



Full Length Article

Technical and economic challenges for landfill gas utilization using different energy generation technologies

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ARTICLE INFO

Keywords:

Landfill gas
Power production
Fuel cell
Internal combustion engine

ABSTRACT

Solid municipal waste disposal and wastewater treatment are important issues in the modern urban economy. Landfill gas can be considered as both a harmful air pollutant and a valuable fuel. However incineration was the most widespread way to prevent methane and hydrogen sulfide release into the atmosphere. The feasibility of various energy-related technologies including internal combustion engines and fuel cells for landfill gas utilization to produce electricity and heat was evaluated in terms of capital and operation expenses, lifetime, air pollution, and cogeneration possibility. The specific cost of energy was used as a criterion for technologies comparison. The calculation technique involved a mass and energy balance, including the pretreatment of landfill gas. Expenses related to the replacement of key components after the end-of-life and the payments for air pollutant emissions were also taken into account. The calculations were verified for the Timokhovo landfill (Moscow region, Russia), where five 2 MW gas-piston engines operating on biogas are currently installed. The gross and technical energy potentials of landfill gas in the Russian Federation were estimated and presented in the form of maps using QGIS software.

1. Introduction

Energy demand and environmental issues associated with the landfill gas utilization from municipal solid waste sites and sewage gas from wastewater treatment plants are constantly increasing with growing population [1–3]. These gases produced by the waste organic fraction anaerobic digestion are specific renewable energy sources located near small and large settlements. After 8–10 years of storage, organic waste starts to produce sustainably methane-rich landfill gas, which typically contains 40–60 vol% CH₄ and balance CO₂, as well as minor amounts of hydrogen sulfide, siloxanes, halides, ammonia, volatile organic compounds, and other contaminants. Landfill and sewage gases must be collected and defused/utilized, as they contain toxic components and pose explosion risks [4]. On the other hand, these gases can be considered as a sort of renewable calorific fuel [1,5], the utilization of which increases settlement energy efficiency and decreases environmental pollution by reducing methane emissions.

Heat can be generated in landfill gas-fired boilers, whereas appliances used for electricity or combined heat and power (CHP) production include reciprocating internal combustion engines (RICEs), gas turbines and microturbines (MGTs), solid oxide fuel cells (SOFCs), and molten-carbonate fuel cells (MCFCs) [1,6–8]. The former two are characterized by lower efficiency. Nevertheless, RICE is the most popular technology in this field due to its relatively low capital costs. NO_x generation and maintenance issues may, however, present a problem. MGTs offer potentially lower emissions, lower maintenance costs, and better mobility than RICEs [9]. SOFCs and MCFCs operating at elevated temperatures (≥ 600°C) show high efficiencies and allow using hydrogen, CO, and methane as fuels with no NO_x emissions [7,10–13]. An additional advantage of the MCFC concept is the possibility of CO₂ capturing [14]. Hybrid fuel cell – MGT systems achieve even higher efficiencies [15].

All of the aforementioned technologies imply that, prior to use, landfill or sewage gases must be purified from contaminants, especially

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<https://doi.org/10.1016/j.fuel.2026.139545>

Received 19 November 2025; Received in revised form 14 April 2026; Accepted 16 April 2026

