The Potentiality of Biogas from Landfilling of Solid Waste in Madinah, KSA

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امكانية تولد الغاز الحيوي من مرادم النفايات الصلبة بالمدينة المنورة

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ملخص البحث (Abstract):

يسبب التخلص من النفايات الصلبة العديد من المشاكل البيئية والاجتماعية والاقتصادية، مما يدعو الباحثين لتطوير بدائل لادارة النفايات الصلبة والاستفادة منها. يعتبر استخراج الطاقة من النفايات احدى الطرق الهامة للاستفادة من النفايات الصلبة بالأخص عند استخدام الطمر الصحي. وبالإشارة الى التنمية الاقتصادية المتزايدة وزيادة الطلب العالمي على الطاقة، والذي خلق ضغطاً بالتبعية على موارد الطاقة الحالية، ومن منطلق تعزيز مفهوم التنمية المستدامة، أمكن التوصل الى بدائل للطاقة الآمنة والمتجددة مثل الطاقة الحيوية المتولدة من مرادم النفايات البلدية الصلبة. لذلك يناقش هذا البحث مدى إمكانية الاستفادة من الغاز الحيوي المتولد من مرادم النفايات الصلبة بالمدينة المنورة وتحويله من عبء بيئي وخطر محدق الى قيمة مضافة.

هناك عدة طرق لاستخراج الطاقة من النفايات بتقنيات مختلفة ومنها عملية الهضم اللاهوائي للنفايات الصلبة في المرادم والذي يفتح الأفاق للأستفادة من مرادم النفايات البلدية الصلبة كمصدر للطاقة الحيوية بجميع أنحاء العالم، حيث لا يوجد فصل وفرز كاف للنفايات القابلة لإعادة التدوير بمعظم البلدان في جميع أنحاء العالم. لذلك للحصول على تنمية بيئية مستدامة يفضل بجانب توفير أحدث تقنيات فرز النفايات للاستفادة منها جنبًا إلى جنب مع أنظمة توليد الغاز الحيوي من مرادم النفايات الصلبة.

ويبلغ اجمالي النفايات المتولدة من المدينة المنورة بالمملكة العربية السعودية حوالي ١,٦٩ مليون طن مشتملة على النفايات الانشائية والبلدية الصلبة والأشجار والمحطات الانتقالية والمجازر. وتصل النفايات خلال شهر رمضان الى ١٤٠ الف طن بنسبة ٨,٣%، بينما ترتفع بشكل ملحوظ خلال موسم الحج الى أكثر من ٣٥٠ الف طن بنسبة ٢١,٢% من اجمالي النفايات بالمدينة المنورة.

ويعتبر الغاز الحيوي نتاج تحلل الطمر اللاهوائي للنفايات الصلبة، حيث تعتمد كميته وتركيبه على نوعية وتصنيف مكونات النفايات الصلبة القابلة للتحلل بالمدينة المنورة. تم حساب كمية الغاز الحيوي (الميثان) الناتجة من مردم النفايات الصلبة المدينة المنورة الواقع بطريق ينبع القديم بناءً على نسبة النفايات العضوية القابلة للتحلل والتي يتم طمرها بهذا المردم سنوياً. ولتقدير كمية الغاز الحيوي وثاني أكسيد الكربون الناتجة من المردم تم استخدام برنامج LandGEM. بلغت كمية غاز الميثان المحسوبة بواسطة البرنامج أكثر من ٨٥٠ مليون م٣/سنة، وغاز ثاني أكسيد الكربون أكثر من ٦٥٠ مليون م٣/سنة.

Unsafe disposal of solid waste causes many environmental, social and economic problems, which leading researchers to investigate and develop alternatives to solid waste management and utilization. Extraction of energy from solid waste is an important way, especially when the solid waste was landfilled. With reference to increasing economic development and increasing global demand for energy, which created a pressure on existing energy resources, and in promoting the

concept of sustainable development, alternatives to safe and renewable energy such as biomass generated from municipal solid waste landfills is preferred. Therefore, this research discusses the potential of biogas production from the landfills of solid waste in Madinah, and transforming the solid waste from environmental load to added value of energy.

There are several ways to extract energy from solid waste by different techniques, including the anaerobic digestion in the landfills, which opens the prospect of benefiting from solid municipal waste landfills as a source of bioenergy throughout the world. There is no sufficient separation and sorting of recyclable solid waste in most countries around the world. For sustainable environmental development, as well as providing the latest waste sorting techniques to be used in conjunction with biogas generation systems from solid waste landfills.

