COMPARISON OF STORED AND RENEWABLE ENERGY POTENTIALS IN LANDFILL CONDITIONS: CASE STUDY FOR KAUNAS WASTE MANAGEMENT REGION, LITHUANIA

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ABSTRACT: the object of the research was the Kaunas regional landfill. The assessment of the stored and renewable energy potential shows that the current period is characterized by a rather high annual energy potential of the landfill gas. The landfill also contains a large potential of solid recovered fuel. The annual wind energy potential is almost 5 times lower than the annual landfill gas potential, and solar energy or crops biomass energy potentials is almost 20 times lower. In this way, the production of renewable energy in the landfill would only be appropriate if the potential of the landfill gas and solid recovered fuel is fully exploited.

Keywords: landfills, landfill gas, solid recovered fuel, wind power plants, solar power plants, energy crops.

1. INTRODUCTION

There are up to half a million operating and closed landfills across Europe, with significant amounts of recyclable and energy-producing materials and potential for new economic activities. With the introduction of the principles of the circular economy, there is a growing interest in Europe and around the world in recovering of materials and energy resources from landfills. In this direction, research is carried out in the framework of various scientific programs (HORIZONE, INTERREG, COST, etc.) and preparations of dissertations. There is also an international consortium EURELCO, which coordinates the activities of business enterprises and academic institutions participating in this research process, in which Lithuanian research and study institutions, such as Kaunas University of Technology (KTU), Lithuanian Energy Institute (LEI) and Vytautas Magnus University (VDU), have successfully joined.

Amending EU Directive 1999/31 / EC on the landfill of waste (COM (2015) 0594 - C8-0384 / 2015 - 2015/0274 (COD)), it also mentions the recovery of recyclable materials, energy resources and space from landfills. In this way, in the EU countries by the end of 2025, it will be necessary to create digital maps and databases of the geographical locations (coordinates) of all landfills and the resources in those landfills.

When referring to the recovery of energy resources in a landfill using accumulated and chemically modified materials and the existing area, we mean the generation of landfill gas, the recovery of solid

recovered fuels or combustible materials suitable for pyrolysis, and the use of landfills for solar and wind power plants and biofuels (shrubs and grasses) plantations. Various scenarios for energy recovery from landfills are available here, the implementation of which would contribute to the implementation of the principles of the circular economy and the development of renewable energy sources. These scenarios would differ in their energy efficiency and environmental sustainability.

The object of the research was the Kaunas regional landfill, which has been in operation since 1973 and consists of two already closed and one operated section. Non-hazardous waste from Kaunas city and district and neighboring Kaišiadorys and Jonava districts is disposed of in the landfill. Landfill gas is extracted since 2012. Mixed solid waste was disposed of in this landfill until 2014, when the mechanical-biological treatment facility for mixed municipal waste started operating in Kaunas. Since then, the residues of the MBA process was removed at the landfill, and disposal of the bottom ash from the incineration of the combustible waste fraction has started when the Kaunas Cogeneration Power Plant starts operating in 2020. Current landfill area is 265 500 m^2, the high – 30 m.

The aim of this study:

- to assess the landfill gas extraction potential;
- to assess the potential of refuse derived fuel;
- to evaluate the possibilities of renewable energy production (solar, wind, biomass) in the reclaimed landfill after depletion of biogas and solid recovered fuel reserves;
- to compare these potentials with each other and assess the prospects for their future use;
- to propose several alternative scenarios for energy recovery from the landfill.

2. RESEARCH METHODOLOGY

Landfill gas extraction at Kaunas regional landfill (Fig.1.) was assessed according to the data of Kaunas Region Waste Management Center. Annual energy potentials of landfill gas in terms of heat and power generation efficiency $E_{LG\ heat}$ and $E_{LG\ power}$, MWh, calculated according to the formula:

$$E_{LG} = V_{LG} * 0,5 * LHV_{CH4} * \eta * 0,278 \quad (1)$$

where
V_{LG} - landfill gas volume, thousand m^3 per year;
0,5 – typical share of methane CH_4 in the landfill gas;
LHV_{CH4} - net calorific value of methane, MJ/m^3, equal to 35,88 MJ/m^3;
η – energy generation efficiency, for heat 0,6, for power 0,3;
0,278 – conversion factor from GJ to MWh.

Data on the composition and properties (including calorific value) of combustible waste fractions (considered as **refuse derived fuel** - RDF) accumulated in the landfill to a depth of 10 m, were taken from the report of trilateral research project “Feasibilities and Sustainability for Energy Resource Recovery from LANDfills (ISLAND)”, jointly developed by Kaunas University of Technology, Lithuanian Energy Institute and Vytautas Magnus University. The potential of RDF E_{RDF}, MWh, in terms of heat and electricity production was calculated according to the formula:

$$E_{RDF} = (S*h/3)*d*RDF*LHV_{RDF}* \eta * 0.278 * 10^{-6} \quad (2)$$

where
S – landfill area, m^2;
h - the height of the landfill planned to be excavated, m;

RDF – share of RDF in excavated material, %;
LHV_{RDF} - low calorific value of RDF, MJ/kg;
η – energy generation efficiency, for heat 0.6, for power 0.3;
0.278 – conversion factor from GJ to MWh.

The possibilities of installing **energy crops plantations** in a landfill were assessed. Annual energy potential of plantations E_{crops}, MWh have been calculated as follow:

$$E_{crops} = S*B_{pr}*LHV_{crops}* \eta* 0.278 * 10^{-6} \quad (3)$$

Where
S – landfill area, m^2;
B_{pr} – crops biomass productivity, t / ha;
LHV_{crops} - low calorific value of crop biomass, MJ/kg;
η – energy generation efficiency, for heat 0.6, for power 0.3;
0.278 – conversion factor from GJ to MWh.