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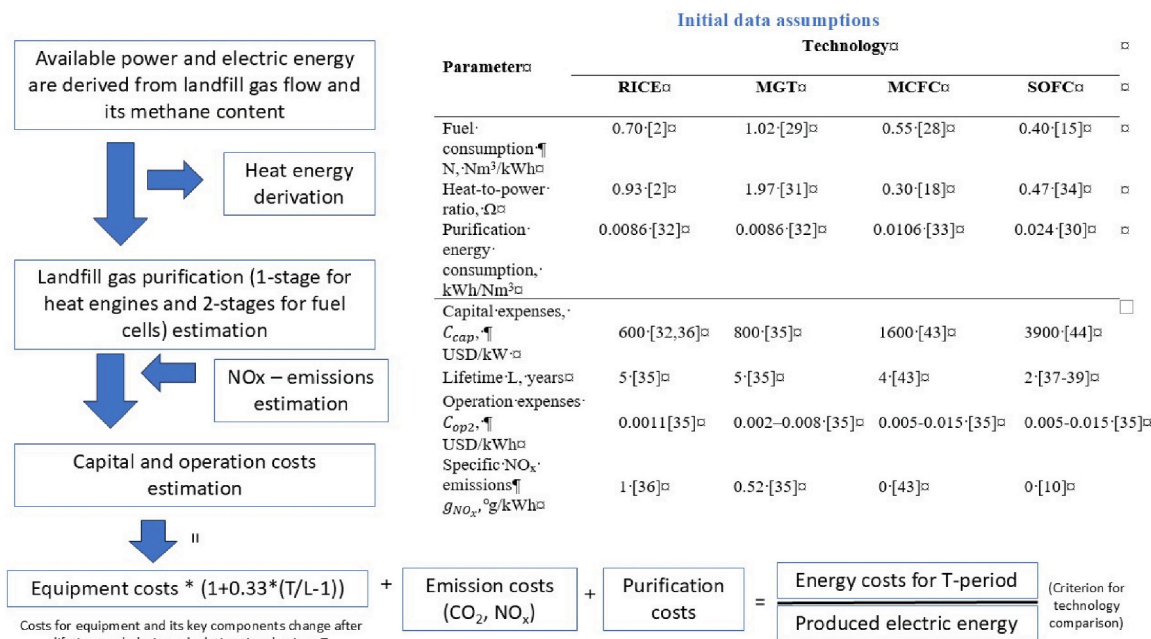


Fig. 1. Calculation flowchart and initial data.

H₂S and siloxanes. These contaminants drastically decrease the lifetime of power units due to the corrosion of components, the formation of an abrasive solid phase, and the poisoning of fuel cell anodes [6,7,16,17]. In addition, the presence of some contaminants in the fuel may cause emissions of hazardous compounds into the atmosphere. The purification process and degree depend on the utilization technology. The most expensive fuel pretreatment procedures are necessary for fuel cells, while for internal combustion engines these costs are lower [6,18].

There is an increasing number of literature reports devoted to both theoretical modeling and experimental studies of various technologies, from heat engines to fuel cells fed by biogas or biomass gasification products (e.g., [15,19–23]) derived mainly from agricultural waste. However, there is still a lack of comparative analysis of existing commercial appliances that may be employed to produce electricity and heat from landfill gas. Continuing our research into waste gas utilization for energy production [5,12,24–26], this work focuses on the comparison of technical and economic potentials of landfill gas utilization by modern energy technologies, such as RICE, MGT, SOFC and MCFC, in the case of stationary operation at landfill sites. The results were verified using one solid waste landfill as a case study.

Thus, the primary objective of this study is to develop and validate a methodology for comparing various energy generation technologies, based on both mature heat engines and modern fuel cells, using biogas as a fuel. Most early studies typically involve one or two technologies as the subject of study, employing a high level of experimental or modeling approach.

This study contribution concerned with multifactor analysis of four most popular technologies in the landfill gas utilization niche (RICE, MGT, SOFC и MCFC), which based mostly on achieved technical and economic parameters of commercial or demonstration projects. Specific energy cost, involving such technology parameters as fuel conversion efficiency, fuel purification degree, equipment lifetime, environment pollution effects has been chosen as objective indicator for technologies comparison. Such quantitative indicator for comparison was needed because of large difference in weak and strong sides of the considered technologies.

The results of experiments with solid oxide fuel cells (SOFCs) were used to evaluate energy efficiency while operating on a model fuel gas simulating various CH₄/CO₂ ratios. The methodology was validated

using data from an operational municipal solid waste landfill site. A large number of scenario calculations were conducted to clarify the impact of various parameters on the specific energy cost. This study also focuses on determining service life and capital costs values, which could improve the competitiveness of fuel cells for landfill gas utilization compared to mature heat engine technologies. From a practical point of view, this paper also highlights the most important parameters of landfill gas energy projects, the actual values of which are crucial for the successful implementation of the project.

2. Input data and estimation technique

For a comparative technical and economic analysis and an assessment of the landfill gas technical potential, a calculation technique was developed, which takes into account a number of factors influencing the RICE, SOFC, MGT, and MCFC application indicators (Fig. 1).

