UTILIZATION OF LANDFILL GAS FOR ENERGY PRODUCTION AND RELEVANT TECHNOLOGY OPTIONS

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Abstract- Landfill biogas (LFG) is a natural byproduct of organic material anaerobic decomposition in municipal solid waste. LFG mostly contains 50 % methane and 50 % carbon dioxide with less than 1 %nonmethane organic compounds and trace of inorganic compounds (although the methane and carbon dioxide ratio depends on the type of refuse being disposed of. LFG is e potent heat trapping gas, but on the other hand, instead of escaping into the air, LFG can be captured and used as an energy source. This second way of LFG utilization would provide a lot of environmental and economic benefits. This paper estimates the potential of landfill gas recovery of the landfill of Tirana city and a short review of technology options used to recover energy by it producing heat and power.

Keywords- Landfill Biogas, Potential of Energy Recovery, Technology Options.

I. INTRODUCTION

In thelast years a lot of important regulations and legislative acts have been approved for wastes and special directives for some other topics in Albania (e.g. Law 9010/2003 on environmental management of solid waste, Law 9537/2006 on dangerous waste management, Law 8934/2002 on the protection of environment, National Strategy of solid waste management (2011), Law on integrated management of solid waste (2011), National plan of solid waste management (2011), etc.). According to the latter, integrated solid waste management (ISWM) is supported on hierarchy principle of waste management. But this hierarchy has not been applied in practice: e.g. actually none of methane emitted from landfills and open damps in Albania is captured and utilized as a source of renewable energy or to flare it. Globally methane emissions from landfill are generally considered to represent the major source of climate impact in the waste sector.

In year 2011 "National Strategy of solid waste management" is approved, which contains basic measures that lead MSW integrated management to ensure the sustainable management ofSW and environmental protection.

This strategy defines objectives to enable Albania to move towards meeting the environmental standards required for the EU accession and includes measures to improve waste management and reduce the risk to human health. Although the legal framework for this area is developed, these laws are often not followedby legal acts and targets set year after year to improve the situation of waste management. So actually the state in view of MSWM in our country is not good and in fact it seems the method of MSW disposal is mainly discharging it in open dumpsites and partially in landfills. The responsibility for MSW management is left to local authorities (municipalities and communes) in our country. Actually the disposal method of MSW is mainly sending it in open dumpsites and in landfills in some cities of Albania. One of these landfills is the dumpsite of Tirana city. Tirana is the capital and the biggest city in Albania. Tirana is the center of education, economy and culture of our country, which has undergone a huge demographic boom and economic growth in these last 20 years.

The amount of MSW generated in our country has increased greatly in comparison with the past (note that this study area suffers from a lack and inaccurate data, and currently there still is not an accurate database about the amounts of MSW generated for the over country).

The method of MSW disposal in Albania is mainly discharging it in open dumps and partially in landfills (ony in some cities). It seems, according to the NPWM, that MSW will be the only method of it disposal after collection process. These are some of the reasons that we will study the potential of LFG energy recovery for Tirana landfill, which is the biggest one in Albania up to now, and the technology options to make valuable LFG energy potential.

II. THE CHARACTERISTICS OF MSW GENERATED IN THE COUNTRY AND TIRANA CITY

MSW generated in Albania in total is about 825.000 tons/year (2012) or about 266 kg/capita/year, from which the organic matter in nationally level constitutes 47,36% and in total the percentage of biodegradable matter is about 62,3%, and in 2013 is 1.039.455 MSW tons and the amount of inert waste is 293.361 tons .

Tirana dumpsite, was opened in 1995, and it was an open dump used for solid waste disposal in Tirana

city until year 2008. In 2008 began the process of converting it in a sanitary landfill and this process is still going on, meanwhile the waste is disposed of in it. The total amount of MSW collected and disposed of in Tirana city in year 1997 was 87.140 tons: the average amount generated per day equaled 238,74 tons, and the daily amount generated per person was about 0,6 kg. In 2012 the annual total, average amount generated per day rose to 383.168 tons and 1049,77 tons, respectively. Before 2008 it was considered as one of the main causes of pollution in Tirana and a "hot spot" for the level of pollution caused by it. MSW is mainly composed of domestic refuse, road cleaning and market refuse, office, business, school refuse, as well as inert refuse, the rate of which is declining.