The total solid waste generated from Al Madinah, KSA is about 1.69 million tons per year, which includes municipal, trees, transit stations and slaughterhouses waste. During Ramadan, solid waste reaches 140,000 tons by a rate of 8.3%, while during the Hajj season it rises to more than 350 thousand tons by a rate of 21.2% of the total waste in Medina.

Biogas is the product of the decomposition of anaerobic landfill for solid waste, depending on the quantity and composition of biodegradable components of solid waste in Madinah. The amount of biogas (methane) produced from the solid waste landfill of Madinah, located in Old Yanbu Road, was calculated based on the proportion of biodegradable solid waste that in this landfill annually. To estimate the amount of biogas and CO_2 produced from the landfill, LandGEM was used. The estimated amount of methane was more than 850 million m^3/yea, where the Carbon Dioxide more than 650 million m^3/year.

Introduction

Madinah is the second holiest city in the Kingdom of Saudi Arabia (KSA), which hosts millions of Muslims every year to visit Prophet's Mosque. The number of visitors to Madinah is growing significantly during the last few decades due to a continuous expansion of the Prophet's Mosque, improved transportation services, high security reduced overall cost and time, and current expansions in the Prophet's Mosque.

In Madinah city, the total waste generated from Madinah during 2017 was about 1688118 tons, including construction, domestic, solid waste, trees, and slaughterhouses waste, on average around 700 thousand tons of MSW is generated per year, in addition to a construction waste by an average of 800 thousand tons, high volume waste by about 200 thousand tons, slaughterhouse waste by about of 16 thousand tons. During the month of Ramadan, the waste reaches 139,667 tons representing a total rate of 8.27% from the total quantity of Madinah, while during the Hajj season it reaches 357,263 tons, representing 21.16% of the total waste (Municipality of Madinah, 2018).

The KSA has recently launched a new policy of Vision 2030 with an ambition to reduce all types of waste and produce renewable energy from its indigenous sources, including the waste. The policy made a roadmap for the development of integrated solid waste management system to optimize the financial and environmental values of waste through reuse and recycling (KSA Vision 2030).

Biogas as a renewable energy source could be an alternate means of solving the problems of energy crisis, which is produced by the anaerobic digestion or fermentation of biodegradable materials such as biomass, manure, sewage, municipal waste, green waste, plant material, and crops. Biogas comprises primarily methane (CH_4) and Carbon Dioxide (CO_2) and may have small amounts of Hydrogen Sulphide (H_2S).

The process of anaerobic digestion entails a community of microorganisms that first convert complex organic wastes to organic acids (such as acetic and propionic acids) and then the organic acids to biogas, containing primarily methane and carbon dioxide. Bio-produced methane is a renewable energy source that can be used in boilers, cleaned of impurities to enable insertion in natural gas lines, burned in a generator to produce electricity or simply flared if energy production

is not economical.

Landfill gas can be defined as a complex mixture of hundreds of different types of individual gases and vapors. However, the most common components are methane (CH_4) and carbon dioxide (CO_2). According to the USA Agency for Toxic Substances and Disease Registry (ATSDR), landfill gas typically contains 45-60% methane and 40-55% carbon dioxide. Landfill gas often also includes small amounts of ammonia, sulphides, carbon monoxide, hydrogen, and volatile organic compounds (VOCs) (Henderson R. E., 2011).

Methane (CH4) is the second largest driver of climate change behind carbon dioxide and one of the six greenhouse gases (GHGs) listed in the Kyoto Protocol, with global warming potential of 25 over 100 years (IPCC, 2007a). CH4 is also a short-lived climate pollutant with an average life-time around 12 years in the atmosphere. According to the IPCC Fourth Assessment Report (IPCC, 2007b), the total CH4 emissions and those from waste management accounted for 14.3% and 2.8% respectively, of the global GHG emissions in 2004. The CH4 emissions from waste management shared 4% of the global total GHG emissions in 2010 (UNEP, 2012), with about half both from municipal solid waste (MSW) landfill and waste water treatment (JRC and PBL, 2012). The CH4 emissions from MSW landfill rose fast from 16.50 Mt in 1970 to 29.50 Mt in 2008, with the total growth of 78.79% (JRC and PBL, 2012). About 73% of safely disposed MSW in China was landfilled in 2012 (NBSC, 2013).

