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MODELLING OF THE INSTALLED CAPACITY OF LANDFILL POWER STATIONS

POLIGONU ELEKTROSTACIJAS JAUDAS IZVĒLES MODELĒŠANA

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Introduction

The enlargement of renewable energy resource proportion is a question of sustainable development of an energetic sector in Latvia. Biogas is one of the types of renewable energy resources. There can be various sources of biogas, and landfills play an important role among them. Different solutions for the use of biogas are searched to fulfil the European Union poses requirements and economically and ecologically substantiate them at the same time. Solving problems of waste management and treatment can be conditionally divided into three periods:

- During the first period every municipality has established a dump where the waste can be carried uncontrolled. Approximately 500 dumps caused great water pollution problems: dumps were not established in the way to keep dump waters away from groundwater, rivers and lakes. Other environmental problem was connected with air basin pollution. Dumps distorted a landscape.

- The second period has begun with an implementation of the programme „500-" during which it was planned to eliminate dumps and to establish large regional sanitary landfills or polygons. In the landfills waste storage facilities were covered with a special waterproof material where the conditions for biogas production can be created. In this way government was determined to solve also questions connected with biogas production in storage facilities of landfills. During the implementation of the project several problems had occurred connected with the use of biogas. The simplest solution is to burn the gas and produce energy: heat and electricity or both separately. An experience shows that there are no heat consumers near the landfills and this is the reason why power stations are established. Unfortunately because of technological reasons a production of electricity are made with a very low efficiency. Other solutions are also possible and they connected with an improvement of biogas and further use of it in vehicles or injection in natural gas grid. In this case the system of improved gas use has to be developed in the state.

- The third period has started now when the question about a speed of waste increase becomes more and more topical: the more waste the bigger territories have to be allocated for landfills. Within the search of radical solutions of waste amount reduction several directions of arrangement of waste management have been established in the centre of which is waste sorting. All waste carried to landfill are sorted to separate that kind of waste which can be burned. This kind of waste is particularly pre-treated, processed and packed. Such processed waste is called residues derived fuel (RDF) and those can be burned in boiler furnace or in technological oven. In this case some waste remain (20-30% of total amount), which are stored in landfill and these are not a source of biogas origination. Other possibility is to separate organic compounds from which are possible to produce biogas in digester and after that to separate RDF remained. In this case the waste treatment in landfill becomes more complicated.

Due to the fact that sanitary landfills are developed and biogas storage facilities are established there is an actual question – how to use biogas and how to develop energy production. It is important to find the answers to various engineering, economical and ecological questions, e.g. what kind of equipment has to be chosen, what power has to be installed, how big will be the costs of produced electricity, will they cover power station capital investment and operational costs [1].

This article is dedicated to solving of questions mentioned above, expounding the results of research which are gained during developing and approbation of methodology for selection of landfill biogas power station.

Model of energy production in landfill

The biogas storage facility is established in landfill and after definite time concentration of methane in biogas reaches the level when it becomes possible to use biogas for production of electricity in power station.

The installed capacity of power station depends on various factors and parameters: capacity of waste storing in landfill, composition of waste, amount of biogas produced during the use of the storage facility as well as conditions at the closing of it, and operation regime of power station. E.g. equipment in power station works without interruption all the time within the period of storage emptying or begin to work at the end of storage operation, emptying it within a couple of years.

The algorithm of mathematical model for selection of biogas power station capacity by analysis of operation time is illustrated in Figure 1.