To estimate the plant capacity of landfill gas utilization, a fuel gas flow was assumed constant owing to low sensitivity of the system efficiency to the total flow rate, discussed below, or, otherwise, supposed presence of buffering vessels onsite. In this case, the electrical capacity P_e (kW) of the plant is:

$$P_e = \frac{q}{N} \tag{1}$$

where q (Nm³/h) is the landfill gas flow and N (Nm³/kWh) is the methane specific consumption by the electric energy generator. Then, the total electrical energy production (W_e) during the calculation time horizon T can be expressed as:

$$W_e = \int_0^T \frac{q \times \theta \times dt}{N} \tag{2}$$

where t is the time and θ is the methane volume fraction in landfill gas, varying typically in the range of 0.4–0.6 [27]. The heat energy production (W_h) was calculated as:

$$W_h = W_e \times \Omega \tag{3}$$

where ω is the heat-to-power ratio, which depends on the applied landfill gas utilization technology. The consumed landfill gas volume during the calculation time is:

Table 1

Data from model experiments on landfill gas purification ([32] and references cited).

Biogas flow, Nm ³ /h	Contamination		Purification technique*	Expenses (C _{op1}), USD/Nm ³	Contaminants removal
	H ₂ S, ppm	Siloxane, mg/m ³			
82	2000	0	Biofilter + water vapor condensation	0.01	100 %
n/a		0	Biofilter + water vapor condensation, IS + AC	0.04	97 %
	0	14	Biofilter + water vapor condensation, IS + AC	0.06	97 %
56	1000	0	IS	0.03	n/a
4250	700	15	IS + AC	0.04	88 %
108	400	0	water vapor condensation + IS + AC	0.06	n/a

* IS and AC refer to adsorption on iron sponge and activated carbon, respectively.

$$Q = \int_0^T q \times dt \quad (4)$$

The initial parameters used to calculate the heat output from different technologies were obtained from the literature data [2,15,18,28–36]. The purification of fuel gas is an important issue for all technologies that affects the key components lifetime. The specific energy consumption for gas purification (W_{cl} , Fig. 1) reduces the electrical energy delivered to the consumer (W_{ec}):

$$W_{ec} = W_e - W_{cl} \int_0^T q dt \quad (5)$$

Different landfill gas compositions (varying from the season and MSW composition) lead to discrepancies in W_{cl} values in the literature. In model experiments, the concentrations of contaminants are often assumed to be higher than those in real pilot projects, so pessimistic scenario has been realized for calculation. For fuel cells, a two-stage scheme is usually considered for fuel purification (as for DEMOSOFCC pilot project [30]), including a heat exchanger for water vapor condensation to remove water-soluble contaminants, followed by one or several sorption systems. Table 1 shows the purification expenses (C_{op1}) depending on the gas flow rate, the content of contaminants, and the purification method/degree.

Table 2

Electricity and heat generation parameters for the Timokhovo landfill (Moscow region).

Parameter	CH ₄ content of 45 vol%				CH ₄ content of 70 vol%			
	RICE	MGT	MCFC	SOFC	RICE	MGT	MCFC	SOFC
	Electric power available, kW	4816	3022	7339	8008	7491	4701	11,416
Energy for fuel purification, MWh/year	258	258	330	720	258	258	330	720
Electricity production, MWh/year	41,930	26,213	63,956	69,427	65,367	40,918	99,670	108,398
Heat production, MWh/year	39,234	52,147	19,286	32,969	61,031	81,118	30,000	51,285
NO _x emissions, t/year	41.9	13.6	0	0	65.4	21.3	0	0
Capital expenses, 10 ³ USD	2408	2720	11,742	31,230	3746	4230	18,265	48,580
Operation expenses, 10 ³ USD	419	131	256	694	654	205	399	1084
Fuel purification expenses, 10 ³ USD	300	300	900	900	300	300	900	900
Specific electricity cost, USD/kWh*	0,04	0,06	0,13	0,92	0,04	0,05	0,12	0,91
Specific CO ₂ emissions, kg/kWh**	1,33	2,12	0,87 (0)	0,80	0,85	1,36	0,56	0,51

* For a 10-year calculation horizon.

** CO₂ emissions are estimated to be 55613 t/year in case of 45 vol% methane content and 55490 t/year in case of 70 vol%. This value supposes full CH₄ oxidation, initial CO₂ from MSW digestion and not supposes CO₂-trace for different technologies equipment production. Since the MCFC-based generator usually includes a special compression system, which allows CO₂ to be captured from the anode exhaust [28], no CO₂ emissions will be generated using this technology.

