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Optimization of landfill gas use in municipal solid waste landfills in Latvia

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Abstract

A mathematical model was developed and applied to estimate an optimal installed capacity of a power plant that uses landfill gas as a fuel. Economic, technological and climate parameters are considered in the model. For benchmarking purposes the feed-in tariffs of power production from renewable energy sources, as well as price of CO₂ emission allowances are used. A landfill in Latvia is taken as a case for modelling. The results show that it is possible to find the optimal capacity for various grades of landfill gas quality.

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1. Introduction

In a municipal solid waste (MSW) landfill, during a biochemical conversion process, called decomposition or biodegradation, a landfill gas is generated. The process consists of five continuous stages including both, aerobic and anaerobic conditions. The initial aerobic stage is of short duration as it occurs right after waste disposal due to entrapped atmospheric oxygen. In the stage, the generated gas consists primarily of carbon dioxide (CO₂). Whereas, in the following stages, where the initially available oxygen has been exhausted, anaerobic conditions dominate.

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generating a gas with typically 40–60 % methane and 35–50 % carbon dioxide with trace concentrations of other gases [1, 2].

Methane (CH$_4$) has a significant energy value – the lower heating value of CH$_4$ is 37.784 MJ/Nm$^3$ on dry volume basis [3]. The heating value of landfill gas is sufficiently high too to use it as a fuel in a combustion processes [4]. Thereof, there is a large interest for landfill gas recovery as an energy source. In addition, CH$_4$ and CO$_2$ are greenhouse gases, and preventing their escape into the atmosphere is of special importance for mitigating the global climate change.

Various technologies have been intensively investigated, developed and implemented for landfill gas collection, upgrading, storage and use [5]. E.g. Bove and Lunghi [1] have analysed various landfill gas energy recovery systems comparing their techno-economic and environmental characteristics. They have concluded that due to economic reasons internal combustion engines are the most widely used technology notwithstanding their poor environmental performance. Whereas, fuel cells though the cleanest energy conversion systems have too high investment costs for their wide application in landfills.

In Europe, and in particular in Latvia, large fraction of MSW is disposed in landfills (see Fig. 1). In Latvia, a policy, where 558 small-scale dumps were supposed to be replaced by 11 sanitary landfill sites, was enforced at the end of 1990’s. At that time, the centralization of waste dumps was considered to be the main task of the waste management system, and an idea of large landfill site depositories, where landfill gas is produced by decomposing organic waste was introduced in the policy [6]. According to Latvia’s National Inventory Report [7], since 1990 greenhouse gas emissions from solid waste disposal have gradually increased composing 450 t of CO$_2$ equivalent in 2012. Nevertheless, landfill gas collection systems and cogeneration plants have been installed only in three of the landfills. In 2012, that allowed collecting and recovering 135.7 t of CO$_2$ equivalent or 30 % of the landfill gas generated. The total capacity of the installed cogeneration plants is 5.9 MW with efficiency $n_e$ of ca.40 %, as the average CH$_4$ content of the landfill gas is 45–54 % [8]. In regions where landfills with landfill gas recovery systems are located, the installed cogeneration plants gave an opportunity to produce renewable energy. Though, in two of the cases lack of heat energy consumers encumbered efficient utilization of the technologies installed. As a result, the cogeneration plants work in the condensing regime as power plants.

![Fig. 1. Waste disposal in landfills in Europe in 2012 [9].](image-url)
Currently there are no plans for bio-waste treatment facilities to be installed in Latvia, except for equipment for mechanical pre-treatment of waste [10]. Thus, it can be projected that a rapid decrease in landfill gas emissions cannot be expected in the near future. Therefore, it is important to find optimal solutions for landfill gas capture and utilization. The objective of the study was to model optimal parameters of landfill gas utilization in MSW landfills in Latvia. In this paper, criteria and methodology for optimization of landfill gas utilization for energy production in MSW landfills have been selected.