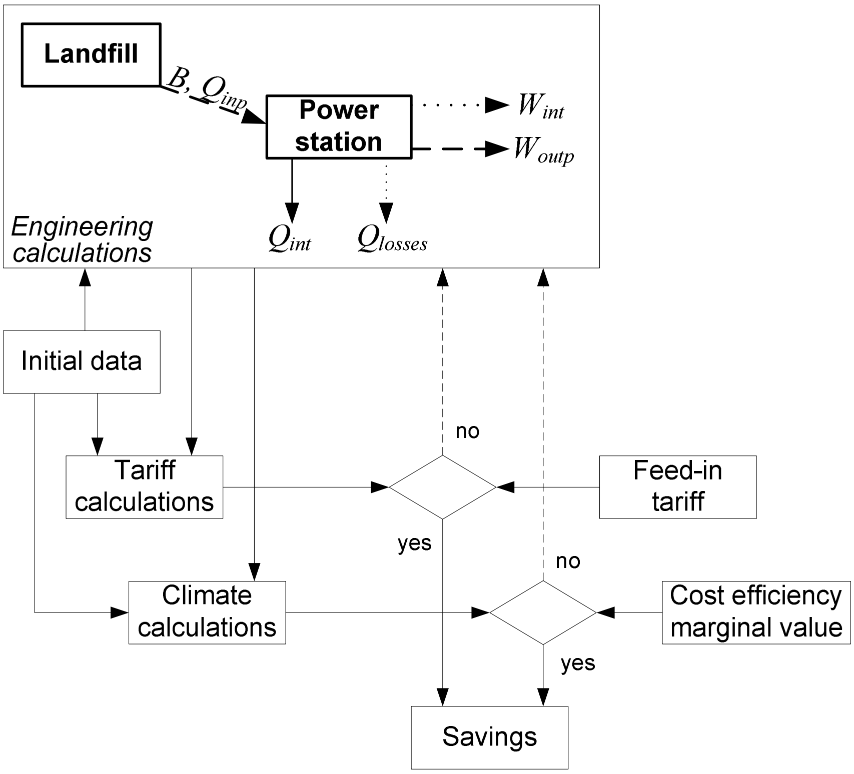


Fig.1. Calculation model for landfill biogas power station

Calculation model for landfill biogas power station is presented in Figure 1 and includes four basic calculation modules:

- initial data module;
- engineering calculation module;
- tariff calculation module;
- climate calculation module,

and two benchmarking data or secondary modules:

- feed in tariff module;
- cost efficiency target module

Initial data module includes data about landfill, biogas content and amount (for example, biogas produced in landfill, B, thousand m^3), technical data of technologies and different assumptions.

Engineering calculation module consists of evaluation equations for identification of installed capacity and operational [2].

W_{outp} - electricity sold, MWh_e/year;

W_{int} - electricity consumption for auxiliary service in power station, MWh_e/year;

Q_{int} - thermal energy consumption in power station, MWh_{th}/year;

Q_{losses} - heat losses (cooling), MWh_{th}/year;

Q_{inp} - biogas energy, MWh/year;.

B_y - annual biogas consumption, thousand m^3/year;

B - biogas consumption, thousand m^3.

Energy efficiency of a power station is a correlation between fuel energy and electricity (also heat) delivered into the grid for consumers of electricity.

$$\eta = \frac{W_{outp} + Q_{\text{int}}}{Q_{inp}} \tag{1}$$

where

η - efficiency of power station.

Tariff calculation module consists of mathematical processing of economical data and calculation of tariffs according to investments and operational and maintenance costs.

A prime cost of electricity production is determined using data about equipment capital investment and operational costs, about biogas amounts, technological equipment and system efficiency and about greenhouse gas emissions.

The prime cost of an implementation of technological solutions for electricity production is determined relating total costs to a unit of produced amount of electricity:

$$T_e = \frac{(K + A) \times \eta}{B \times Q_L} \qquad (2)$$

where

T_e - biogas energy tariff, LVL/MWh;

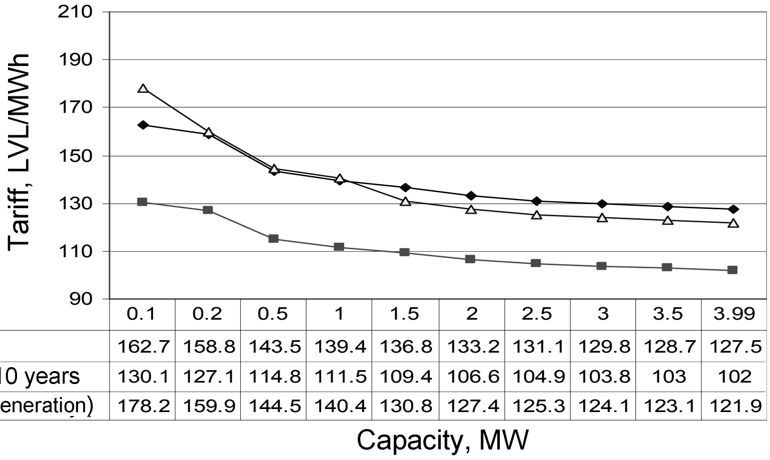
K - capital investment, LVL;

A - sum of operation and maintenance costs over life time of the plant at current costs, LVL;

Q_L - lower heat value of biogas, MWh/m^3.

