Environmental Consequences of Poor Landfill Management

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ABSTRACT

Landfill is a popular method of waste disposal in many countries due to its relatively low cost of operation. The offensive aspect of the method is improper removal or disposal of the waste, which has resulted in avoidable sicknesses, diseases and preventable deaths. Carbon dioxide and methane are the two main gases emitted from landfill sites; municipal solid waste issue accounts for almost 5% of total greenhouse gas emissions and methane from landfills accounts for 12% of the total quantity of global methane emissions. Landfills can be put to sustainable use by employing it to produce energy from waste whenever is feasible and it has the capacity to generate revenue. Furthermore, many advanced waste treatment technologies have been developed which received commendable attention in developed countries and are evolving in developing countries. Landfill gas-to-energy is viable economically and for control of methane emissions and effective management of time, costs and quality with minimum risks to humans and the environment.

Keywords: GHGs, landfill, leachate, municipal solid waste, sustainability indicators, treatment technologies.

I. INTRODUCTION

Environment is the pivot in which physical, social, and economic activities takes place. Some analysts mostly describe environment, whose main resource is land, as ‘living earth’. This connotes that the earth or land is capable of reacting positively or negatively depending on the human activities. A common negative approach of dealing with ‘earth’ is dumping of waste into the ground, streets or drainages indiscriminately thereby causing sicknesses, diseases, and avoidable deaths.

A survey of waste disposal methods employed by selected countries was conducted in 2002 [1]. The survey demonstrated that all the countries have landfill sites: with Canada, 96% leading, followed by Finland, 95% and UK, 88%; the least is Switzerland, 20%; but had the highest in incinerated scheme of 80%. Many landfill sites accommodate waste that can be recycled. This makes it attractive to scavengers, who by this process are exposed to the risk of contracting diseases and possible sicknesses that may lead to premature death.

A. Aim and Objectives of the Study

The research paper is aimed at assessing the sustainability indicators of various landfill sites using a list of parameters, the objectives are to discuss and analyze waste to energy, and profits by various treatment technologies, as this will help to reduce overdependence on landfilling.

B. Research Limitation

All data were found through desk study rather than at real sites. The main information sources were with regulators, online and academic studies. The standards and regulations guiding many countries vary, this would tend to impact on the quality of data. The confidence came from the fact that many of the countries are signatories to many international organizations, regulations and associations. Nevertheless, an issue that the data collection process threw up was the need to consider the stakeholders’ opinions being part of a decision-making process. It would have been imperative to know the views of the citizens of many of the countries about current Waste Management techniques. This was dealt with by deep review of relevant journals and literature of many countries, especially the ones where data were collected.

C. Landfill

The unsystematic and unregulated/unscientific choice of landfill sites can pose a danger to the environment, humans,
and possibly, adjacent aquatic bodies, including groundwater [3]. One main criteria for selecting landfill include providing a reasonable distance away from significant water bodies. This is because of the danger of pollution of the water bodies, which may be of adverse effects to the aquatic life [4]. Other factors are climatic conditions, hydrology, local environmental conditions, e.g., nearness to network of roads, and land availability in its construction [5].

II. GHGS EMISSIONS FROM LANDFILLS

GHG emissions from municipal solid waste has been considered as a major issue because it accounts for almost 5% of total greenhouse gas emissions and methane from landfills account for 12% of the total quantity of global methane emissions [6], [7]. The primary composition of landfill gas is methane and carbon dioxide. Methane is regarded as one of the pronounced GHGs because it has a high potent global warming capability, that is, 28 times higher than carbon dioxide [8]. The relative high concentrations of methane have the capability of replacing oxygen in the surrounding atmosphere thereby leading to increased human health risks. Municipal solid waste dumped into the landfill undergoes anaerobic decay process because of the action of methanogens and methane is released into the atmosphere [8], [9].

A. Monitoring of Landfill Sites

The purpose of gas monitoring is to ascertain gas production that has given rise to hazard- the potential of agent, in this case gas level, to cause damage or injury. The monitoring of any landfill should commence six months from the time it was opened for operation and monitoring should be undertaken at 15 years after closure of a landfill as landfill sites consists predominantly of inert waste that may have produced landfill gas (Table 2). Leachate migration in landfills is due to water percolation that accumulates within or below the landfills especially in unsealed landfills above aquifer [10]. A leachate is typically characterized by two factors, viz, its composition and the volume generated [11] both varies among landfills and highly influenced by type of waste, volume, age, climatic conditions, mode of operation and landfiling technology [11], [12]. The efficiency or adequacy of a landfill is in the monitoring of leachate and regular control of groundwater migration [13]. [14] posited that the most important factor influencing landfill leachate composition is the age of the landfill. Many methods of disposing leachate have been evolved over time. For example, in Poland, one main municipal landfill leachate disposal technique is the co-treatment with domestic wastewater. The implementation seems to limit the total number of landfills [15].

