Potential For Energy Production From Landfill Methane In Bulgaria

Nikolai Vitkov
Faculty of Electrical Engineering,
Technical University of Sofia[1]
Sofia, Bulgaria
nvitkov@tu-sofia.bg

***Abstract* — The possibilities of processing the old MSW accumulated in the open landfills have been considered in order to minimize their long-term environmental impact on the air, water and soils, as well as the inevitable additional negative impacts on the environment in their processing. Some potential challenges and difficulties related to the accomplishment of this task are highlighted - transportation logistics, pre-treatment, recultivation of the terrains, as well as the possibilities for the implementation of the useful technologies of thermal processing. An approach is proposed to estimate the potential for the production of landfill methane from decommissioned landfills using the freely available Exel-based LandGem program of the US EPA. The quantitative potential for landfill methane production from the point of view of partial temporary diversification of fuel sources - methane in Bulgaria is analyzed. The technical and economic parameters of landfill methane capture projects are briefly summarized based on researched publications and good practices. The environmental benefits, environmental and processing risks of landfill methane capture and treatment in Bulgaria by different technologies are highlighted. Conclusions have been drawn on the feasibility of implementing landfill methane capture and processing projects in Bulgaria in terms of energy potential, economic effect, environmental effect and risk to health and safety of personnel and the population.**

Keywords* — *MSW, processing, landfill methane, environmental impact, energy potential, safety.

I. INTRODUCTION

Landfill methane treatment is the last applicable measure to reduce greenhouse gas emissions from landfilled old municipal solid waste (MSW) in Bulgaria when thermal treatment is not practicable.

II. MSW TREATMENT IN BULGARIA HEREAFTER

Open landfill is still a major way of treating (MSW) in Bulgaria with negative environmental impacts. In developed European countries, this method is minimized at the expense of industrial thermal processing technologies. Although Bulgaria has been a part of the EU for over 10 years and is an associate to waste management regulations, the application of industrial technologies is lagging behind. In recent years the first projects for MSW thermal treatment with predominantly European funding have been prepared and implemented in the big cities and tourist centers in Bulgaria. In the near future, the gradual decommissioning of the open landfills for permanent disposal on the territory of the country will be started.

The question arises as to what will be done with the waste in these landfills, which will continue to decompose and release methane into the atmosphere, as well as highly toxic leachate into soil and water over the next few decades. Modern technologies for thermal treatment of MSW allow minimizing the environmental impact - methane emissions, pollution by leachate and disturbance of terrains from old MSW. Thermal processing includes:

- loading and primary transportation of the waste in specialized trucks to pre-treatment plants;
- pre-treatment - separation, crushing, drying and baling of combustible non-recyclable waste named “Refuse Derived Fuel” (RDF);
- recycling of recyclable as material;
- composting of low calorific biodegradable ingredients with high humidity [4];
- secondary transportation of baled waste (RDF) to specialized installations or cement plants with non-specialized transport;
- gasification/incineration with or without energy recovery;
- disposal of the final product from gasification/incineration plants - slag and ash or adding to the cement clinker;
- reclamation of landfill sites.

III. MSW TREATMENT IN BULGARIA HEREAFTER

Transport from landfills to pre-treatment facilities with non-specialized transport is inadmissible, as it would lead to partial waste and infiltration spillage on and around roads, spreading odors and harmful bacteria, molds and parasites. Causes further pollution of the environment and would provoke fair protests by communities along the route. The provision of a sufficient number of specialized vehicles to be used for a limited time (until disposed MSW run short) is not always economically effective. Primary transportation and the loading and unloading activities of the waste lead to unavoidable greenhouse gas emissions, which depend primarily on the transport distance.

Pre-treatment of waste - separation, drying, internal transport, packaging and purification of by-products (gas and water treatment) is an automated industrial technological process accompanied by electricity consumption and also generates greenhouse emissions.

Secondary transportation of RDF to combustion plant adds more greenhouse emissions.

Thermal treatment of waste – incineration or gasification is the key useful process that allows the potential methane emissions from natural decomposition of waste to be replaced by carbon dioxide emissions. Thus reduces methane greenhouse effect by more than 20 times, produces useful energy that reduces the consumption of fossil fuels to produce the same amount of useful energy, and prevents carbon

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emissions from doing so. Installations for gas and dust purification, treatment of leachate, and disposal of end products - dust, ash, slag are also sources of greenhouse emissions.