Now, landfilling is the most dominant treatment of MSW disposal at present in Madinah, with the development of economy, advance of urbanization and improvement of people's living standards, both the waste generation and landfill are substantially increasing. The gaseous emissions emitted from landfills constitute one of the major environmental concerns. Gaseous compounds are produced following biochemical reactions, such as the methane and carbon dioxide generated in MSW landfills from the anaerobic degradation of the organic fraction of the waste.

The gaseous compounds emitted from landfills have various impacts on their surroundings at different scales (Fig. 1). In addition to, their impacts over a large spatial scale, gaseous emissions also act on different time scales. Compared to most other processes used in waste treatment, those occurring inside the landfill and the emissions they generate extend over a very long period of time after the waste has been disposed: from tens to hundreds of years.

Not only is the period of significant emissions long, but the compounds emitted will themselves have effects and life-spans of varying duration. Odours and dust, for example, are mainly transient phenomena. Methane constitutes both a very short term and acute explosion hazard and has a much more far-reaching and long-term effect on global warming (Fischer C., et al., 1999).

Research aims

the potential of biogas production from the landfills of solid waste in Madinah, and transforming the solid waste from environmental load to added value of energy.

Research methodology

1. Landfill Gas Generation

Gas formation and quality in landfills depends on constitutes of landfilled wastes, the environmental conditions at/in the landfill and on landfill technology. LFG composition is the result of degradation processes in the landfill, as well as of evaporation of volatile substances and exchange of gaseous compounds between the landfill and the surrounding atmosphere. The composition of the gas will also in itself affect landfill processes, and thus the formation of gas.

When predicting landfill gas formation, the focus is usually put only on biogas formation as a result of the anaerobic degradation of the biodegradable fraction of the waste, neglecting the fraction resulting from other processes. A potential gas generation can be calculated from the composition of the substrate. Empirical data is used or anaerobic degradation tests are carried out. The rate and ultimate yield of LFG is highly variable from site to site. A typical yield may be in the range of 200-300 m^3/ton of fresh MSW and the range of methane generation may range from below 1-40 m^3/ton and year (Lawson et al. 1992).

Nowadays, there is much interest in energy production from Municipal Solid Waste. It generally comprises a mixture of organic matter (food wastes), plastics, paper, glass, metal and other inert parts. It can also include some commercial and industrial waste that is similar in nature to household waste. MSW is primarily considered a liability. It needs to be collected and processed, which comes at a certain cost. If managed improperly, it can cause severe human health problems and harm the environment (UN Habitat, 2010).

Waste to Energy (WTE) is a general term to describe an incineration process which uses MSW as raw material. WTE industry is gaining growing acceptance worldwide as an important part of the waste treatment hierarchy- reduce, reuse, recycle, recover and dispose, with WTE being considered part of "recover". However, it is only applicable when a number of overall criteria are fulfilled (UN Habitat, 2010), as following:

- Existence of a mature and well-functioning waste collection and management system for a number of years.
- A minimum and stable supply of combustible waste (at least 50,000 tons/year).
- A minimum average lower calorific value (at least 7 MJ/kg, never below 6 MJ/kg).
- A community that is willing to absorb the increased treatment cost.
- Skilled staff that can be recruited and maintained.
- Solid waste disposal at controlled and well-operated landfills.
- A stable planning environment for the community (planning horizon at least 15 years).

2. Landfill Gas Composition and Characteristics

Landfill gas is the product of solid waste decomposition. The quantity and the composition depend on the types of solid waste that is decompositing. A waste with a large fraction of easily biodegradable organic material will produce more gas than one consisting largely of ash and construction debris. The rate of gas production is governed by the rate at which decomposition is occurring in the wastes. When decomposition ceases, gas production also ends. Gas production begins almost immediately after the solid waste is placed in a landfill. (Willumson 9/1990) noted that the most significant gas production usually begins 200 days after solid waste is disposed of in a landfill.

Landfill gas evolves from the breakdown of biodergradable materials in a landfill. The composition of gas varies according to the type and phase of breakdown which occurs within the site at specific time. Schumacher (1983) noted that after the refuse has been placed in the landfill, aerobic decomposition of the organic waste begins and a small amount of greenhouse gas, i.e CO_2 is produced. Once the Oxygen has been depleted, the anaerobic microorganisms become dominant and produce the greenhouse gases in landfill sites.

During the second stage of methane fermentation, the organic acids are consumed by a special group of methanogenic bacteria and concerted into methane and carbon dioxide (EMCON, 1980). It is believed that the anaerobic process in a typical landfill occurs between 180 and 500 days after landfilling, depending on the waste composition, moisture content, temperature, pH, nutrients and refuse density (Boyle, 1977).