The NO_x emissions (E_{NO_x}) originating from the air in the combustion engines were estimated as:

$$E_{NO_x} = g_{NO_x} \times W_e \quad (6)$$

where g_{NO_x} (g/kWh) is the specific NO_x emissions (Table 3). The CO₂ emissions (E_{CO_2}) were calculated by assuming that all the methane from landfill gas is oxidized to CO₂ and by taking into account the transition from volumetric to mass flows. Specific values of operation expenses (C_{op2}) and air pollutant emissions were also taken from the literature (Fig. 1).

In order to compare different landfill gas utilization technologies from an economic point of view, the specific energy cost was calculated for all cases. The capital expenses (C_{cap}) included the costs of the fuel purification system and the power plant. The operation expenses during the calculation time horizon included purification expenses, maintenance expenses, and air pollution payments. Only the engine replacement for MGTs or RICEs or of the fuel cell stack change for MCFCs and SOFCs was accounted for according to the lifetime of the corresponding power plant. In the latter case, the data vary significantly in the range of > 15 000 to > 90 000 h depending on the stack rated power, operating temperature, fuel, and other parameters [37–39]. The sensitivity of electric energy specific cost to the power plant lifetime a is discussed below. The total costs (C_w) are:

$$C_w = C_{cap} \times P_e \times (1 + 0.33 \times (\frac{T}{L} - 1)) + C_{op1} \times W_e + C_{op2} \times P_e \times T + E_{NO_x} \times C_{NO_x} + E_{CO_2} \times C_{CO_2} \quad (7)$$

where L is the lifetime of the key components of the power plant and C_{NO_x} and C_{CO_2} are the air pollution fees. The coefficient 0.33 takes into account the fact that only the key components of the power plant are to be replaced. The specific energy cost (C_{ws}) for the calculation time horizon is defined as:

Table 3

Detailed cost structure for different landfill gas utilization technologies (methane content of 45 vol%).

Expenditure item	Technology			
	RICE	MGT	MCFC	SOFC
Capital expenses and components change, %	56.4	70.5	96.0	99.6
Fuel gas purification expenses, %	17.6	19.4	3.1	0.2
Maintenance expenses, %	24.6	8.5	0.9	0.2
Air pollution payments, %	1.5	1.6	0.1	0.0

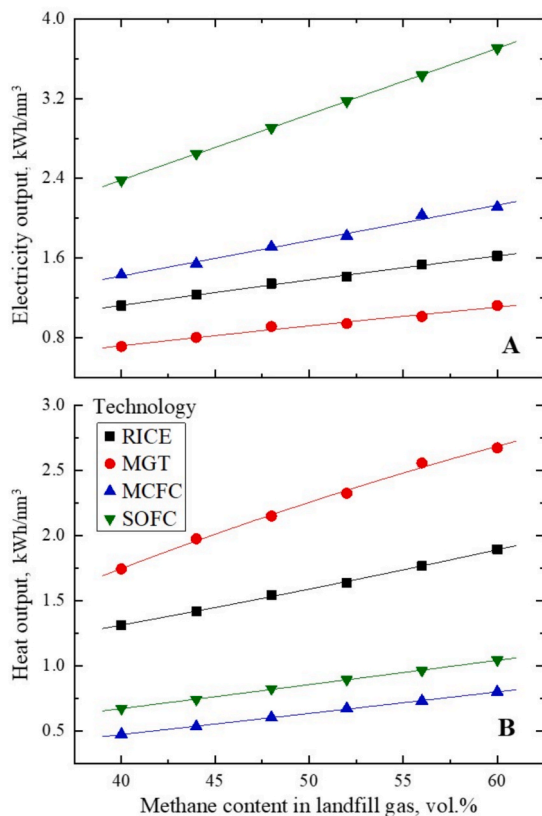


Fig. 2. Dependencies of the electricity output (A) and heat output (B) per 1 Nm³ of landfill gas on the gas composition for various utilization technologies. Lines are for visual guidance.

