment at Kodok landfill uses the controlled landfill method by adding composting for organic waste from the garden and 3R for usable waste -are examined by LCA. However, the end findings can be considered for other cities in developing nations, particularly in South East Asia, where MSW is composed similarly, and solid waste management practices are comparable.

Fig. 1. Klotok Landfill Site Location



2 Method

An environmental assessment of methane from the solid waste in Klotok Landfill was carried out using IPCC and life cycle assessment (LCA) method. According to ISO14040/44 [18,19], an LCA consists of the following four steps: aim and scope definition, life cycle inventory, life cycle impact assessment (LCIA), and interpretation of results. The weighting step in the life cycle impact assessment is the most critical and contentious stage. In this study using the IPCC model to determine methane produced by landfills and using simapro 9.5 software with the ReCiPe 2016 Midpoint method to determine the environmental impact produced. The general outcomes of Life Cycle Assessment (LCA) encompass four consecutive processes in Life Cycle Impact Assessment (LCIA), including categorization, characterization, normalization, and weighting [20]. The primary focus of this study concerns to the consequential effects on atmospheric conditions.

2.1 Sampling method

In this study, sampling of waste composition referred to SNI 19-3964-1994 [21]. Sampling for waste composition data will be carried out on May 31, 2023. The type of waste composition taken is based on the 2006 IPCC, where the components consist of; food waste, paper, garden, wood and straw, textile, and nappies. these components are considered as significant components to produce methane [22]. While data on the weight of waste entering landfills was obtained from landfill operator records.

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Technium: Romanian Journal of
Applied Sciences and Technology
Vol. 16, 388-392, October, 2023
ISSN: 2668-778X
www.techniumscience.com

Table 1. Methane generation from various composition of waste

Waste composition	Amount deposited	MCF	Decomposable DOC (DDOCm) deposited	DDOCm not reacted. Deposition year	DDOCm accumulated in SWDS end of year	DDOCm decomposed	CH_4 generated
	Mg	fraction	Mg	Mg	Mg	Mg	Mg
food waste	34.748	0.71	1.850	1.850	4.659	1.381	0.921
Garden	16.430	0.71	1.166	1.166	5.323	0.770	0.513
Paper	33.636	0.71	4.776	4.776	33.724	2.099	1.399
wood and straw	21.595	0.71	3.296	3.296	28.097	0.884	0.588
Textiles	6.744	0.71	0.574	0.574	4.0575	0.252	0.168
Nappies	3.072	0.71	0.261	0.261	1.1946	0.172	0.115

2.2 Methane Generation

The following equation can be utilised in order to make estimates on the generation of methane (CH_4). The volume and composition of the garbage that is placed at the Klotok Landfill as well as the processes that are utilised there for the management of waste will be used to determine the potential for methane generation throughout the course of time. Methane generation calculations use calculations from IPCC 2006 tier one, methane generation calculation expressed as:

$$\text{Methane generationT} = \text{DDOCm dT x F x } \frac{12}{16} \ldots\ldots(1)$$

$$DDOC_{maT} = DDOC_{mdT} + (DDOC_{maT-1e}{}^{-k})\ldots\ldots\ldots (2)$$

$$DDOC_m = DOC \text{ x } DOC_f \text{ x } W \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where;

DDOCm :Decomposable Degradable Organic Carbon
$DDOC_{mdT}$: DDOCm disposed into landfill in T(year)
DOC : Degradable Organic Carbon
DOC_f : fraction of DOC decomposed
K : reaction constant
f : fraction of CH_4
$\frac{12}{16}$: molecular weight ratio CH_4/C
W : weight of waste that goes into landfills

The ability of the IPCC model to accurately anticipate the quantity of methane produced at landfills by taking into account the types of trash deposited there is the most important aspect of the model. Predictions based on the make-up of this trash that are not included in any other models [23].

3 Results and Discussion

The results of the waste composition analysis showed that plastic had the dominant value of 43.56% from total weight waste (146,310 Kg), followed by paper waste of 22.99%, wood and straw waste 14.76%, garden waste 11.23%, textiles 4.61%, disposable nappies 2.1% and food waste 0.73%. The results of the waste composition analysis showed that plastic had the dominant value of 43.56%, followed by paper waste of 22.99%, wood and straw waste 14.76%, garden waste 11.23%, textiles 4.61%, disposable nappies 2.85% and food waste 0.73%. This result is similar to several studies which show that plastic waste is the most dominant waste among inorganic waste [10] [24] [25].