In general, landfill gas composition depends on the composition of the waste, but it will generally contain about 40-60% methane (CH_4), 40-50% carbon dioxide (CO_2), small amounts of 0.2-1% oxygen, 2-5% nitrogen, 0-1% hydrogen and other trace components such as hydrogen sulfide (0.0017-0.01%) and vinyl chloride (<0.0001%) (Senior, 1990) (Table 1).

A large landfill may produce gas for a period in excess of 50 years and can result in a total yield of landfill gas in the range 0.06 m^3/kg up to 0.53 m^3/kg. typically, the heating value of typical landfill gas is roughly 16.8 mega Joule/m^3 (450 BTU/ft^3) or approximately half the lower heating value of natural gas (David, 1997).

3. Factors Affecting Landfill Gas Generation

There are a numbers of factors affecting gas generation including: refuse deposits, pH, temperature, nutrients, moisture content, and site operational factors. These will be discussed as following:

- **Refuse Deposits:** Refuse high in organic matter, such as food waste, and paper, will decompose more rapidly than inorganic materials such as demolition and construction debris (Owens and Chynoweth, 1992).
- **pH:** Optimum pH values for anaerobic digestion range from 6.34 to 7.4. The pH value in landfills may be influenced by industrial waste discharge, alkalinity, and clear water infiltration (Boyle, 1977). The average pH value in a landfill does not drop below 6.2 when methane is produced (Rare Earth Research Conference, 1978).
- **Temperature:** Temperature of the landfill will indicate which class of bacteria is functional. Mesophile bacteria grow best in the temperature range of 20 to 40 °C, while thermophiles grow best above 45 °C (Schmuacher, 1983).
- **Nutrients:** Sufficient nutrients are required for the growth of bacteria in the landfill. These primarily are carbon, hydrogen, oxygen, and phosphorus (EMCON Association, 1980).
- **Moisture Content:** Rate of methane production increases with higher moisture content. The optimum moisture content should be approximately 40 to 45% (wet weight) for the maximum gas production (Pacey, 1986). Studies have shown, in addition, that the gas production increase after a heavy rainfall as recorded high moisture content as 80% phosphorus (EMCON Association, 1980).
- **Site Operational and Characteristic Factors:** Gas production increase with the reduction in particle size and the resultant increase surface area. Pacey (1986) suggested that reduced particle size will expose a greater

surface area of refuse to the key parameters: moisture, nutrients and bacteria. In addition, gas production increase with the increment of refuse thickness. The designed refuse height of 40 meters (or more) is the standard landfill designed structure for landfill gas recovery.

4. Characterization of Solid Waste in Madinah City

The target of characterization of solid waste in Madinah will provide a primary figure out of the main components of the solid waste, especially the organic matters, that represents an important role controlling the generation of landfill gas in the landfills in Madinah, in addition to the characterization of solid waste will provide baseline data for its municipality to assess their progress toward specific sustainable waste management goals.

In Madinah City, the solid waste was received and collected from all municipalities by means of compressors and transferable containers. Large-size materials, trees, solid and liquid slaughterhouses and medical waste are also received, in addition to some commercial private companies. There is a separation unit of solid waste was initiated to sort the different types of solid waste before the landfilling process, where there is a treatment incineration unit for medical waste and a specific unit for slaughterhouses waste.

Generally, the total quantities of solid waste generated during 2017, reached to about 1688118 tons, where the construction and demolition waste representing about 48%, domestic waste representing 40%, High-volume waste representing 11%, slaughterhouses waste representing about 1%, and finally the trees representing less than 1% (Fig. 2). During Ramadan 2017, the generated total quantities of solid waste representing about 8% of the total solid waste throughout the year of 2017 (Fig. 3), the most dominant component is the domestic waste representing about 58%, construction and demolition waste representing about 28%, High-volume waste representing 12%, slaughterhouses waste representing about 1.4%, and finally the trees representing less than 1%. While in Hajj season 2017, the generated total quantities of solid waste representing about 21% of the total solid waste throughout the year of 2017 (Fig. 4), the most dominant component is the construction and demolition waste representing about 58%, domestic waste representing about 33%, High-volume waste representing 8%, slaughterhouses waste representing about 1%, and finally the trees representing less than 1%

Morsy and Al-Sebaei 2015, stated the classification of solid waste after the manual sorting, the component of the organic matters represents the largest component by a rate of 49%, where the plastics rate of 29%, paper and card board rate of 13%, metals of 6%, glass of 1%, textiles of 1%, and finally the wood with a rate of 1% (Fig. 5).