Climate calculation module includes estimation of cost efficiency of greenhouse gas reduction unit.

In addition to basic calculation modules calculation module includes two secondary modules: feed-in tariff and cost efficiency target or marginal value. Both secondary modules are elaborated for determination of benchmarking.



	0.1	0.2	0.5	1	1.5	2	2.5	3	3.5	3.99
Reg.198*	162.7	158.8	143.5	139.4	136.8	133.2	131.1	129.8	128.7	127.5
Reg.198 in 10 years	130.1	127.1	114.8	111.5	109.4	106.6	104.9	103.8	103	102
Reg.221(cogeneration)	178.2	159.9	144.5	140.4	130.8	127.4	125.3	124.1	123.1	121.9

**Reg. – Regulations issued by the Cabinet of Ministers*

Fig.2. Example of electricity feed-in tariff versus installed capacity according to regulations issued by the Cabinet of Ministers

Feed-in tariff module includes electricity feed-in tariffs according to regulations of Cabinet of Ministers No. 221 (cogeneration) and regulations of Cabinet of Ministers No. 198 (electricity production) [3,4]. Value of feed-in tariff depends on fuel type, natural gas tariff and installed capacity. An example of feed-in tariff calculation is graphically presented in Figure 2. The graphic shows that legislative situation is made in the way that feed-in tariff for just electricity production is the same as for electricity production in cogeneration with better efficiency.

Module of cost efficiency marginal value is necessary to make possible to define a threshold value of specific costs of greenhouse gas reduction for comparison. GHG emission allowances in the emission trading (ETS) or in realisation of joint implementation (JI) projects can be admitted as such threshold value.

Characterization of model approbation landfill

The model is approbated for Daibe landfill. Calculation of biogas content and amount of formation is made for Daibe landfill located in Cēsis district Stalbe parish and launched at December 1, 2004. The landfill is constructed according to requirements of legislation of the European Union and the Republic of Latvia. Total reserved area taking into account perspectives of landfill future development is 49,2 ha. The landfill area is 12,96 ha (4 waste disposal storage facilities). An area of the first stage storage facility is 3,6 ha (by dykes) and maximum height of disposed waste hill accordingly to surrounding landscape is ~20 m.

A potential of biogas production from waste disposed in municipal solid waste landfill calculated by years with a help of LandGEM model is presented in Figure 3.

A total amount of biogas is assumed by summing up the amount of methane produced during a year which is recalculated for every chosen biogas improvement technology. The total calculated amount of biogas in landfill is 42266 thousand m^3. Operational time of landfill is 12 years.

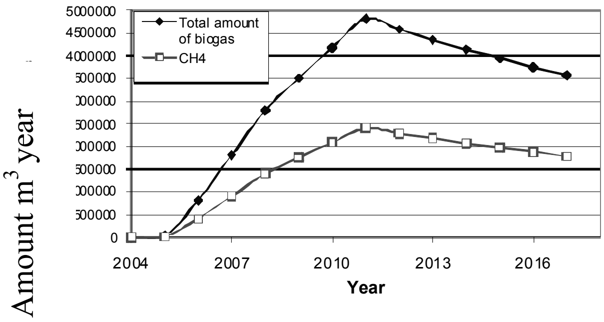


Fig.3. The amount of biogas produced at landfill "Daibe"

An approbation of electricity production calculation model in landfill „Daibe"

Electricity production can be done in power stations of various capacities. A type of station depends on amounts of landfill biogas. The bigger capacity is the quicker biogas storage facility is emptied and vice versa – the smaller capacity the slower reservoir is emptied but there are better possibilities to increase efficiency of equipment. On the other hand the slower reservoir is emptied the greater losses of biogas occur through the coating. That causes an increase of greenhouse gas emissions.