Annual **wind energy** potential E_{wind} have been calculated as follow:

$$E_{wind} = n * C_{tot} * (\rho * A_{blade} * V^3/2)* t \quad (4)$$

where
n- number of wind turbines instaled on the landfill;
C_{tot} - overall energy efficiency ratio, the value is usually 0.3−0.5;
ρ – air density, kg/m^3;
A_{blade} - area of wind turbine blades flowing through the air stream, m^2;
V – wind speed, m/s
t - wind farm operating hours per year

Annual **solar energy** potential E_{solar} have been calculated as follow:

$$E_{solar} = A_{modules} *r * H * PR \quad (5)$$

where
$A_{modules}$ - total area of solar modules, m^2;
r – efficiency factor (0.11-0.13)
H - average annual solar radiation for inclined panels (shadows not included), kWh / m^2;
PR - loss ratios (0.5-0.9)

Figure 1. Kaunas regional landfill – remediated and exploited sections

3. RESULTS

3.1 Landfill gas potential

Calculated landfill gas energetic potential is presented in the Table 1. Until 2018, a slight increase is observed, followed by a similar decline. Only 2019 is characterized by a somewhat extreme fall compared to next year.

Table 1. Landfill gas utilization potential for heat and electricity production, MWh, from 2009 to 2021 m. (Kaunas regional landfill, LT)

Year	V_{LG}, m^3	$E_{LG\ heat}$, MWh	$E_{LG\ power}$, MWh
2012	5,740,561	17,178	8,589
2013	7,239,068	21,662	10,831
2014	6,803,209	20,358	10,179
2015	6,404,491	19,165	9,582
2016	7,715,507	23,088	11,544
2017	8,133,255	24,338	12,169
2018	7,756,105	23,209	11,605
2019	578,266	1,730	865
2020	6,146,994	18,394	9,197
2021	6,126,086	18,332	9,166

3.2 RDF potential

After analysis of waste samples taken from Kaunas regional landfill wells, it was found that the average density of the removed waste is 220.56 kg/m^3, the share of RDF (mainly plastics and textiles) in the waste is 14.81% and its average calorific value is 15 229 kJ/kg. Since the accumulated amount of RDF is 86 725 tons, the calculated total RDF energy potentials for heat and power are correspondingly **220 300 GWh** and **110 150 GWh**.

3.3 Solid biofuel potential

The energy potential of crops like sida, elephant grass, cup plant, reed stripe and fiber hemps were assessed for Kaunas regional landfill. The greatest energy potential is characteristic for elekphant grass, lowest – for cup plant. The assessment data are presented in the Table 2.

Table 2. Possibilities of biofuel production by installing energy plantations in Kaunas regional landfill, LT

Energy crop	Annual crops mass in the landfill, tons DM	Energetic value, GJ	$E_{crops\ heat}$, MWh	$E_{crops\ power}$, MWh
Sida *Sida hermaphordita*	268	4663.2	777.26	388.63
Elephant grass *Miscanthus sinensis*	670	11926	1987.83	993.91
Cup plant *Dactylis glomerata L.*	134	2291.4	381.93	190.97
Reed stripe *Phalaris arundinacea*	139.36	2424.9	404.18	202.09
Fiber hemps *Canabis ruderalis*	214.4	3987.8	664.69	332.34

3.4 Wind energy potential

The power energy potential of wind was assessed for Kaunas regional landfill. The greatest energy potential would be characteristic for wind speed of 6 m/s. The assessment data are presented in the Table 3.

Table 3. Seasonal electricity generation possibilities for installing wind power plants in Kaunas regional landfill, LT

Dominant wind speeds V>5 m/s	Wind blowing time of V> 5m/s , h/year	Power energy can be produced E_{wind}, MWh
5	1324	453
6	744	497
7	332	383
9	149	273
10	57	156
11	19	74
12	9	48
14	2	14
	Total:	**Total:**
	2636	**1,899**

3.5 Solar energy potential

The power energy potential of solar was assessed for Kaunas regional landfill. The greatest energy

potential would be characteristic from April till September. The assessment data are presented in the Table 3.

Table 4. Seasonal possibilities of electricity generation by installing solar power plants at Kaunas regional landfill, LT

Month	Solar radiation H, kWh/m^2	Seasonal distribution, %	Duration of sunlight, h	Solar energy can be generated E_{solar}, MWh
January	24.03	2.23	42.1	10
February	36.18	3.37	63.4	16
March	80.92	7.53	141.8	35
April	117.28	10.91	205.5	51
May	156.94	14.60	275	68
June	155.51	14.46	272.5	67
July	158.14	14.71	277.1	68
August	145.30	13.51	254.6	63
September	100.44	9.34	176	43
October	60.49	5.63	106	26
November	21.51	2.00	37.7	9
December	18.43	1.71	32.3	8
Total:	**1075**	**100**	**1884**	**464**

4. CONCLUSIONS

After the assessment of the energy potential of the Kaunas regional landfill, it becomes clear that the current period is characterized by a rather high annual energy potential of the landfill gas in terms of possible heat and electricity production - about 18,400 MWh and 9,200 MWh, respectively. The landfill also contains 86,725 tons of combustible waste, so the potential of solid recovered fuels for heat and electricity is 220,300 GWh and 110,150 GWh, respectively. The annual wind energy potential is almost 5 times lower than the annual landfill gas potential, and solar energy or crops biomass energy potentials is almost 20 times lower. In this way, the production of renewable energy in the landfill would only be appropriate if the potential of the landfill gas and solid recovered fuel is fully exploited. Power generation in wind power plants could be combined with alternatives to solar modules and biomass plantations.

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