Reclamation involves the excavation and transportation of contaminated soil for disposal in closed underground storage facilities (exhausted mining galleries / shafts) or the burial of a thick layer of excavated and brought clean soil. These activities are related to excavation, loading and unloading and transport activities - continuous operation of heavy earth moving and transport machines, i.e. greenhouse gas emissions.

In some cases, the transportation of old MSW from landfills for thermal processing may be unreasonable or difficult – with remote landfills, lack of adequate road infrastructure, lack of specialized vehicles and loading equipment, financial impossibility of municipalities etc.

Another important factor is the content of organic carbon in the waste – at low content i.e. calorific value, it is unsuitable for gasification/incineration [4], and the calorific value of waste decreases with age [4].

The capacity of processing facilities is usually chosen so that they can receive the MSW flow in a specific region – a regional center with its smaller municipalities, taking into account the development trend and population growth. If the amount of old waste landfilled were taken into account, it would result in the oversizing of the installation, which is economically inappropriate, because after a few years, the installation would operate with reduced capacity due to a lack of fuel. Economic logic would lead to the import RDF from neighboring regions or countries – i.e. a waste market would be created in Bulgaria.

Globally, RDF trading is a huge business, for instance a significant part of US MSW has been processed in China. The construction of higher capacity processing plants could absorb the old landfill and, when exhausted, to treat imported waste. This is possible in the areas of the large ports on Black sea or the Danube River. It would create the prospect of economic growth, job creation, etc.

Despite the economic logic, the mentality of the population would hardly allow Bulgaria to become an international waste processing center. An example of this is a number of negative publications in the Bulgarian media related to the import of RDF for the first private MSW processing plant in the region of Varna town and authority reactions to unregulated combustion of RDF in coal TPPs, tried to do this.

The foregoing suggests that a significant portion of the landfilled waste will hardly be processed in the coming years, i.e. it will remain landfilled and release methane emissions and leachate. Instead of incinerators, part of the old landfill could be burned in the cement plants after pre-processing, but logistical problems remain.

The reduction of methane emissions from old MSW that cannot be processed by gasification or incineration is possible in two ways - open burning or "burial" with landfill gas capture. Open burning is the simplest and cheapest method, but it is unacceptable because of its severe environmental effects and is not applied in Bulgaria. The alternative is to capture landfill gas and burn it with or without energy recovery.

IV. Landfill Assessment And Selection Of Technologies To Minimize The Environmental Effects Of Landfilled Waste

The selection of technology to minimize greenhouse gas emissions from landfills is possible after an individual assessment of each landfill. The most accurate assessment is achieved when verified software products are applied after analysis of samples [9]. Different software are available based on different calculation methods.

Free available are the EXEL based calculators developed for the United States Environmental Protection Agency (US EPA): "Solid Waste Emissions Estimation Tool" SWEET and "LandGEM". LandGEM requires a minimum of input data and works with firmly set parameters, adapted for MSW and US-specific climatic conditions. SWEET requires more and detailed input, enables the modeling of four different scenarios for each depot. It can be applied to forecast methane emissions from any particular landfill over a long period of time based on the amount of waste deposited in it, composition, age, history of annual deposited quantities, average temperature and humidity, etc. details. The SWEET program allows quantitative estimation of greenhouse gas emission reductions when applying the available MSW processing technologies, taking into account the additional generation of emissions from the entire technological process, including transportation, loading and unloading activities, etc. Both programs provide quantitative data on the emissions released in the process of waste decomposition. The software analysis allows the individual choice of the optimum technology for the treatment of landfilled MSW at each landfill, while minimizing methane and total carbon equivalent emissions.

When forecast for methane quantity generated in the next at least 20-25 years is enough large, combustion technologies can be applied to recover methane by utilizing energy from boilers, piston engines, or gas turbines to produce energy. Otherwise, the landfill gas caught could be burned without energy recovery. Refining the landfill gas to methane and compressing it as clean fuel is also possible, but expensive. If the projected greenhouse gas emissions from the waste are low and comparable emissions would be generated for the installation of a gas collection system, the only possible solution is to bury under a thick layer of soil without gas capture.