The analysis of biogas use in landfill „Daibe" is performed for 6 power station capacities: 0.08 MW; 0.5 MW; 1MW; 2MW; 3MW;4 MW.

Biogas measurement data in municipal solid waste landfill „Daibe"

It is important that in calculations of technological methods determining an amount of produced electricity an incoming flow of unprocessed biogas as well as percentage of methane content in biogas CH_4 has to be considered in equal amounts. The percentage of methane content in biogas is determined by the use of data gained in landfill "Daibe" [5].

During the trial a concentration of methane in biogas has been measured. The results showed that concentration is high, on average more than 62%. This is a very good parameter which is caused by the fact that waste is being sorted in Daibe. The changes of biogas during time are showed in Figure 4.

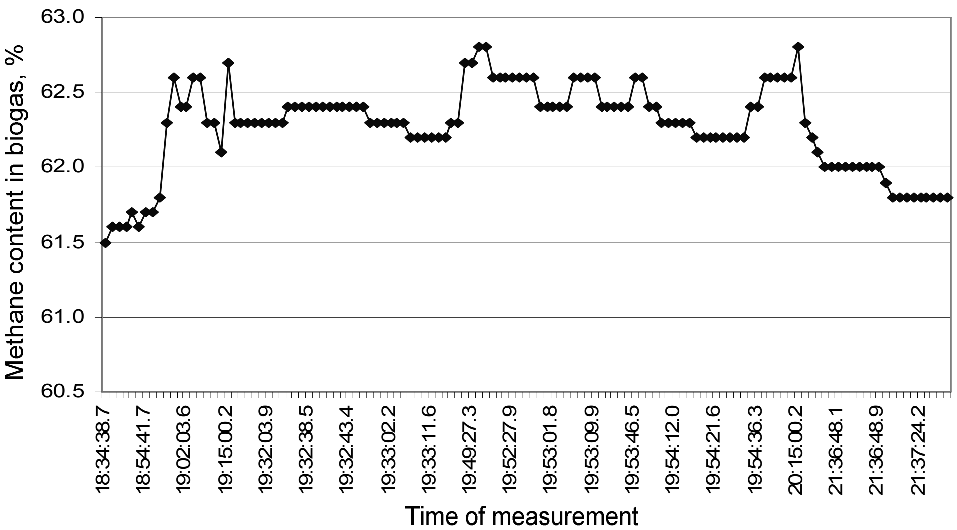


Fig.4. Methane concentration in the biogas produced at "Daibe" landfill

Economical analysis of landfill „Daibe" data

It is important to determine a true capital investment as equipment is installed in the way to use all biogas produced in municipal solid waste landfill. Based on consideration that a small power station has to be operated for longer period of time and it has to be changed after every 15 years, it has to be determined how long the equipment could be operated. The results of operational time calculations of power station equipment are graphically showed in Figure 5.

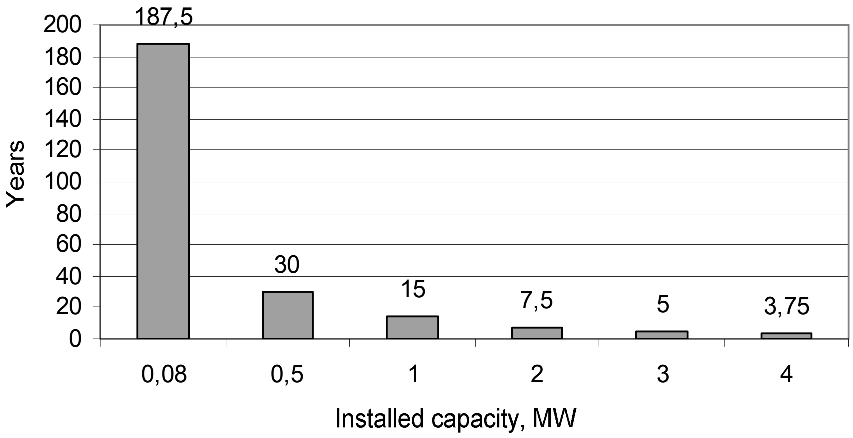


Fig.5. Operational time of cogeneration equipment

As results in Fig. 5 shows, the biggest incomings are possible with small capacities. However during equipment operation for 187 years it has to be considered that it should be changed for 14 times and there will be also considerable losses of methane. Therefore this alternative has to be considered only as theoretical possibility.