Landfills and open dumpsites pose a significant risk to human and environmental health. According to the Environment Report 2012, landfills are one of the largest sources of potential pollution in communities of all types and especially the organic waste disposed of is the main source of methane emissions in the air. This fact is related to typical MSW composition in our country since there is a very high percentage of organic matter in nationally municipal solid waste (47,36 %) and in total the percentage of biodegradable matter is about 62,3 % Methane produced at solid waste disposal sites contributes approximately 3-4 % to the annual global anthropogenic greenhouse gas emissions. LFG energy recovery projects can contribute to reduce emissions of GHGs, improve air quality; reduce environmental compliance costs; increase economic benefits through job creation and market development; conserve land, etc.

One of the objectives of national plan of waste management (NPWM, 2010) is the building of 12 regional MSW landfills. The regional landfills will create the possibilities to profit from the economy of scale: so it will be possible not only to install a LFG collection system and to flare it, but to use it for energy recovery. MSW management is an expensive service if it will be managed according to EU directives and in this framework energy recovery from LFG could create revenues for landfill owners; the individual cost of each municipality will be reduced and the possibilities to have higher service standards will increase. The first step of LFG recovery project is to determine if the landfill site is likely to produce enough methane to support an energy recovery project, than the next step is to estimate gas flow. The extracted LFG is of high calorific value and this is a good premise to use it as a source of renewable energy. Electricity generation technologies from LFG include reciprocating engines, but gas turbines, boiler/steam engines and combined cycles can also be used, which arepresented in this paper.

III. ESTIMATION OF ENERGY RECOVERY POTENTIAL OF TIRANA LANDFILL SITE

The landfill of Tirana city is the principal disposal site used by Tirana municipality to dispose of MSW. The landfill is located about 7 km southwest of Tirana center and the total surface of it is about 55.000 sq. meters. Its operation started as an open dump in 1995. Firstly it is operated as an uncontrolled open dump up to 2008 and it was considered as one of the main causes of pollution of Tirana, with constant open fires and deep fire burning at the site, assuming an average amount of 30.000 tons of waste burned per year [9]; (20-25 % of total amount this landfill site being near a great urban center and surrounded during the last few years by many illegal building (less than 200-300 m away from landfill), causes sanitary and ambient problems, constituting a high risk for the area population.

Waste was often exposed to the elements, vectors and scavengers and susceptible to open burning or combustion . Since 2008 the waste field of Sharra has been converting in a landfill and this process is still going on, meanwhile the waste is disposed of in it. This project is one of the largest one in the field of solid waste in our country. Up to the year 2012 are building some other landfills in Albania with a capacity smaller than Sharra landfill: Bushat landfill (Shkodër), landfill of Rrëshen, landfill of BajramCurri city and are studying the feasibility of some other regional landfills, about 12 over the country.

The solid waste growth rate is estimated to be for the period 2011 – 2015 approximately 2 % .

Actually none of methane emitted from landfills and open damps in Albania is captured and utilized as a source of renewable energy. Combusting captured methane to generate electricity produces two by products: water and CO_2. Carbon dioxide that is emitted from LFG energy projects is not considerably to contribute to global climate change because the carbon was contained in recently living biomass and would have been emitted through the natural decomposition process .

The total annual waste generated in Albania is about 825 000 tons or about 266 kg/capita/year, from which the organic matter in nationally municipal solid waste constitutes 47,36 % and in total the percentage of biodegradable matter is about 62,3% . While for Tirana city these percentages are respectively: organic waste 45,2 % and biodegradable waste: 64,9 % , and the waste composition for Tirana city is given in fig. 1.

The rates of LFG capture can be measured, but the rates of LFG generation in a landfill can’t be

measured. A model is used to estimate LFG generation. Collection efficiency is a measure of the ability of the gas collection system to capture the general LFG.