5. Landfilling of Solid Waste in Madinah City

There is a waste sorting unit, which is responsible for sorting all the recyclable materials such as, plastic, cardboard, iron, aluminum and paper, are extracted in the form of bales, which are directed to the specialized companies. There is a baling unit consists of two pistons equipped with conveyors to transport the sorted waste into the compressor chamber. The pistons operated automatically until the bales are released from the piston and connected automatically to be ready for transmission to the recycling facilities.

Worth mentioning, the landfill of Madinah city, is covered daily with sand deposits not less than 20 cm, and lined with High Density Poly Ethylene layer (HDPE), in addition to a network of sewage water to collect the generated leachate, and a gas collection system (The landfill gas connected to a main pipe to reach the gas burners for the safe disposal of gas by burning).

Results and discussion

6. Estimation of Potential of Landfill Gas Production in Madinah City

LandGEM is based on a first-order decomposition rate equation for quantifying emissions from the decomposition of landfilled waste in MSW landfills. The software provides a relatively simple approach to estimating landfill gas emissions. Model defaults are based on empirical data from U.S. landfills. Field test data can also be used in place of model defaults when available. Further guidance on EPA test methods, CAA regulations. LandGEM uses the following first-order decomposition rate equation (1) to estimate annual emissions over a time period that you specify. The model parameters k and L_0 used by this decomposition equation.

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} KL_0 \left(\frac{M_i}{10}\right) e^{-kt_{ij}} \qquad 1$$

where

$QCH4$ = annual methane generation in the year of the calculation (m^3/year)

i = 1-year time increment

n = (year of the calculation) - (initial year of waste acceptance)

j = 0.1-year time increment

k = methane generation rate ($year^{-1}$)

Lo = potential methane generation capacity (m^3/Mg)

Mi = mass of waste accepted in the i^{th} year (Mg)

tij = age of the j^{th} section of waste mass M_i accepted in the i^{th} year

7. Estimation of Methane Gas Generation Potential

The Scholl Canyon model was applied to estimate the energy potential of Madinah's landfill. Two steps were carried out to determine waste management options, that consisted of inputting:

1) field data to determine constants into Scholl Canyon model to determine gas generation under different waste management options for composting: and
2) accepted constants into model for comparison of results with field data.

To calculate landfill gas production. The different parameters were input into the model including greenhouse gas production constants from US EPA upper and lower limits for both wet and dry climates (US EPA, 2001), and Madinah's landfill site-specific parameters were applied. These compared the variation possible in landfill gas generation rates under two different waste management scenarios to investigate the impact of a composting program on gas generation.

- **Step 1: Site-Specific Inputs into Scholl Canyon Model**

  Although it is easy to input constants into this model in this step, it is much more demanding to input site and waste specific factors. Below the methane generation potentail (L_O) was calculated by using % degradable organic compound and the decay rate constant (K) inputs to determine these specific inputs.

- **Step 2: Calculating Methane Generation Potentail (L_O) of Kakia Landfill**

  To determine the site-specific value of (L_O) the following equation was applied (IPCC, 1996)

$$L_o\left(m^3 of \frac{methane}{tonne} of\ waste\right)^3 = MCF * DOC * DOC_F * \frac{16}{12} * F \quad (2)$$

Where:

MCF= methane correction factor (1=well managed landfill, it is assumed in our case 0.7).

DOC= degradable organic carbon (fraction).

DOC_F= fraction DOC dissimilated; and

F= fraction of methane in landfill gas (measurement at landfill has indicated a value of 56% CH_4 in biogas).

- **Determining Degradable Organic Carbon for Methane Generation Model**

The site-specific degradable organic carbon (DOC) is calculated based on IPCC (1996) formula (3), The inputs, into degradable organic carbon (DOC), Madinah waste stream are shown in Table (2).

$$\%\ DOC\ (by\ weight) = 0.4(A) + 0.17(B) + 0.15(C) + 0.3(D) \quad (3)$$

Where municipal solid waste consists of:

A= % paper and textiles;

B= % garden waste, park waste or other non-food organic putrescibles;

C= % food waste; and

D= % wood or straw.

According to equation (3), DOC content value of 13.02% was obtained based on the composition of waste, calculated from a weighted average of the carbon content of various components of the waste stream. the biodegradable fraction was calculated by using equation (3) that considers the state of decomposition. The average volatile lignin content 44.1% was employed in equation (4): this yields a figure of 0.82 dissimilated DOC.