$$C_{ws} = \frac{C_w}{W_{ec} \times T} \quad (8)$$

The technical potential for landfill gas in Russian regions has also been estimated and visualized in the form of maps. For the sake of convenience, the quantities W_{ec} from Eq. (5) and W_h from Eq. (3) were normalized to Q (Eq. (4)). Q can be considered a gross landfill gas potential, defined as the amount of gas generated by a landfill throughout a year. It is assumed that the entire amount of MSW yearly delivered to the landfill site is involved in the methane production during the same year. This amount and the fraction of wastes that can be decomposed with methane emission can be used to estimate the gross potential for the region [5]. For the Russian Federation, the average MSW composition was taken from Ref. [40]. Due to the growing urban population and the decreasing rural population, the MSW generation was mainly ascribed to the former and was roughly estimated from the urban population in the region and waste production per capita. Only relatively large cities (with more than 100 000 inhabitants) were taken into account for each region. The total gross potential of methane production as part of landfill gas in the Russian Federation was estimated to be 2 722 kt/year [26]. The spatial distribution of the gross potential correlates with the degree of regional urbanization and is presented in maps produced using the QGIS software [41].

The zero-dimensional model constructed in the Wolfram Mathematica software package was adapted to calculate the efficiency of SOFCs operating on landfill gas with variable methane concentration, as detailed previously [25].

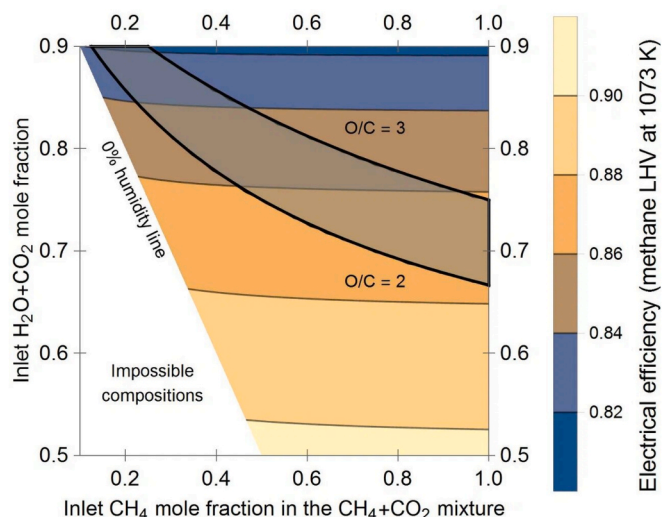


Fig. 3. Theoretical electrical efficiency of an ideal SOFC with zero resistance as a function of fuel composition. Black lines show the boundaries where O/C ratio is equal to 2 or 3.

3. Results and discussion

3.1. The impact of fuel composition, flow rate and cost of the power plant

The calculation scheme for technical and economical estimations of energy production from the landfill gas was used to compare RICE, MGT, MCFC, and SOFC technologies if employed in different Russian regions. The specific electric energy and heat production rates are determined by the technology applied and also increase with the methane content in landfill gas (Fig. 2). The maximum available electricity output of 2.8 kWh/Nm³ was obtained for SOFCs at 60 vol% methane.

In the case of SOFC-based power plants, the fluctuations in methane content in the fuel should have a slight impact on the efficiency. For the methane content in the landfill gas ranging from 40 to 60 vol%, steam still must be added to the fuel in order to prevent carbon deposition at the SOFC anode [25]. In practice the O/C ratio (the molar ratio of O/C respectively from all oxygen- and carbon-bearing species in the fuel) is usually maintained in the range of 2 to 3. Fig. 3 shows the efficiency dependence of an ideal zero-resistance SOFC on the fuel composition. The efficiency was obtained by integrating the electromotive force

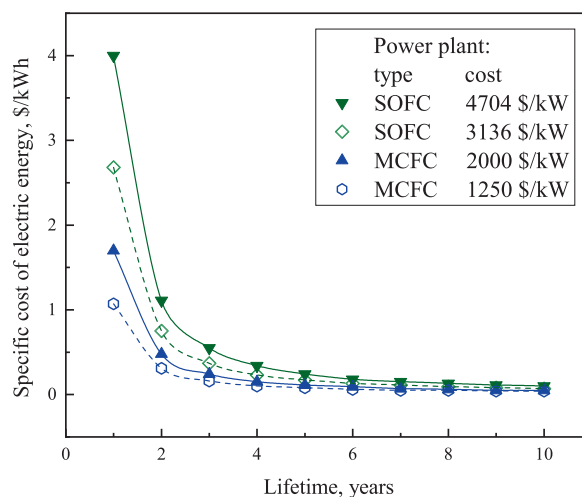


Fig. 4. Specific cost of electric energy as a function of lifetime of the SOFC and MCFC based power plants of various costs.