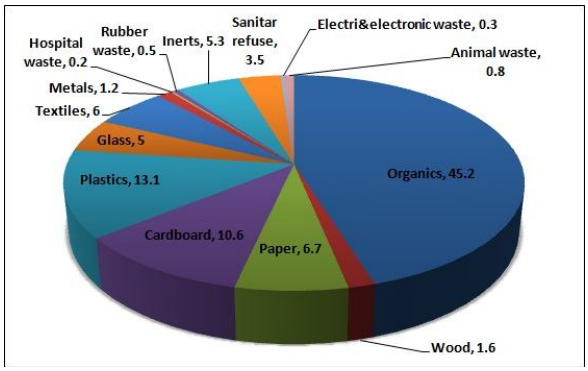


Figure 1: Waste composition for Tirana city (% by weight).

Estimation of methane emissions from landfill are generally made using a first order decay (FOD) model which calculates the rate of methane generation as proportional to waste input. LFG collection typically begins after a portion of the landfill is closed to additional waste placement.

To do this estimation, it needs to know some information of the landfill site, such as: a) the amounts of waste disposed at the landfill annually; b) the opening and closing years of landfill operation; c) the methane generation rate (k) constant; d) the potential methane generation capacity (L_o); e) the collection efficiency of the gas collection system and some other landfill features.

The Landfill Gas Emissions Model (LandGEM) is an automated estimation tool with a Microsoft Excel interface that can be used to estimate emission rates for total landfill gas (LFG), methane, carbon dioxide, nonmethane organic compounds, and individual air pollutants from municipal solid waste landfills [12]. The Colombia Model version 1.0 (2010) is selected in this study to estimate the LFG generation rate in a given year using the following first-order exponential equation, which was modified from the U.S.EPA's Landfill Emission Model (Land GEM) version 3.02 (EPA, 2005):

$$Q_{LFG} = \sum_{t=1}^{n} \sum_{j=0,1}^{1} 2kL_0 \left[\frac{M_i}{10}\right](e^{-kt_{ij}}) \cdot (MCF) \cdot (F) \quad (1)$$

in which:

- Q_{LFG}= maximum expected LFG generation flow rate (m^3/year);i = 1 year time increment;n = (year of calculation) – (initial year of waste acceptance);j = 0.1-year time increment;k = methane generation rate (1/year);L_o = potential methane generation capacity (m^3/Mg);M_i = mass of solid waste disposed in the i^{th} year (Mg);
- t_{ij} = age of the j^{th} section of waste mass M_i disposed in the i^{th} year (decimal years);MCF = methane correction factor;F = fire adjustment factor.

The total LFG generation, according to the model, is equal to two times the calculated methane amount. LFG generation is at its peak following a time lag representing the period prior to methane generation. The model assumes a six month time lag between placement of waste and LFG generation;, the model assumes that after six months LFG generation decreases exponentially as the organic waste is consumed. The year of maximum LFG generation normally occurs in the closure year or the year following closure (depending on the disposal rate in the final years) . Then the landfill biogas recovery rate is calculated by multiplying the calculated amount of biogas generation by collection efficiency estimating.
The model automatically assigns values for k and L_0 based on climate and waste composition data.

Total LFG generation for all wastes is calculated as the sum of the amounts of LFG generated by each of the four organic waste categories. The Model's calculation of LFG generation also include an adjustment to account for the degree to which wastes decay aerobically, known as the methane correction factor (MCF), and an adjustment to account for the extent to which the site has been impacted by fires (fire adjustment factor, F).

The inputs of site-specific data required by the model are: first year of disposal estimate is 1997 and the projected closure year is 2018 ; its capacity is enough for about 6-8 years ;due to active surface erosion in this area, both slopes of the valley are very steep with angles of about 40^o ; the climate of Tirana is classified as "Plain Mediterranean", by a dry summer and a wet, relatively cold winter: the average rainfall is around 1247 mm/year with most rain during the period October-February (about 70-75 %) .Table 1 presents the annual MSW rates disposed of up to 2012 and the estimated disposal rates from 2013-2018 are calculating by the model (in metric tons), assuming the annual solid waste growth rate 2%.