DOC_F can be determined through the lignin content of the volatile solid (VS) (Tchobanoglous et al., 1993, pp.88)

$$DOC_F = 0.83 - 0.028\ LC \quad (4)$$

0.83 = empirical constant;

0.028 = empirical constant; and

LC= lignin content of the VS expressed as a percent of dry weight from leachate sample.

Using equation (2) and the data profiled in Table (4), the measured methane potential of 62.68m^3 of methane per tonne of waste (1.336 ft^3/lb) was obtained. This value is the first time to be calculated for landfill of Madinah City where the default values (170 kg methane per tonne of waste or 2.72 ft^3/lb) recommended, while it is different from the US EPA value by LandGEM model.

By entering data on the LandGEM worksheet that relate to the identity and size of the landfill being modeled, Landfill name or identifier: Madinah, Landfill open year: 2006, Landfill Closure Year: 2020, Waste design capacity: 12538000 short tons, Methane Generation Rate, K: 0.050 year^{-1}, Potential Methane Generation Capacity, L_0: 62.68m^3/Mg (based on classification of solid waste in Madinah), NMOC Concentration: 4000 ppm as hexane, Methane Content: 50% by volume, and Gases/Pollutants selected (Total Landfill Gas, Methane, Carbon Dioxide, and Non-methane organic Compounds-NMOC).

For the estimation of methane from the landfill sites, user specified inputs are used in the LandGEM model. The methane generation potential, (L_0) has been specified as a default value of 62.68 m^3/Mg, while the methane generation constant (k) has been specified as 0.050 per year. The methane and carbon dioxide in the LFG have been considered to be 50%.

As indicated in Figs. (6 and 7), it is ca concluded the estimation of Madinah's landfill gases in Mg/year for the period of 2003 to 20143 as following:

- Sum of landfill total gases = 1573854200 m^3/year,
- Sum of Methane = 881358352 m^3/year,
- Sum of Carbon Dioxide gas = 692495848 m^3/year, and
- Sum of NMOC = 6295416 m^3/year.

Summary and conclusion

In this article the evaluation of landfill biogas potential in Madinah City is performed in order to estimate the electricity that can be generated if the methane obtained from the Biogas is used as a fuel in a reciprocating combustion engine. The LandGEM model and the available data of the solid waste characteristics of the most important cities in Madinah City were used to quantify the potential methane generation obtained from the landfill of Madinah. Other models to predict the generation of landfill biogas as IPCC can be used; also in situ data from the landfills have to be obtained for better prediction of methane efficiency capture and production especially for the k and L_o parameters.

Madinah City has a high annual technical biogas potential. Unfortunately, this potential is currently unused. This would help Madinah City to reduce greenhouse gas emissions, increase the stability of the economy, open new work area and employment opportunities; as a result, sustainable energy production which could meet country´s rapidly increasing primary energy demand driven by increasing population. The results presented in this article could provide valuable information to the solid waste management industry, policy makers and investors.

Recommendations

1. Maximizing the benefits of the emitted enenrgy from Landfills.
2. Constructing A bioenergy system for solid waste landfill in Madinah.

Figures and Tables:

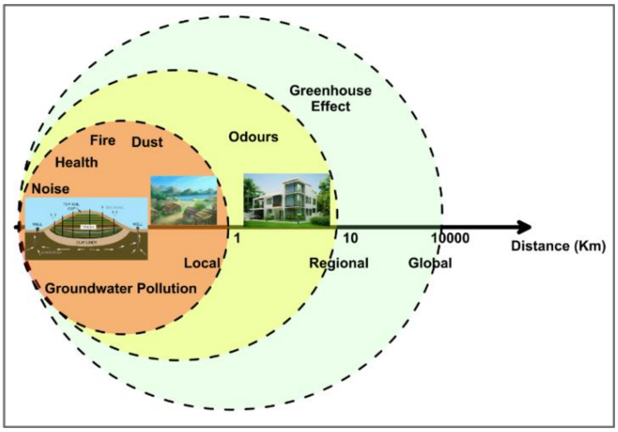

Fig. (1): The different scales of the impacts of gas from landfills (modified after Kjeldsen, 1996).