The implementation of landfill gas to energy micro-projects is an expensive initiative. International experience demonstrates the need for flexible multilateral financing with the participation of international, state, municipal and private investors, including insurance companies and emission traders, as well as subsidies in one form or another [3]. Difficulties may be encountered in the connection of generating capacities to the electrical power system and the commercial realization of the produced energy. The construction of such facilities implies an individual feasibility study of each potential project. The total number of permanent open MSW depots in Bulgaria as of 2017 is 104 and software analysis is quite possible in a short time.

V. Theoretical Energy Potential Of Landfill Methane In Bulgaria

A hypothetical scenario is considered in which all landfills for permanent landfill in Bulgaria are equipped with landfill gas capture systems and buried under a layer of soil at least 1 meter thick by 2020. The amount of methane generated in 2020 is determined as linear extrapolation of the base period. An approximate estimate of the maximum theoretical potential is made on the basis of the available statistical information [1] for the period 2007-2016, accepted as the base period Fig. 1.

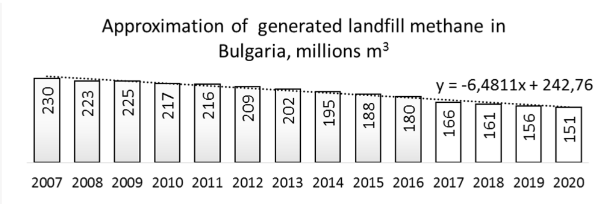

Fig. 1

In a scenario of hypothetical capture of 100% of the landfill methane generated in 2020, and a baseline of natural gas consumption [1], Fig. 2 in retrospect and extrapolated, it can be concluded that by 2020, landfill methane would cover about 5% of the country's natural gas needs, Fig. 3.

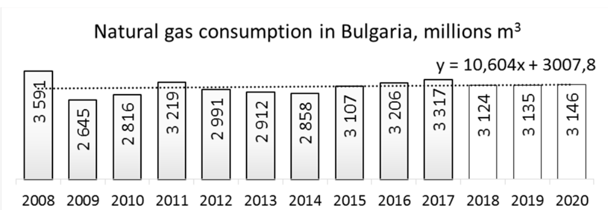

Fig. 2

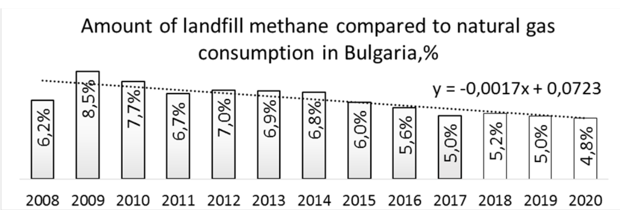

Fig. 3

However, landfills emit could be estimated of about 150-200 m^3/t of methane over the entire degradation cycle [10]. International experience of operating such installations showing capture of 50-80 m^3/t of MSW, i.e. in the order of 25-40% [10]. There are 50-90% capture projects reported, but they are rather exceptions [10]. Averaged capture efficiency of 33% was assumed for the calculations. Then, the actual potential methane capture by 2020 would cover about 1,58% of the natural gas needs, which is a negligible amount in terms of the potential for diversification of natural gas sources in Bulgaria, Figure 4.

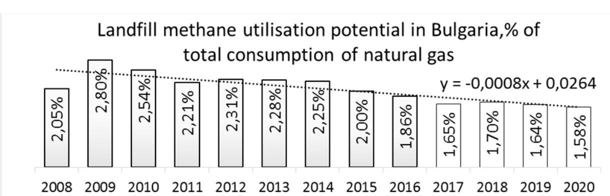

Fig. 4

At a lower calorific value of combustion of 47.44 MJ / kg, the theoretically generated energy from trapped landfill methane in retrospect [1], [2] and with extrapolation would be according to Fig. 5. Total generated energy in Bulgaria for the same period would be according to Fig. 6.

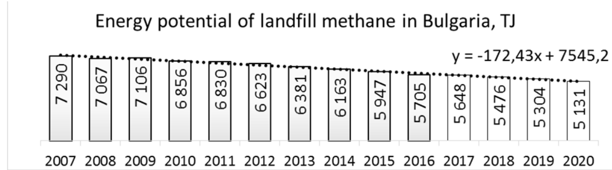

Fig. 5

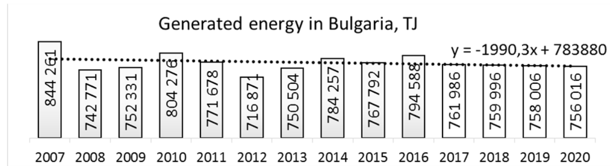

Fig. 6

The relative share of potentially produced energy from landfill methane compared to the total produced energy in Bulgaria would be according to Fig. 7 and for 2020 is about 0.68%, which is a negligible amount in terms of energy production.