Table 1 MSW generated in Tirana in years (in metric tons).

Year	**1997**	**1998**	**1999**	**2000**
MSW (tons)	87.140	96.869	140.097	170.077
Year	**2001**	**2002**	**2003**	**2004**
MSW (tons)	186.907	169.180	217.650	282.518
Year	**2005**	**2006**	**2007**	**2008**
MSW (tons)	250.606	300.979	373.685	594.188
Year	**2009**	**2010**	**2011**	**2012**
MSW (tons)	327.237	340.506	414.377	383.168

The values for some of model input variables for LFG projections are:
annual precipitation (mm/year): moderately wet:1247; estimated growth in annual disposal: 2 %; average landfill depth:10 m; percentage of landfill area impacted by fire:30 %; percentage of waste area to be covered with wells: 100 %; percentage of waste area with final cover:80 %; percentage of waste area with intermediate cover: 0 %; percentage of waste area with daily cover:0 %; percentage of waste area with no cover: 20 %; percentage of waste area with clay cover:50 %; the waste is compacted on a regular basis; methane volume content: 50 %; collection efficiency estimate:74 % (due to different calculated causes listed above); MSW in total: 335 184 metric tons.

The values for L_o and k parameters, calculated, by model, for four waste groups, are as following:

CH4 generation rate constant k for:
- Fast decay: 0,26
- Moderately decay: 0,120
- Moderately slow decay: 0,048
- Slow decay: 0,024

CH_4 generation potential L_o (in m^3/Mg), for:
- Fast decay: 56
- Moderately decay: 99
- Moderately slow decay: 129
- Slow decay: 160

IV. THE POTENTIAL OF LFG GENERATION AND RECOVERY

The projected LFG generation and recovery for Sharra Landfill site is given in Figure 3.

The detailed calculation of predicted LFG recovery biogas quantity, maximum power plant capacity and power generation are represented in the following table 2.

The peaking value of LFG can be recovered is 2950 m^3/hour, in the second assumed year after closure and installation of collecting system.

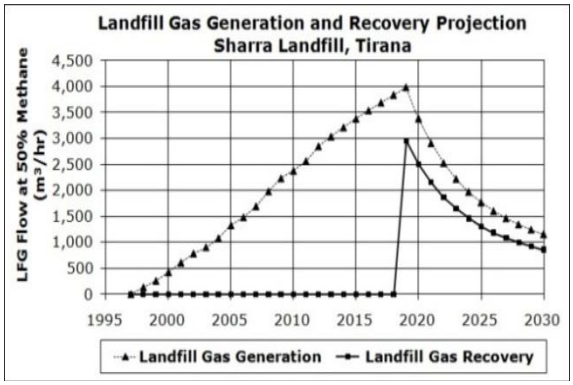


Figure 2 Projected LFG generation and recovery for Tirana landfill site.

V. TECHNOLOGY OPTIONS OF LFG ENERGY RECOVERY

The selecting of appropriate management option of LFG use depends of the contained methane ratio. Electricity may be generated by LFG of a minimum of 35% methane content. The technical limit of LFG flare operation is 20% of methane content per volume, while there is an another opinion about flaring of LFG in the literature, e.g. the percentage of methane to be flared is 20-25% . The purpose of LFG flaring is to safely dispose of the flammable constituents of it and to control odor nuisance, health risks and other environmental impacts.

Table 2 Predicted LFG recovery, maximum power plant capacity and power generation for Tirana landfill site.

Year	Predicted LFG recovery biogas (m^3/h)	Max. Power Plant Capacity (MW)	Power Generation GWh/year
2018	2842	8,0	57,60
2019	2950	8,3	59,76
2020	2506	7,0	50,40
2021	2153	6,1	43,92
2022	1871	5,3	38,16
2023	1644	4,6	33,12
2024	1460	4,1	29,52
2025	1310	3,7	26,64
2026	1186	3,3	23,76
2027	1082	3,0	21,60
2028	995	2,8	20,16
2029	921	2,6	18,72
2030	856	2,4	17,28
2031	801	2,3	16,56
2032	751	2,1	15,12
2033	707	2,0	14,40
2034	668	1,9	13,68

Electricity produced from landfill gas is classified as a renewable energy source.