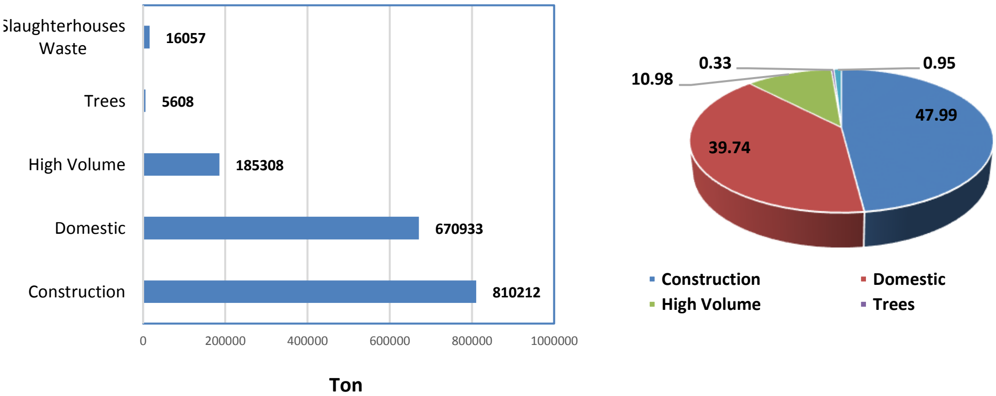

Fig. (2): Total quantities of waste generated in Madinah during 2017.

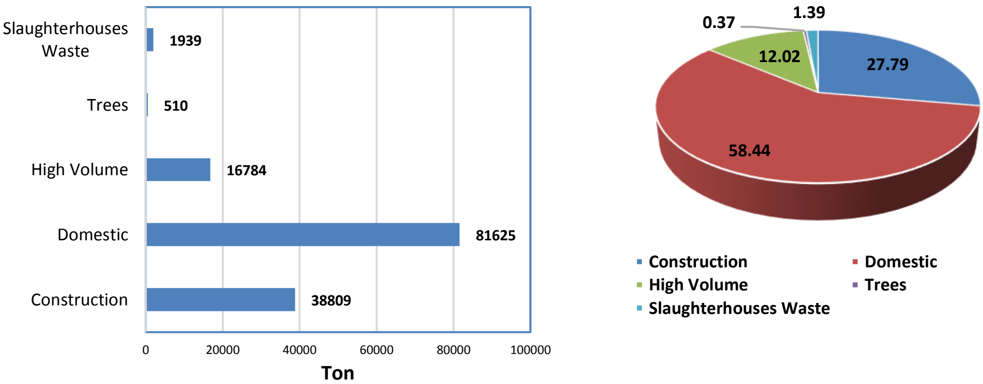

Fig. (3): Total quantities of waste generated in Madinah during Ramadan 2017.

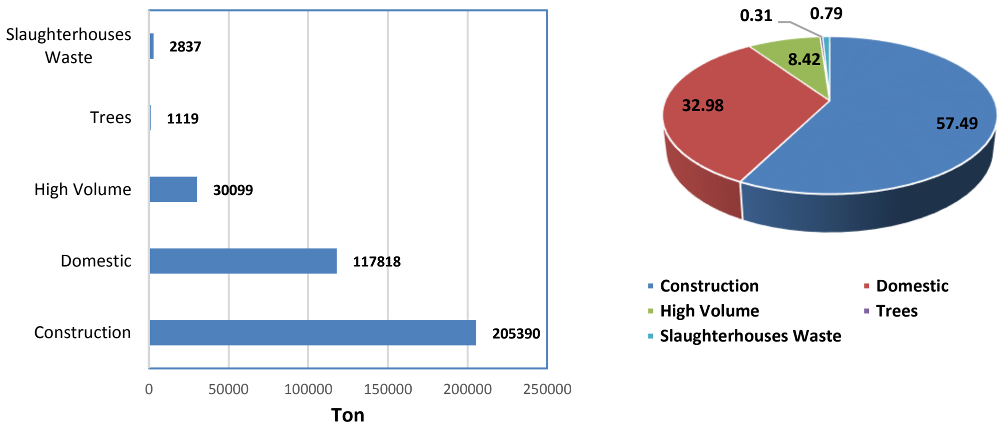

Fig. (4): Total quantities of waste generated in Madinah during Hajj 2017.

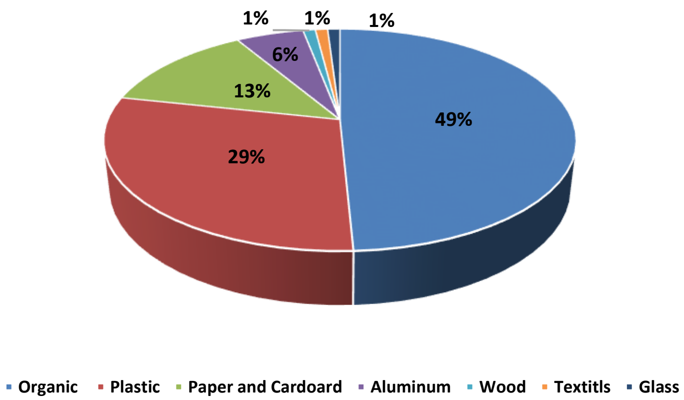

Fig. (5): Classification of solid waste in Madinah City.