Total costs of power plant operation include capital investment and operational and maintenance costs (see Fig.6). As can be seen in the analysis of results the lowest tariff is possible in the case of installed capacity of 1 MW.

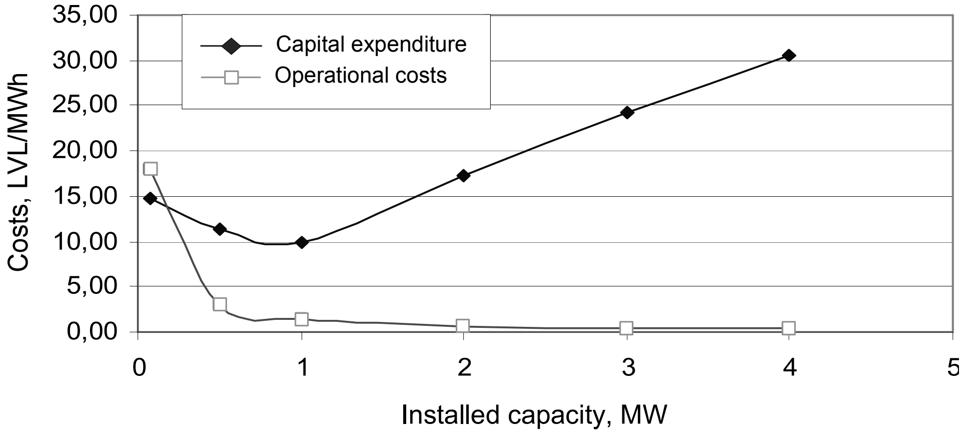


Fig.6. Capital investment and operational costs in tariff depending on capacity

A threshold value of tariff is equal with feed-in tariff, it differs depending on capacity but it is not lower than 100 LVL/MWh. Difference between calculated costs or expenses and feed-in tariff value presents profit of biogas power plant in landfill. The highest profit could be in the case of installed capacity of 1 MW. In Figure 7 a prime cost of electricity is compared with a benchmarking or a threshold value which is feed-in tariff. It has been calculated based on regulations issued by Cabinet of Ministers No. 198 regulating feed-in of electricity from stations which are using renewable energy resources.