III. RESEARCH METHODS

A. Advanced Waste Management Technologies

Four core types of advanced waste technologies: gasification, plasma arc gasification, pyrolysis, and steam classification, utilized for municipal wastes was adopted in this work. However, only gasification, plasma arc gasification and pyrolysis were considered being the only technologies available in the public domain.

B. Selection of Technique(s) through Decision Analysis

The criteria are clearly spelt out in Fig. 1 and the environmental parameters represented in Fig. 2.

Every key sustainability indicator was weighted against environmental options and award points are given to it on a random scale of 1 to 5 (1 is best and 5 is worst). Fig. 4 shows a flowchart of the relationship between the options and the sustainability indicators. The costs range quoted are 2009 prices and in US Dollars (Table 3). However, many variations in labour, materials and equipment have occurred since 2009 in the USA; in addition to the impact of exchange rate of Dollars and other currencies used in other countries. Table 4 was used to develop flowchart in Fig. 2.
TABLE 2: REGULATORY LIMITS OF LEACHATE CONTAMINANTS COMPOSITION IN SOME SELECTED COUNTRIES OF THE WORLD IN SEVEN REGIONS

| Region | Parameter | Country | COD (MgL⁻¹) | BOD₅ (MgL⁻¹) | TOC (MgL⁻¹) | NH₄⁻N (MgL⁻¹) | PO₄⁻P (MgL⁻¹) | Dissolved Solids (MgL⁻¹) | SS (MgL⁻¹) | Total Nitrogen (MgL⁻¹) | Phenolic Compound (MgL⁻¹) | Ref. |
|--------|-----------|---------|-------------|---------------|-------------|---------------|---------------|------------------------|-------------|----------------------|-------------------------|------|
| SAR    |            | Cameron | 320         | 44            |             |               |               |                        |             |                      |                         |      |
|        |            | Nigeria | 338         | 111           |             |               |               |                        |             |                      |                         | [16] |
|        |            | South Africa | 680         | 117           | 0.1         |               |               |                        |             |                      |                         | [17] |
|        |            | China  | 100         | 15            | 0.5         |               |               |                        |             |                      |                         |      |
| EAP    |            | Malaysia | 100         | 50            | 10          |               |               |                        |             |                      |                         | [18] |
|        |            | Singapore | 718         | 529           | 375         |               |               |                        |             |                      |                         | [19] |
|        |            | Macedonia | 985         | 1250          |             |               |               |                        |             |                      |                         | [20] |
| ECA    |            | Tajikistan | 4921        |               |             |               |               |                        |             |                      |                         |      |
|        |            | Ukraine | 2           |               |             |               |               |                        |             |                      |                         |      |
|        |            | Mexico | 790         | 4780          | 3395        |               |               |                        |             |                      |                         |      |
| LAC    |            | Uruguay | 0.3         | 8             | 0.7         | 0.15         |               |                        |             |                      |                         | [21] |
|        |            | Venezuela | 160         |               |             |               |               |                        |             |                      |                         | [22] |
|        |            | Egypt  | 12850       | 11700         | 7736        |               |               |                        |             |                      |                         | [23] |
|        |            | Lebanon | 50000       | 350           |             |               |               |                        |             |                      |                         | [24] |
|        |            | Saudi Arabia | 50000       | 350           |             |               |               |                        |             |                      |                         | [25] |
| MENA   |            | Arabia | 14.1        |               |             |               |               |                        |             |                      |                         | [26] |
|        |            | Australia | 10          | 15            | 0.5         | 0.1          |               |                        |             |                      |                         | [27] |
| OECD   |            | Germany | 200         | 10            | 15          | 0.3          | 3              |                        |             |                      |                         | [28] |
|        |            | Sweden | 33          | 3361          | 297         |              |                |                        |             |                      |                         | [29] |
|        |            | Bangladesh | 200        | 20            | 20          | 5            | 0.05           |                        |             |                      |                         | [30] |
|        |            | India  | 100         | 50            | 100         | 200          | 2100           | 150                    | 0.2         |                      |                         | [31] |