Optimization finds many applications in engineering, science, business, economics, and in these applications, quantitative models and methods are employed [11]. Optimization is a continuous process, because always scope for optimizing the current industrial operations exists, particularly with the ever changing economic, energy and environmental landscape. Optimization of industrial processes requires a mathematical model that describes and predicts the process behavior. The essence of the problem may be described by developing mathematical models, and then applying mathematical procedures to solve the models. Therefore, the mathematical model of a problem is a system of equations and mathematical expressions [12].

2. Methodology

The installed capacity of a power plant in a landfill depends on various factors and parameters as waste disposal capacity of landfill, composition of waste, projected amount and quality of landfill gas, etc. Figure 2 shows the algorithm of mathematical model that helps selecting the capacity by analyzing the landfill gas quality, technological parameters of the plant and amount of greenhouse gas emissions.

It can be seen from Figure 2 that the mathematical model includes four basic calculation modules: (i) initial data module, (ii) module of technological parameters, (iii) module of economic assessment, and (iv) climate assessment module.

![Fig. 2. Algorithm of mathematical model for landfill gas power plant.](image-url)
technological parameters. The module of economic assessment processes data to estimate the optimum tariffs with respect to investment, operational and maintenance costs of the plant. The cost of electricity production is determined by using data on equipment’s capital investment and operational costs, amount and quality of landfill gas and efficiency of the equipment (see Eq.1). Finally, the climate assessment module estimates cost efficiency of reduction of greenhouse gas emissions. The cost efficiency shows how much investment is necessary to avoid emissions of 1 ton of CO2 (see Eq.2).

\[
T_e = \frac{(C_I + C_O + C_M)(P + Q)}{\tau B Q_L E_B},
\]

where
- \(T_e\) – tariff for energy produced from landfill gas, €/MWh
- \(C_I\) – investment costs, €
- \(C_O\) – plant operation costs, €
- \(C_M\) – plant maintenance costs, €
- \(P\) – amount of electricity generated, MWh/a
- \(Q\) – amount of thermal energy generated, MWh/a
- \(\tau\) – lifetime of power plant, years
- \(B\) – annual landfill gas consumption, m³/a
- \(Q_L\) – lower heating value of landfill gas, MWh/m³
- \(E_B\) – amount of energy produced from landfill gas, MWh/a.

\[
C_{GHG} = \frac{C_I \eta}{B Q_L R},
\]

where
- \(C_{GHG}\) – costs of avoided greenhouse gas emissions, €/(tCO₂·a)
- \(\eta\) – energy efficiency of power plant, %
- \(R\) – emission factor, tCO₂/MWh.

For benchmarking and comparison purposes feed-in tariffs and target or marginal value of cost efficiency are included in the algorithm. Feed-in tariffs set in the national legislation \[13, 14\] are considered. According to it, feed-in tariffs depend on the type of fuel used, natural gas tariff and installed capacity of a power cogeneration plant. In order to define a threshold value of the specific costs of reducing greenhouse gas emissions a marginal value of cost efficiency is used. For this, greenhouse gas emission allowances in the emission trading system or joint implementation projects are considered.

Optimization model for the landfill gas use in landfills includes the four modules described above. The target function for optimization includes engineering, climate and economic parameters applied to forecast the potential of landfill gas use for energy production. Amount of power produced in a condensing regime depends on installed solutions for landfill gas’ collection, availability of landfill gas, set parameters of a plant, installed capacity, efficiency of technologies, sustainability factor, and other factors. In case of cogeneration regime, the produced amount of power depends also on behavioural parameters of heat energy consumers, heat load duration curve, and factor of development level of demand side management. By considering these factors the production of power from landfill gas can be technologically optimized. In order to optimize the economic performance, a cost-benefit analysis should be used, that includes feed–in tariffs, capital investments, installation costs, operation and maintenance costs, energy efficiency, costs of greenhouse gas emissions, landfill management costs and state energy policy. Whereas, to minimize the impact of power production in landfills on climate change, the greenhouse gas emissions should be
reduced. Thus, the target functions for optimization are to maximize the energy efficiency of power production, minimize the production costs and minimize greenhouse gas emissions associated with it. For simplification purposes, two objective functions are used – quality of landfill gas characterized by the lower heating value and technological equipment characterized by installed electrical capacity.