Table 4

Estimated levels of heat and electricity production from landfill gas (methane content of 40 vol%) using various technologies for top 10 regions of Russia.

Region	Type of power plant			
	RICE	MGT	MCFC	SOFC
Electricity production, GWh/year				
Moscow	514.4	334.5	647.5	841.7
Moscow Region	260.0	169.1	327.3	425.5
Saint Petersburg	222.4	144.6	279.9	363.9
Sverdlovsk Region	177.2	115.2	223.0	289.9
Chelyabinsk Region	142.2	92.5	179.0	232.7
Krasnodar Region	130.5	84.9	164.2	213.5
Republic of Tatarstan	123.7	80.4	155.7	202.4
Rostov Region	117.7	76.6	148.2	192.6
Nizhny Novgorod Region	104.7	68.1	131.8	171.3
Samara Region	103.9	67.5	130.7	169.9
Heat production, MWh/year				
Moscow	478,4	659,0	194,3	395,6
Moscow Region	241,8	333,1	98,2	200,0
Saint Petersburg	206,8	284,9	84,0	171,0
Sverdlovsk Region	164,8	226,9	66,9	136,3
Chelyabinsk Region	132,2	182,2	53,7	109,4
Krasnodar Region	121,4	167,3	49,3	100,3
Republic of Tatarstan	115,0	158,4	46,7	95,1
Rostov Region	109,5	150,9	44,5	90,5
Nizhny Novgorod Region	97,4	134,2	39,5	80,5
Samara Region	96,6	133,0	39,2	79,9

(EMF) over the utilization factor up to the Ni/NiO equilibrium voltage and dividing by the lower heating value (LHV) of methane at 1073 K. A detailed description of the calculation based on the 0-dimensional model is found in Ref. [25]. Ultimately, the total (CO₂ + H₂O) fraction will be greater than the amount of steam added to pure methane. This reduces the stack potential by 2–3 % for 40 to 60 vol% methane (Fig. 3).

Moderate variations in the landfill gas flow would have no essential effect on the efficiency of SOFCs. For instance, according to the Bloom Energy white paper [42], the efficiency remained virtually constant (0.53–0.54) for the range of system load from 30 to 100 %. At the fuel flow rates, corresponding to the lower load than 30 %, the efficiency should, however, drop. Compared to the fuel cells, the efficiency of gas turbines is significantly lower. Under the conditions of partial load, this efficiency further decreases while the emissions increase significantly [42]. Note, however, that the taxes for CO₂ and NO_x emissions should increase by 10–20 times to promote the competitiveness of fuel cell-based technologies.

Whatever the impacts of time-instabilities of the total landfill gas flow and composition, insufficient durability and excessively high capital costs are the key issues for the fuel-cell based generators, hindering their applicability for landfill gas utilization. The analysis of sensitivity of the electric energy specific cost to these parameters was carried out (Fig. 4). The costs of MCFC-based power plants were taken from Ref. [43], while the costs of SOFC-based power plants were estimated using the cost of 2 kW SOFCMAN stack [44] and assuming that the system cost is thrice higher than that of constituting stacks. For the lifetime periods of 2–3 years, the role of capital costs for fuel cell-based generators is crucial (Fig. 4). However, after achieving the lifetime of 6–8 years, this role becomes much less significant.

3.2. Case study

In order to verify the calculations, the estimates were made for the Timokhovo landfill (Bogorodsky district, Moscow region, Russia), which is one of the largest landfills in Europe [45]. After being recultivated several years ago, this landfill is now used to produce electricity from waste. The power plant designed and manufactured by Electrosystems LLC [46] for the Timokhovo anaerobic digestion biogas plant consists of five container-type units based on TCG series gas engines (MWM,

Germany) with a total rated power of 10 MW. This is the first RICE (gas piston) power plant in Moscow region that operates exclusively on biogas. The total landfill gas output for this power plant is planned to be 30×10^6 m³/year, yielding 70 GWh/year and significantly reducing greenhouse gas emissions [46]. Methane content is estimated to be in the range of 45 to 70 %. The technical and economic parameters for the Timokhovo landfill were also estimated for all the technologies under consideration; the obtained results are given in Table 2.