Legend: 
- Acceptable 
- Unacceptable

Fig. 2. Flowchart illustrating outcome for three advanced thermal solid waste management technologies options.
TABLE 3: SUMMARY OF ADVANCED SOLID WASTE TECHNOLOGIES [6], [32]-[37]

| Type of Waste Mgt          | Average Capital Cost ($ Millions) | Average Annual Operating Cost ($ Millions) | Average Tipping Fee | Average # FTE | Renewable Energy (MW) | Average Disposal Capacity (Thousand tons/year) | Average Land Space Required (Acres) | Emissions | # of facilities |
|----------------------------|----------------------------------|-------------------------------------------|---------------------|--------------|-----------------------|-----------------------------------------------|------------------------------------|-----------|----------------|
| Landfill Gas-to-Energy Gasification | 5                                | 0.6                                       | $34                 | 2            | 3.0                   | 500                                           | 172                                               | Low       | 485            |
| Pyrolysis Plasma Arc Gasification | 65                               | 7.1                                       | $40                 | 30           | 4.0                   | 350                                           | 8                                                 | Low       | 110            |
| Mechanical Biological Treatment | 90                               | 6.6                                       | $40                 | 50           | 4.3                   | 200                                           | 5                                                 | Low       | 3              |
|                                 | 78                               | 7.9                                       | $70                 | 30           | 4.0                   | 225                                           | 6                                                 | Low       | 70             |

C. Data Collection and Analysis

A systematic collection of data from various landfill sites globally was carried out for the 21 countries selected from 7 regions (Table 7). All data collections were done through desk study; sources would be regulators, online and academic studies. This was subjected to the environmental parameters that produced Table 5.

TABLE 4: INDICATING ENVIRONMENTAL SET OF CRITERIA ASSESSMENTS FOR THREE OPTIONS

| Options                  | Gasification | Pyrolysis | Plasma Arc Gasification |
|--------------------------|--------------|-----------|-------------------------|
| Tipping Fee              | 3            | 3         | 2                       |
| Environment Impact       | 2            | 2         | 1                       |
| Public Acceptability     | 4            | 3         | 1                       |
| Number of Facilities     | 3            | 4         | 2                       |
| Total                    | 12           | 12        | 6                       |
| Rank                     | 2            | 2         | 1                       |

TABLE 5: INDICATING ASSESSMENT OF THE COSTS FOR THREE OPTIONS

| Options       | Gasification | Pyrolysis | Plasma Arc Gasification |
|---------------|--------------|-----------|-------------------------|
| Environment   | 12           | 12        | 6                       |
| Operation     | 16           | 13        | 10                      |
| Costs         | 14           | 13        | 14                      |
| Total         | 42           | 38        | 30                      |
| Overall Rank  | 3            | 2         | 1                       |

IV. PROCEDURE FOR COMPUTATION

For the feasibility study on the technological aspects of solid waste to energy generation, the following equation was adopted from an earlier work [38]. The essence was to analyze the weights of waste as par the reviewed literature on ‘Gasification and Pyrolysis’ technologies already discussed.

Let the rank in the selected criterion be represented by \( r_{ij} \), for \( i = 1, 2, 3, j = 1 \ldots 13 \), where \( i \) represents the technologies and \( j \) represents the criterion.

The value of the inward will determine the relative weights of rank for each criterion.

Let the values awarded for each criterion be represented by \( a_{ij} \), for \( j = 1 \ldots 13 \). Then,

\[
W_j = \frac{a_{ij}}{\sum_{j=1}^{13} a_{ik}} \quad \text{for} \quad j = 1 \ldots 13 \tag{1}
\]

Equation (2) demonstrates how the total rank was computed:

\[
r_{T, i} = \sum_{j=1}^{13} (r_{ij}w_j), \text{for all} \quad i \tag{2}
\]

The ranking of technologies \( i \) will now be determined based on the minimum \( r_{T, 1}, r_{T, 2}, r_{T, 3} \).

Illustration of the calculation process using the equation using tipping fee as an example.

From Table 4 Awarded Points on the three technologies = 3+3+2 = 8.

Average value of awarded points = 8/3 = 2.67.

From Table 5 Total Costs based on the three options gives: 42+38+30 = 110.

Average of Total Costs = 110/3 = 36.67.

Weight of Criteria = 2.67/36.67 = 0.072.

All other values in Table 6 were computed using the above procedure as illustrated.