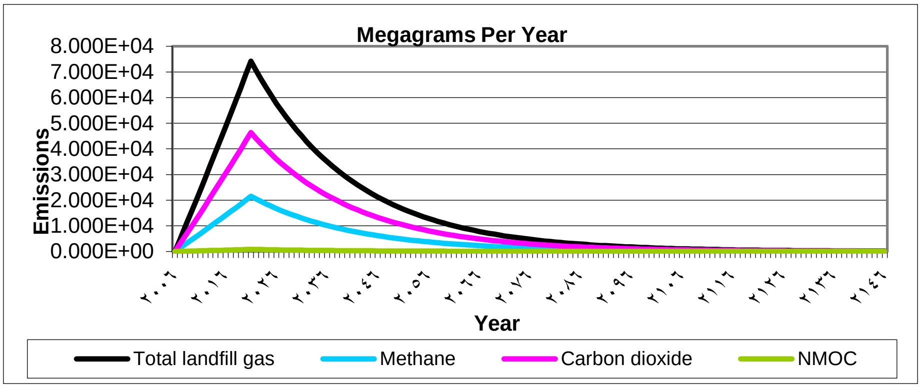

Fig. (6): Landfill gas emission estimation in Mg/year for Madinah's landfill utilizing LandGEM model for the years 2006-2020.

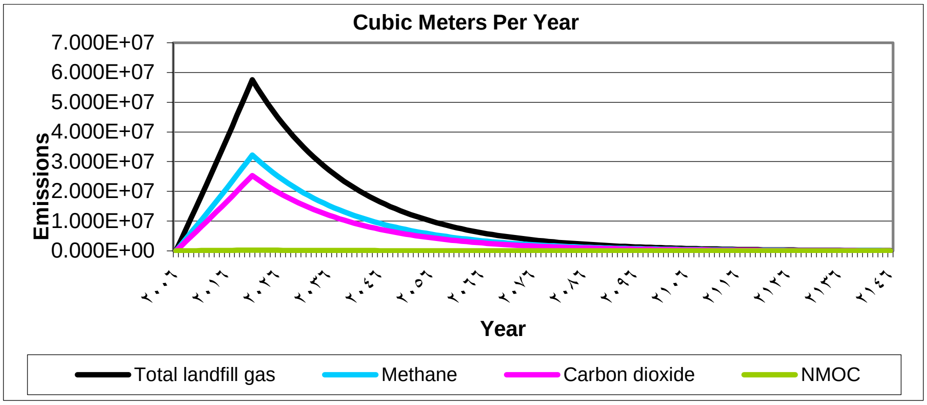

Fig. (7): Landfill gas emission estimation in m3/year for Madinah's landfill utilizing LandGEM model for the years 2006-2020.

Table (1): Typical landfill gas composition and characteristics (Ham, 1979).

Component	**Component % (dry volume basis)**
Methane	47.5
Carbon Dioxide	47.0
Nitrogen	3.7
Oxygen	0.8
Paraffin Hydrocarbons	0.1
Hydrogen	0.2
Hydrogen Sulfide	0.01
Carbon Monoxide	0.1
Trace Components	0.5
Characteristic	Value
Temperature (at source)	41 °C
Specific Gravity	1.04

Table (2): Average waste streams (%) in municipal solid waste (MSW) in Madinah's landfill.

Waste Stream	**% MSW (by weight)**
A: paper and textiles	13
B: Non food organic wastes	1
C: food waste	49
D: wood and straw waste	1
% $\boldsymbol{DOC}$ (by weight)	13.02

Table (3): The results for the determination of methane gas potential (L_o)

Category	**Input Parameters**				$\boldsymbol{L_o}$ $\left(\boldsymbol{m^3 of \frac{methane}{tonne} of\ waste}\right)$
	$\boldsymbol{MCF}$	$\boldsymbol{DOC}$ (%)	$\boldsymbol{DOC_F}$	(%)$\boldsymbol{F}$	
Result	0.8	0.1302	0.806	0.56	62.68

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