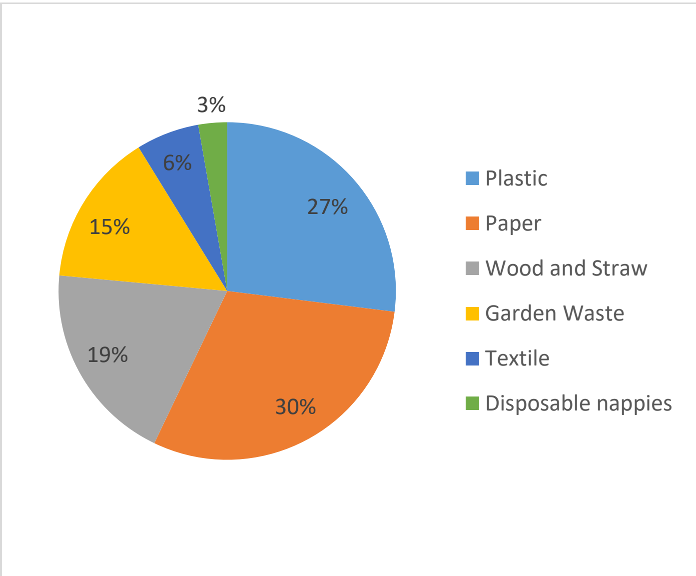

Fig. 2. Klotok landfill waste composition

Methane waste generation

The amount of methane in the Klotok landfill is calculated based on the amount of waste that goes to the landfill, the amount of waste that entered the Klotok landfill on May 31, 2023 was 146,310 Kg. using calculations from the IPCC model, it is obtained that methane gas generation in the Klotok landfill is 3.518 Mg CO_2 eq.

The generated methane in Klotok Landfill according to IPCC is then separated into six waste compositions, which are, food waste, garden, paper, wood and straw, textiles, and nappies. According to the amount deposited to the landfill, food waste has the biggest mass contribution, followed by paper, wood and straw, garden, textiles, and nappies as shown in Table 1. With a methane-carbon factor (MCF) of 0.71, the generated CH_4 can be calculated as described in

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Applied Sciences and Technology
Vol. 16, 388-392, October, 2023
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www.techniumscience.com

section 2.2. The generated CH_4 from paper in Klotok landfill gives the biggest proportion of CH_4, with 1.399 Mg of CH_4. This is in accordance with previous research from Subak and Craighill [26], that paper may contribute nearly one third of the total methane from landfill. The second biggest is from food waste, followed by wood and straw, garden, textilles, and nappies.

Characterization

In contrast to the characterization stage, the normalization stage states the impact categories with the same unit, making it easier for researchers to compare the impact categories that arise, thus facilitating the stage of proposing alternative improvements. The impact value from the normalization stage is obtained by calculating the division between the characterization results and normalization values based on the available database using the CML-IA (baseline) calculation method. The category with the highest impact will be identified at the normalization stage.

Table 2. Characterization table

Impact category	Value	Unit
Global warming	273201.5	kg CO_2 eq
Stratospheric ozone depletion	1.035819	kg CFC11 eq
Ozone formation, Human health	590.4852	kg NOx eq
Human carcinogenic toxicity	10340.88	kg 1,4-DCB
Human non-carcinogenic toxicity	136045.7	kg 1,4-DCB

Normalization

The characterization stage still cannot compare the value of the impact categories that become hotspots; this is because the characterization units are different, so a normalization stage is needed. This stage functions to standardize units, making it easier to compare impact categories and determine the highest impact category.

Table 3. Normalization Table

Impact category	Value
Global warming	34.205
Stratospheric ozone depletion	17.298
Ozone formation, Human health	28.698
Human carcinogenic toxicity	3733.057
Human non-carcinogenic toxicity	912.866

Based on the impact assessment in table 3. the highest impact value generated by TPA Klotok is the impact on human carcinogenic toxicity, followed by human non-carcinogenic toxicity, Global warming, ozone formation, and the smallest impact in this study is stratospheric ozone depletion. The potential impact of human carcinogenic toxicity has the greatest value. This indicates that the biggest potential impact of methane produced by landfills is human carcinogenic.
The impact value of human carcinogenic toxicity in the normalization table is the largest when compared to the values of other impact categories. The results in the normalization table are different from the characterization table, where in the characterization table the value for global warming is the greatest, this is due to differences in the multiplier factor in the resulting impact magnitude factor. The carcinogenic impact on humans is considered to have a very large impact [20].

While methane itself is not considered carcinogenic, it is important to note that the process of methane oxidation can lead to the formation of formaldehyde, which is known to have carcinogenic properties [27]. Natural gas contains a substance called methane, which is mostly put to use in industrial settings as a source of fuel and as a chemical feedstock. In low quantities, it does not pose a health risk; nevertheless, at higher levels, it can lessen the amount of oxygen in the air, which can lead to suffocation [28]. Methane has been found to be linked to various human diseases and is utilised in the realm of medical diagnosis. Moreover, there exists a correlation between the generation of methane and the occurrence of large bowel cancer [29] [30].

4 Conclusions

A study on environmental impact assessment of methane gas emitted from landfill was conducted in Klotok landfill, Kediri, East Java, Indonesia. This study used the IPCC model to assess the methane emission generated in the landfill. Additionally, Simapro 9.5 software is utilised in conjunction with the ReCiPe 2016 Midpoint approach to evaluate the corresponding environmental consequences. The Klotok landfill was found to generate methane, by the composition from paper may contribute nearly one third of the total methane from landfill. The second biggest is from food waste, followed by wood and straw, garden, textilles, and nappies. The impact assessment that has been analyzed in this study includes the impact on global warming, Stratospheric ozone depletion, Ozone formation, human carcinogenic toxicity, and human non-carcinogenic toxicity. The impact assessment found that the largest environmental impact has observed in the human toxicity carcinogenicity category, as indicated by the life cycle assessment (LCA) analysis with a value of 912.866.

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