Utilization of the recuperated biogas in the MSW sites is considered as an effective process not only for treating organic wastes, but providing at the same time a significant amount of electric power.

Energy recovery projects with LFG, usingthe appropriate technologies that capture methane (CH4) from MSW landfills, prevents it from being emitted to the atmosphere, and using it to produce various forms of energy, including electricity, boiler fuel, steam, alternate vehicle fuel, and pipeline quality gas.

LFG energy projects employ proven technologies to capture LFG, a product of solid waste decomposition in landfills that contains approximately 50 percent $CH_4$and 50 % (CO_2), both of which are greenhouse gases (GHGs). The low heat value of typical unprocessed LFG (50%CH_4/50%CO_2) is roughly 16,8 MJ/m^3 and represent a good source of energy.

An LFG energy project can reduce CH_4 emissions from a landfill by between 60 and 90 %, depending

on project design and effectiveness e.g. the annual CH_4 (landfill methane) and CO_2(avoided fossil fuel usage) emission reductions of a typical 3-MW electricity generation project using LFG is about 34.700 metric tons of carbon equivalent per year, the environmental equivalent of the CO_2emissions from nearly 296.000 barrels of oil consumed. The annual $CH_4$and CO_2 emission reductions of a typical direct-use LFG energyproject using 1.000 scf per minute of LFG is nearly 32.300 metric tons of carbon equivalent per year, the environmental equivalent of the CO_2 emissionsfrom more than 13,3 million gallons of gasoline consumed.

Technologies for converting LFG into energy include: Electricity generation: this form of energy can be achieved using a variety of technologies, such as reciprocating internal combustion engines (RICE), gas turbines (GT) and microturbines, with 85 % of LFG electricity generation projects using RICE or GT. One million tons of landfilled MSW can produce an electricity generation capacity of 0.8 MW.

RIC engines represent the most used technology to produce electricity from LFG because of their relatively low cost, high efficiency, and good size match with the gas output of many landfills. RICE have generally been used at sites where gas quantity is capable of producing 800 kilowatts (kW) to 3 MW, or where sustainable LFG flow rates to the engines are approximately 0,4 to 1,6 million cubic feet per day at 50 %t methane. Multiple engines can be combined together for projects larger than 3 MW. The two types of RICE are: spark ignition engines (SIE) and dual–fuel engines (DFE). The SIE have simpler construction, while DFE produce higher emissions than SIE. Therefore more than 98% of RIC engines are SIE type. RIC engines characterize by a noise level 80-110 dB and their efficiency varies in the range of 25 to 35%. RICE can be used in combined heat and power plants (VHP), which have higher energy efficiency than the simple plants.

Gas turbines (GT) are the second most used technology used to recover energy from LFG and typically used in larger LFG energy projects, where LFG volumes are sufficient to generate a minimum of 3 MW, and typically more than 5 MW (i.e., where gas flows exceed a minimum of 2 million cfd .

GT plants can achieve efficiencies of 20 to 28 % at full load; but, these efficiencies drop substantially when the unit is running at partial load.

One of their essentially disadvantages of gas turbines is that they require high gas compression (about 11 bar-a or greater), causing high parasitic load loss. On the other hand, the advantages of gas turbines are that they are more resistant to corrosion damage than internal combustion engines, have lower nitrogen oxides emission rates, are relatively compact and have low operations and management costs compared to RICE.

Another technology options to produce electricity from LFG is Organic Rankine Cycle engine (ORC), which may represent a technically alternative in the range 1-3 MW. Although their advantages related to limited emissions, etc., they have high capital cost and are sensitive to ambient air temperature variations.