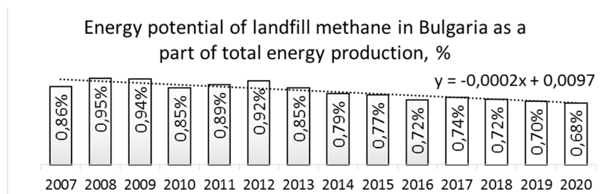

Fig. 7

VI. Technical And Economic Parameters Of Landfill Methane Processing Facilities

The most widely used technology for landfill gas capture is by installing a system of vertical perforated pipes in cylindrical beds of gravel, connected to horizontal collector pipes and a system for suction and transport of gas to a processing facility.

Applicable technologies for the direct processing of landfill methane to carbon dioxide are [7]:

- burning in an open torch or closed combustion chamber without energy recovery;
- combustion in steam boiler - electricity generation or co-generation;
- combustion in a piston engine - electricity generation or co-generation;
- combustion in an Integrated Combined Cycle – primary and secondary generation by gas and steam turbine;
- combustion in an Integrated Combined Cycle followed by Organic Rankin Cycle (ORC) – primary, secondary and tertiary electricity generation with gas and steam turbines + organic fluid steam turbine.

The applicable post-separation technologies after purifying of landfill gas to methane are [7]:

- compression and connection to the gas distribution network;
- compression in gas stations for refilling bottles for domestic use and vehicles;

- utilization in fuel cells.

The approximate costs of designing and installing a landfill gas capture and combustion chamber without energy recovery [3] are shown in Table 1.

TABLE I. COSTS OF DESIGNING AND INSTALLING

N	***Research and design***	***USD***
1	Research works	15 000 – 30 000
2	Landfill performance assessment – drilling, test pipes layout, measurements	40 000 – 70 000
3	Conceptual design, registrations, legalization	50 000
4	Technical project	10% of the investment
	Investments	***USD***
5	Pipe capture system	30 000 – 50 000/ha
6	Fans / compressors, dryers, filters, gas metering and control systems	75 – 200/(m^3/h)
7	Closed combustion chamber without energy recovery	40 – 80/(m^3/h)

The approximate costs of installing a power generation system according to the primary machine and purification technology [3] are presented in Table 2.

TABLE II. COSTS OF POWER GENERATION SYSTEM

№	***Generating power***	***USD***
1	Piston engine	1100 - 1700 / kWe installed capacity
2	Gas turbine	1000 / kWe installed capacity
3	Micro turbine	3000 - 5000 / kWe installed capacity
4	Boiler	30 - 50 / kWe installed capacity
5	Gas pipeline	100 - 125 / m
6	Infiltrate evaporation system	7000 - 10,000/(m^3 infiltrate/day)
7	Purification to pure methane	1800 - 4000/(m^3 landfill gas/h)

The estimated operating and maintenance costs [3] are presented in Table 3.

TABLE III. OPERATING AND MAINTENANCE COSTS

№	***Facilities***	***USD***
1	Electric power generation facilities	10 - 12% of the investment / year.
2	Evaporation of the infiltrate facilities	4 - 10 / m3 infiltrate
3	Purification plants to pure methane	17 - 21% of the investment / year.
4	Facilities without energy recovery	4 - 8% of the investment / year.

An example of determining methane emissions from the landfill of Razgrad district with a population of 112 972 inhabitants by 2018 is considered. The following initial data for analysis are adopted, Table 4.

TABLE IV. INITIAL DATA FOR ANALYSIS

Estimated amount of MSW deposited by 2020	855 709 t
Available statistics for landfill waste and landfill area - base period	2011 – 2017
Conditional period of operation of the landfill	2000 – 2020
The landfill is conditionally "buried" at 1meter thick soil layer	2020
Capture installation service life	2021 – 2050
A drainage system is installed to collect the infiltrate	
The accumulation of MSW and the landfill area outside the base period are determined by linear extrapolation, Fig. 8 and 9, [2]	
The amount of methane generated was calculated with the LandGEM program, Fig. 10	