Except for emissions of nitrogen oxides, the best parameters are provided by RICEs (Table 4). Nowadays, it is the most popular technology for utilizing different gases [14]. Although the fuel cell-based technologies are more ecologically friendly, their cost of energy is much higher than that of heat engines due to high capital expenses and a low lifetime when operating on landfill gas. The calculation results are less optimistic than those expected from Ref. [46]. Nevertheless, the estimated energy output (~61 GWh/year) in the case of a high methane content of 70 vol% is close to the expected value of 70 GWh/year. According to the data reported in Ref. [45], only 48.5 GWh of electrical energy was actually produced in 2024 and about 39 GWh in 2023. The reasons may refer to the lower methane content in biogas or the shorter average time of equipment operation due to commissioning works or service maintenance. The energy cost is reported to be 0.06 USD/kWh, possibly due to inclusion of labor costs for the entire landfill and margin norm of the operating company into expenses. Variation of landfill gas output and its methane content throughout the year (mainly due to environmental temperature variation) also has been considered (besides gasholders usage on the site and the whole practice of gasholders application for such projects to mitigate landfill gas output variation effect [47]). This variation leads to 5 % decrease in energy output, that doesn't match with real energy output at Timokhovo landfill site. But decrease of maximum (throughout the year) methane content from 70 to 60 vol% leads to 22 % decrease in energy output, which is much closer to real data from Timokhovo landfill site, so the overestimation of methane content in landfill gas is the most probable cause for difference between calculated and really fixed results.

The minimal total expenses are found for gas microturbines due to low operation expenses and for RICEs due to lower capital expenses. In the former case, however, the gain in the operation expenses does not offset the relatively low electrical efficiency and high capital expenses of this technology. The cost structures for all the considered technologies are detailed in Table 3.

The capital expenses and the key components replacement costs after their lifetime ending are dominant factors for all the technologies. The variations in capital costs and lifetimes can significantly change the specific energy cost. For example, achieving a SOFC lifetime of up to 40 000 h will lead to a specific energy cost level of 0.19–0.28 USD/kWh for this technology (Fig. 3). This can be used to derive the target values of some parameters in order to make the fuel cell technologies more economically competitive with heat engines. SOFCs need a capital cost of 2 000 USD/kW and a lifetime of at least 10 years to achieve similar specific energy cost level as modern RICEs. For MCFCs, the lifetime must also be increased to 10 years to be competitive with MGTs.

Specific cost of energy, calculated in this research, is very close to LCOE, it can be also classified as a net cost of produced energy. Financing costs and inflation haven't been taken into account due to difficulties in long-term synopsis for these values. Considering current financing situation for such objects in Russia it can be mentioned, that discount rate accounting in calculation will increase energy costs for roughly 15–20 %.

The main ecological effect for all considered technologies is achieved due to the transformation of methane into carbon dioxide and the energy production from waste instead of fossil fuels. The calculations were performed assuming the complete methane oxidation for all technologies. The amount of emitted CO₂ was, therefore, equal in all cases. However, due to the different efficiencies, specific CO₂ emissions (per kWh of produced electric energy) should be considered. From this point