LFG direct use to produce thermal heat: This is the simplest method and most effective as a fuel for boiler or in industrial process use (in dryers and kilns) as a replacement or supplementary fuel, transmitting LFG via pipeline to be combusted by the end user. Boiler systems are only effective at verylarge landfills with sufficient LFG for over 10 MW-20 MW. A potential problem for boilers is the accumulation of siloxanes. The presence of siloxanes in the LFG causes a white substance to build up on the boiler tubes. Operators who experience this problem typically choose to perform routine cleaning of the boiler tubes. Boiler operators may also choose to install a gas treatment system to reduce the amount of siloxanes in the LFG prior to delivery to the boiler.

An efficient application of LFG is using it in infrared heating of facility space and in greenhouses when they are located near a landfill.

One specific type of LFG use is as a fuel source for combined heat and power (CHP) or cogeneration systems that generate both electricity and thermal energy. CHP systems can achieve substantially higher efficiencies than separate heat and power systems that do not use the waste heat produced in electricity generation. CHP is often a better economic option for end users located near the landfill or for projects where the end user requires both electricity and waste heat.

Alternative fuel: LFG can be used to heat the boilers in plants that produce biofuels including biodiesel and ethanol. In this case, LFG is used directly as a fuel to offset another fossil fuel. Alternatively, LFG can be used as feedstock when it is converted to methanol for biodiesel production**.**

Generally, production and quality of the biogas are influence by several factors such as temperature, moisture content, waste composition and diversity of substrates for microbial degradation. There are possibilities to upgrade the landfill gas to a nearly 100% methane content, although it has high costs, after which it can be distributed through the natural gas distribution network.

The use of biogas as a fuel source is environmentally sound because it contributes to a reduction of fossil

fuel use and mitigates the greenhouse effect. In particular, the emissions of CH_4, one of the two greenhouse gases emitted, are almost 21 times more dangerous than CO_2 for the greenhouse effect .

Another application of LFG is to be converted it to vehicle fuel, which can be achieved using LFG to produce compressed natural gas (CNG), liquefied natural gas (LNG) or methanol. This process requires to remove CO_2 and other traces impurities from LFG to produce a high grade fuel with least 90% CH_4. Methanol can be used for vehicle fuel or as a chemical feedstock, with reduced emissions in comparison to gasoline and diesel fuels .

Use of LFG to evaporate landfill leachate: LFG can be used for this application when leachate and condensate disposal are too expensive. There are several variations of leachate evaporator systems, which only differ in the methods used to transfer heat to leachate and how the exhaust vapor is treated. The leachate evaporation can be realized in evaporators in different sizes able to treat about 38 to 105 cubic meter per day of leachate.

In particular, the emissions of CH4, one of the two greenhouse gases emitted, are almost 21 times more dangerous than carbon dioxide for the greenhouse effect,

Some characteristics for LFG electricity production technologies [22] for:

1) Reciprocating internal engine:
   - Electric efficiency 33%
   - Fuel consumption (kJ/kWh) 10.972
   - Emissions (μg/kJ):
     - NO_x 56,6
     - CO 56,6
2) Gas turbine:
   - Electric efficiency 28%
   - Fuel consumption (kJ/kWh) 12.872
   - Emissions (μg/kJ):
     - NO_x 15
     - CO 19
3) Organic Rankine cycle:
   - Electric efficiency 18%
   - Fuel consumption (kJ/kWh) 19.202
   - Emissions (μg/kJ):
     - NO_x 16
     - CO 18,9

CONLUSION

Although test wells provide real data on the site's LFG production rate at a particular time, models of gas production predict gas generation during the site filling period and after closure.The theoretical estimation of potential of LFG energy recovery and methane gas emissions from Tirana landfill site, using the first order decay model, predicted the time as peak production as occurring in 2019;the total peak annual methane recovery:2950 metric tons, and the predicted peak production of plant power capacity and power generation was respectively 8,3 MW and 59,76 GWh/year.

LFG can be converted into useful forms of energy using a number of different processes. The selection of the appropriate conversion technology depends on a lot of factors. The most common beneficial use application of LFG energy projects are producing electricity. The most technology options to achieve, are internal combustion engines, gas turbines, organic Rankine cycle, CHP, etc. Internal combustion engines are the most technology used due to economical reasons, but they present the poorest environmental performance.

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