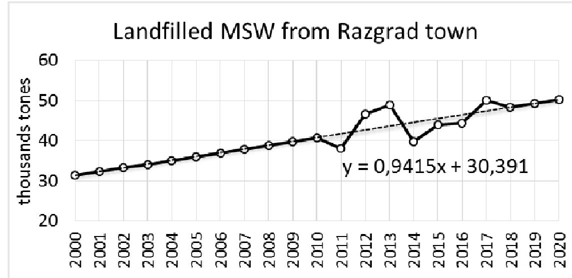

Fig. 8

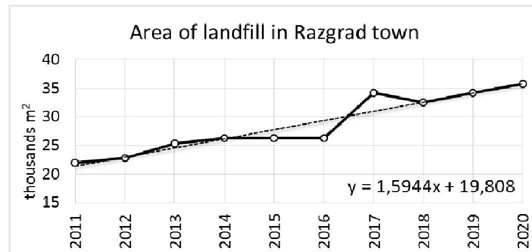

Fig. 9

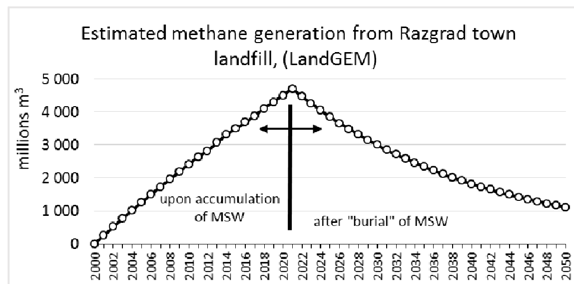

Fig. 10

An approximate feasibility study has been made for the installation for capturing the generated methane after covering the landfill with 1-meter soil layer, Table 5.

TABLE V. EQUIPMENT WITHOUT ENERGY RECOVERY

The minimum values in Table 1 and 3 are accepted except the position 6 in Table 1 where \$ 130 are accepted	
Landfill estimated area by 2020	3,58 ha
Computational thickness of the MSW layer by 2020	30 m
Capture efficiency of generated methane	33%
Earthworks, drilling and transportation calculated	196 636 USD
Gas pipeline length	300 m
Investments calculated	499 119 USD
Operating Costs and Maintenance calculated	19 965 USD/y

A simplified financial evaluation is shown in Fig. 11.

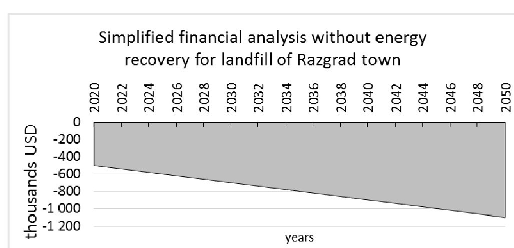

Fig. 11

For 30 years of lifetime with no revenue, the simplified costs amount is just over \$ 1,000,000, with 16,490 tones of methane being processed, which is equivalent to reducing carbon emissions of about 366 908 tones. The processing cost is about \$ 67/t methane.

Based on the minimum values in Table 2 and 3, the economic efficiency of a landfill methane processing plant with electricity production under the same operational conditions is estimated, taking in account Table 6.

TABLE VI. PLANT WITH ELECTRICITY PRODUCTION

Methane conversion factor	13,1 kWh/kg
Primary generating machines	piston engines
Total Installed Power	500 kW_e
Electric efficiency, P_e	35%
Operating life	30 years
Infiltrate evaporation system	yes
Investments	1 097 572 USD
Operating Costs and Maintenance	162 748 USD/y
Electricity sale price	70 USD/MWh

A simplified financial evaluation is shown in Fig. 12

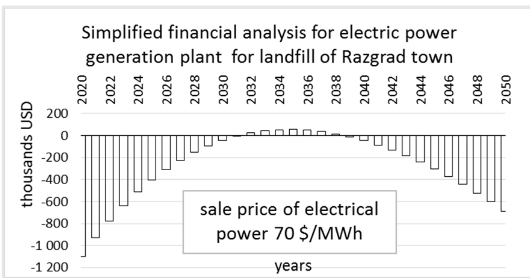

Fig. 12

Given the set parameters and the price of electricity of 70 USD per MWh, the investment is losing (-8 549 792 USD) for the operating period. If the 80 USD per MWh electricity price is set, the investment is a profitable Fig. 13, with revenue of 5 900 626 USD.