A. Interpretation of Results

The procedure made pairwise comparison of technologies alternatives of the 7 regions of countries selected. Local priorities of alternatives were interpreted in the calculations in this intermediate step which are reflected in Fig. 4. These computed criteria weights for each region where the sum of criteria weights in each region is equal to 1 (Fig. 3).
**TABLE 6: RESULTS OF CALCULATIONS AND ANALYSIS FROM RESEARCH METHODS**

| S/N | Tipping Fee | Environment Impact | Public Acceptability | Number of Facilities | Revenue | Development Period | Flexibility of Process | Net Conversion Efficiency | Capital Cost | Land Requirement | Ease of Permitting | Marketability | Operation Cost |
|-----|--------------|-------------------|----------------------|----------------------|---------|-------------------|------------------------|--------------------------|--------------|-----------------|-------------------|----------------|----------------|
| 1   | 2.67         | 1.67              | 2.67                 | 3                    | 2.67    | 4                 | 3.67                   | 3.33                     | 3.33         | 2.67            | 3                | 2              | 2.67           |

**Fig. 3.** Criteria weights obtained from ATSWM technologies:
(a) Latin America and Caribbean, (b) Organisation and Economic Cooperation and Development, (c) Sub-Saharan Africa Region, (d) Middle East and North Africa, (e) South Asia Region, (f) Eastern and Central Region, (g) East Asia and Pacific.

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TABLE 7: COUNTRY CLASSIFICATION ACCORDING TO REGION [2]

| Region | Africa (AFR) | East Asia & Pacific (EAP) | Eastern & Central Asia (ECA) | Latin America & the Caribbean (LAC) | Middle East & North Africa (MENA) | Organisation for Economic Co-operation and Development (OECD) | South Asia (SAR) |
|--------|--------------|---------------------------|----------------------------|----------------------------------|----------------------------------|---------------------------------------------------------------|-----------------|
| Angola | Brunei Darussalam | Albania | Antigua & Barbuda | Algeria | Andorra | Bangladesh |
| Benin | Cambodia | Armenia | Argentina | Bahrain | Australia | Bhutan |
| Botswana | China | Belarus | Bahamas, The | Egypt, Arab Rep. | Australia | India |
| Burkina Faso | Fiji | Bulgaria | Barbados | Iran, Islamic Rep. | Belgium | Maldives |
| Burundi | Hong Kong | Croatia | Belize | Iraq | Canada | Nepal |
| Cameroon | Indonesia | Cyprus | Bolivia | Israel | Czech Republic | Pakistan |
| Cape Verde | Lao PDR | Estonia | Brazil | Jordan | Denmark | Sri Lanka |
| Central African Rep | Macao, China | Georgia | Chile | Kuwait | Finland | France |
| Chad | Malaysia | Latvia | Colombia | Lebanon | Costa Rica | Malta |
| Comoros | Marshall Islands | Lithuania | Malta | Germany | Greek |
| Congo, Dem. Rep | Mongolia | Macedonia, FYR | Cuba | Morocco | Greece |
| Congo, Rep. | Myanmar | Poland | Dominica | Oman | Hungary |
| Cote d’Ivoire | Philippines | Romania | Dominican Republic | Qatar | Iceland |
| Eritrea | Singapore | Russia Federation | Ecuador | United Arab Emirates | West Bank and Gaza | Luxembourg |
| Ethiopia | Solomon Island | Serbia | El Salvador | Syrian Arab Rep | Italy |
| Gabon | Thailand | Slovenia | Grenada | Tunisia | Japan |
| Gambia | Tonga | Tajikistan | Guatemala | United Arab Emirates | Spain |
| Ghana | Vanuatu | Turkey | Guiana | Peru | Sweden |
| Guinea | Vietnam | Turkmenistan | Haiti | Monaco | Switzerland |
| Kenya | Honduras | Jamaica | Mexico | Norway | Portugal |
| Lesotho | Madagascar | Nicaragua | Panama | Slovak Republic | Spain |
| Liberia | Mali | Mauritania | Mauritius | St. Kitts and Nevis | Morocco | New Zealand |
| Malawi | Mali | Mauritania | Mauritius | St. Vincent and the Grenadines | Norway | Portugal |
| Madagascar | Malawi | Peru | Nicaragua | Suriname | Portugal | Portugal |
| Malawi | Malawi | Nigeria | Togo | United Kingdom | United States | United Kingdom |
| Mali | Mali | Nigeria | Togo | United States | United States | United States |
| Mauritania | Mauritania | Rwanda | United States | Venezuela, RB | United States | United States |

V. CONCLUSION

Sustainable solid waste management is practically difficult; however, finding solutions to the waste situation that is ever increasing is paramount for any country and indeed the rest of the world. In order to progress the process, analytical hierarchical process (AHP), which was first made known by [39] and best practicable environmental option (BPEO) are renowned approaches of resolving complex decision-making problems by deriving weights to denote the comparative significance of different criteria has been applied.

Many technologies are available as well as many have been reviewed. In all, landfill gas-to-energy seems the most viable economically and for control of methane emissions, in addition to producing dependable source of energy.

These three technologies virtually reduce or eliminate the need for landfills in some instances, in addition to meeting
sustainability measures; however, the economic aspects of plasma arc gasification have not been fully verified because of its high technical requirements.

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