Data of a MSW landfill in Latvia are used in the optimization model. In addition, the following assumptions are made: (i) the amount of landfill gas generated in the landfill coincides with the amount estimated by using the first order kinetic gas generation model of methodology provided by the Intergovernmental Panel on Climate Change [15]; (ii) the internal engines are adjusted in the power station, and their installed capacity is in the range of 0.1 MW<sub>e</sub> to 6.0 MW<sub>e</sub>; (iii) the feed-in tariffs are as set in the national legislation [13, 14]; (iv) the lower heating value of the landfill gas is constant over time and is 10 MJ/m<sup>3</sup>, 13 MJ/m<sup>3</sup>, or 18 MJ/m<sup>3</sup> (three scenarios); (v) the costs of installed capacity, operation and maintenance are as provided by producers and suppliers of power production technology; (vi) energy efficiency of the power production is 40 %.

3. Results

The mathematical model was used to estimate the economic benefits of power production from landfill gas. For this, an indicator showing specific investment costs was used. In addition, benefits that develop from difference in the feed-in tariffs and power production costs were estimated. It can be seen from Figure 3, that the specific costs are smaller in case of higher landfill gas quality and lower installed capacity of the power plant. The optimum of the specific costs is found between installed capacity of 0.2 MW<sub>e</sub> and 0.6 MW<sub>e</sub>.

![Fig. 3. The specific investment costs for power production from landfill gas.](image)

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The results of economic benefits’ assessment show that in case of low-grade landfill gas (10 MJ/m$^3$) the optimum installed capacity is 3.0 MW$_e$ (see Fig. 4). This is estimated based on the market price of electricity produced from biogas and the benchmark level of feed-in tariffs. If a landfill gas is of higher quality, i.e. 13 MJ/m$^3$, the optimum capacity increases to 3.8 MW$_e$. Whereas, for high-grade landfill gas, it was not possible to find the optimum economic benefit in the studied capacity range. Considering the requirement set in the Landfill Directive 1999/31/EC [16] and Waste Directive 2006/12/EC [17] to decrease the amount of biodegradable waste disposed in landfills, the amount and quality of landfill gas will reduce within the next two decades. Thus, a technology consuming a low-grade landfill gas for energy production might be a reasonable choice. In addition, the installed capacity of the power plant should be within the optimum range to provide the maximum economic benefit.

The results of estimated avoided greenhouse gas emissions show that the highest reduction is achieved in case of higher installed capacity. However, to achieve the reduction, larger cost has to be invested in technologies for landfill gas use. Figure 5 shows that cost of avoided emissions increase with increase of installed capacity. Besides, the lower the landfill gas quality, the higher is cost for reduction of emissions.
The European Union Emissions Trading System is the central pillar of European climate policy. Therefore, the European Union Allowance price per ton of CO₂ eq. can be used as a benchmark for comparison. During the last year the price has remained at the level of around 5 €/tCO₂eq. Since it is much higher than the estimated cost of avoiding emissions, the collection and use of landfill gas can be considered cost efficient.

4. Conclusions

Model of power production in a landfill shows that feed-in tariff stated as financial support today in Latvia allows to reach economically feasible projects even in case if cogeneration unit is operated in a condensing regime. Results of the study show that economic benefits increase with use of higher-grade landfill gas. In addition, to achieve the highest benefit, a power plant installed in a landfill should be selected based on the quality of the landfill gas. With the increase of quality of gas the installed capacity of power plant can be selected higher, thus being more profitable. As specific investment cost increase with higher installed capacity, the cost of avoided greenhouse gas emissions increase, but still are lower than the emission allowance price per ton of CO₂.

The developed model can be well adapted for estimating installed capacity of a power plant that uses biogas produced from agricultural residue. In addition, by changing the economic input data the model can be adapted for other countries with landfill gas collection and/or biogas production.

References

[13] Regulations No 221 issued by the Cabinet of Ministers: Regulations on power production and price determination for power produced in cogeneration. Latvijas Vestnesis 2009;42.
[14] Regulations No 198 issued by the Cabinet of Ministers: Regulations on power production by using renewable resources, and on price determination. Latvijas Vestnesis 2009;41.