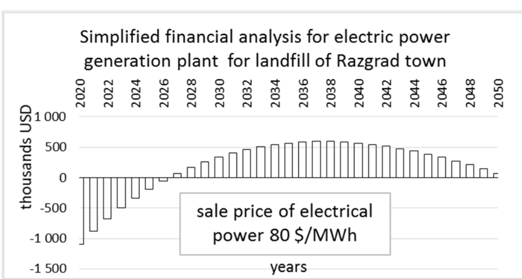

Fig. 13

This demonstrates the high sensitivity of such projects to the purchase price of the electricity produced and the need for individually accurate pre-project studies and the technical and economic evaluation of each landfill methane processing project. Particularly of these projects is the progressive reduction of primary fuel over time, which leads to incomplete use of the initially installed generating capacity, especially towards the end of the operational period, i.e. the installed power to energy ratio is low and has a negative impact on economic parameters. Emissions trading would increase the economic efficiency of installation. The electricity generated by years for the operating period is shown in Fig. 14, amounts to a total of 75 608 MWh, providing additional carbon savings from fossil fuel combustion, which is also a subject of emissions trading.

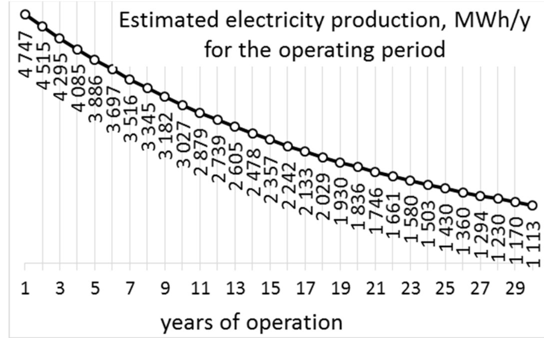

Fig. 14

VII. HAZARDOUS FACTORS OF WORKING AREA, ENVIRONMENTAL BENEFITS AND NEGATIVES FROM LANDFILL METHANE PROCESSING IN BULGARIA

The gas installation, gas pipelines and gas treatment plants operate with gas containing about 50% methane, i.e. they are explosive devices, the operation of which is accompanied by the risk of explosions and fires. Also the installation for evaporation of the leachate. There are also risks associated with CO poisoning from flue gases, burns on contact with hot surfaces, mechanical injuries from rotating parts, electrical injuries in the operation of landfill gas treatment plants, Table 7.

TABLE VII. HAZARDS IN PLANT WITH ELECTRICITY PRODUCTION

Operational process of landfill gas utilization	Fires	Gas Explosions	Gas Poisoning	Electrical. injuries	Burns	Mechanical traumas
Landfill gas capture and transportation	■	■				
Landfill gas purification	■	■				
Gas combustion	■				■	
Piston engine/gas turbine combustion			■		■	■
Electricity Generation				■	■	■
Flue gas cleaning			■	■	■	
Leachate Evaporation	■	■	■		■	

Explosion risks are possible in case of damage or leakage of equipment, non-compliance with technological instructions or human errors.

The potential positive environmental advantage of landfill methane capture and processing in Bulgaria is expected to reduce methane emissions from landfilled waste to about 30%, according to the sources surveyed. The rest 70% of the landfill methane remains greenhouse gas emissions. “Burial” of MSW minimizes the probability of fires and gassing. The lack of a waterproofing layer at the landfills in Bulgaria does not allow the installation of an effective system for capturing the leachate and implies the continuation of its leakage into the environment during the operation of the facilities. The technology does not allow reclamation of the affected areas.

VIII. CONCLUSIONS

The efficiency of landfill methane capture in Bulgaria is expected to be in the order of 30%. The expected energy potential of the captured methane is negligible in terms of overall energy production. Landfill methane capture installations without energy recovery are expected as losers and could only be financed through subsidies and trading in emission allowances. The installations for electric power generation highly depend on preferential price increases for electricity purchases.

The technology is dangerous and brings serious risks to operating personnel. The environmental effect is partial and only concerns the partly reduction of greenhouse gas emissions. Landfill gas incineration plants are economically unstable and long-term losers.

The study shows that the installation of landfill methane capture and treatment facilities could be viable only for environmental reasons, in the absence of other options for the treatment of landfilled waste.

The generation of electricity from landfill methane in Bulgaria is unpromising, the risks to staff are high and the environmental advantage are unsatisfactory.

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