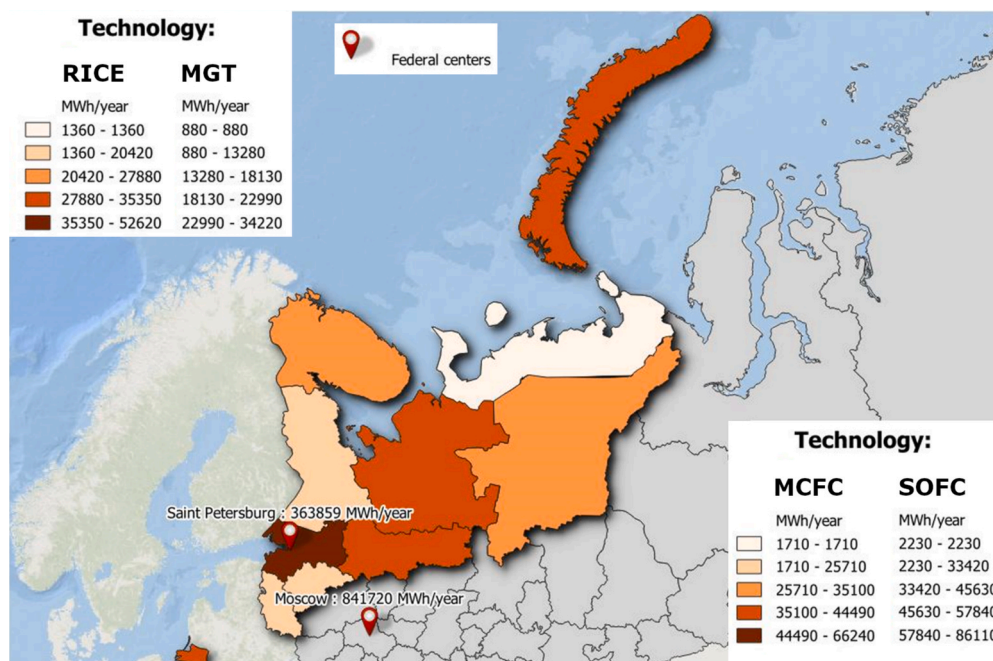


Fig. 5. Technical potential of landfill gas (CH_4 content of 40 vol%) for different technologies: electricity production in the North-West Federal District of Russia.

of view, SOFCs seem to be the most efficient solution when taking into account the possibility of operation without an external pre-reformer. MCFCs may be used to produce liquid carbon dioxide by capturing it from the anode exhaust, which may also be advantageous.

The estimates of annual production levels for heat and electricity were based on the values of specific energy production and gross landfill gas energy potentials in Russian regions. The data for 10 leading regions is given in Table 4. The technical potentials are also presented as maps with detailing of federal subjects, assuming different methane contents in landfill gas and different energy technologies. As an example, Fig. 4 shows the technical potential of landfill gas, containing 40 vol% of CH_4 , in the North-West Federal District of Russia. The linear dependence of gross landfill gas energy potential on the urban population led to maximum technical potentials for the most urbanized and populated regions (Fig. 5). This visualization is suitable for applying calculation results in geoinformation technologies.

4. Conclusions

An approach for estimating the technical and economic indicators for energy production from landfill gas was proposed to compare different modern technologies, such as reciprocating internal combustion engines, gas microturbines, molten carbonate and solid oxide fuel cells. The key calculation parameters were the methane content in landfill gas, the electric efficiency, the specific energy required for landfill gas purification from contaminants, and the heat-to-electricity production ratio for each technology. The calculation technique involved a mass and energy balance, including the landfill gas pretreatment. The capital and operation expenses for each technology were also taken into account, including expenses related to the replacement of key components after the end-of-life and the payments for air pollutant emissions. The developed technique was used to perform a comparative technical and economic analysis of different technologies for the Timokhovo landfill (Moscow region, Russia). RICEs appeared to be the most economically efficient technology, while fuel cells appeared to be less economically efficient due to the short lifetime of components and high capital costs. Target parameters for fuel cell-based generators were estimated. In particular, the SOFC stack lifetime should be increased to 10–15 years, while the capital costs should be reduced to 2 USD/W. At the same time,

the fuel cells provide the best ecological efficiency, producing more energy from landfill gas with no NO_x emissions. Specific CO_2 emissions were estimated to be 1.5 kg/kWh for RICEs, 2.3 kg/kWh for MGTs, 1.2 kg/kWh for MCFCs, and 1.5 kg/kWh for SOFCs. Statistical data was used to estimate and map the gross and technical potentials of landfill gas in Russian regions, considering the applications of fuel cells and heat engines. Key components of the power plant and methane content in landfill gas appeared to be the most important parameters for economics of such projects according to the calculation and verification results.

CRedit authorship contribution statement

Dmitrii A. Agarkov: Writing – review & editing, Project administration, Investigation. **Sophia V. Kiseleva:** Writing – review & editing, Writing – original draft, Investigation. **Vladimir P. Shakun:** Visualization, Data curation. **Alexey B. Tarasenko:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Ekaterina V. Tshipis:** Writing – review & editing, Supervision, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors are sincerely grateful to Azat U. Sharafutdinov for his help in modelling the SOFC efficiency.

Data availability

Data will be made available on request.

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