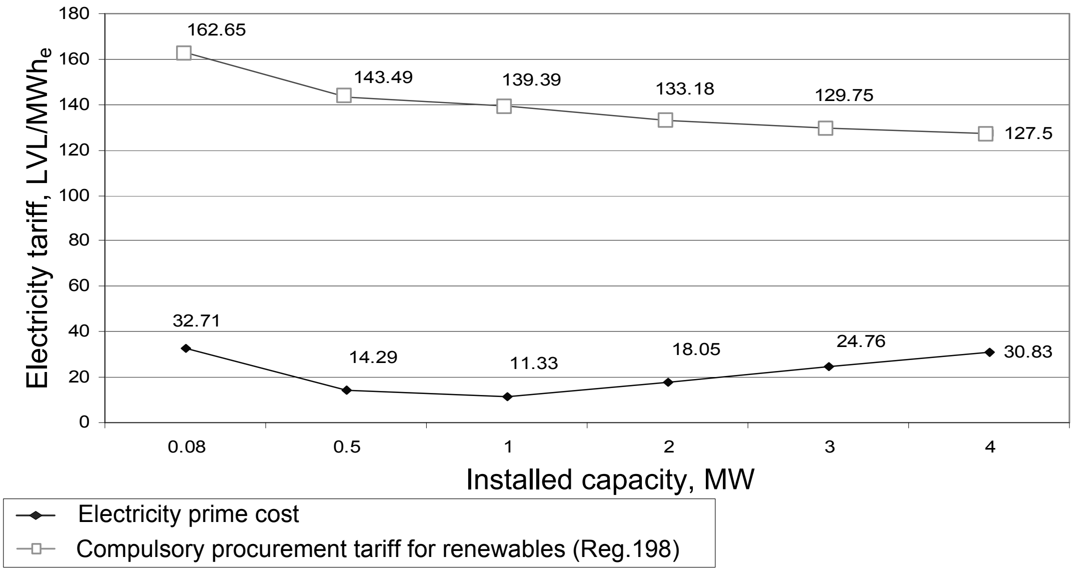


Fig.7. Prime cost comparison with feed-in tariff

All the difference between prime cost and feed-in tariff is a profit of company. Figure 7 shows that prime cost is considerably lower than feed-in tariff. It shows that electricity production from biogas is not only an environmentally friendly process but also financially profitable.

Analysis of cost efficiency

A calculation model of reduction of impact on climate changes can be based on conception of biogas use instead of natural gas. It means that electricity is generated with biogas producing zero emissions.

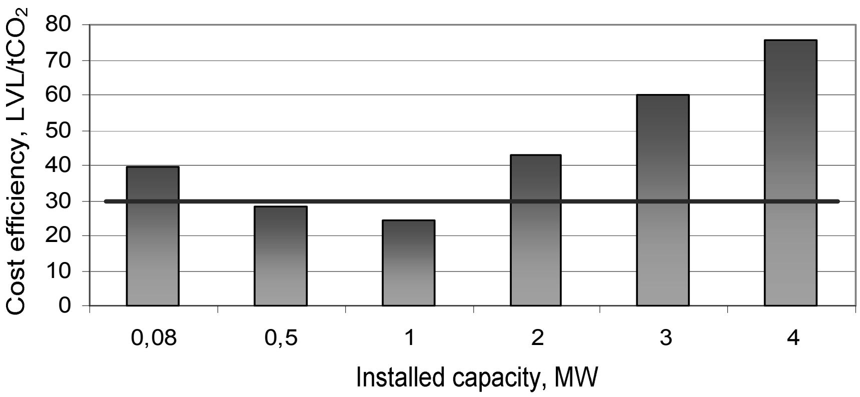


Fig.8. Cost efficiency of natural gas replacement

Efficiency calculation results in the case of natural gas replacement with biogas are gathered and illustrated in Figure 8. The lowest cost efficiency is for installed capacity of 1 MW.

Cost efficiency is an indicator of emission trading. Kioto flexible mechanisms provide possibility of financial support for greenhouse gas emission reduction projects. It can be done by taking part in the European Union greenhouse gas emission trading scheme. Although at the moment of economical crisis 1 emission allowance (1 tCO_2) costs 9 -11 LVL, it can be forecasted that in the nearest future (after economical crises) it can be within 21-35 LVL/tCO_2. Other greenhouse gas emission reduction costs are in the joint implemented projects and in the projects of clean development projects and these costs do not exceed 10 euro for tCO_2. In both cases those can be called benchmarking threshold value.

This time as a benchmarking can be used European Union greenhouse gas emission trading scheme forecast which indicates increase of values in period of 2010-2012.

Continued line characterises a benchmarking of greenhouse gas emission reduction which is equal with 30 LVL/ tCO_2. Only for installed capacity of 0.5 MW and 1 MW it is lower than benchmarking threshold value.

Conclusions

1. Elaborated model for determination of landfill biogas power station capacity is tested on Daibe landfill. Analysis of biogas use is done for 6 power station capacities: 0.08 MW; 0.5 MW; 1MW; 2 MW; 3 MW; 4 MW. Results show that optimal power station capacity for particular landfill is 1 MW.
2. Taking a feed-in tariff calculated basing on regulations issued by Cabinet of Ministers No. 198 as a threshold value all the calculated production tariffs are lower and operator of landfill will have considerable profit. The highest profit could be possible in the case of installed capacity of 1 MW. It shows that electricity production from biogas is not only an environmentally friendly process but also financially profitable.
3. Calculation model of reduction of impact on climate changes based on conception of biogas use instead of natural gas shows that cost efficiency is comparatively high: within 23 till 75 LVL/tCO_2. If the benchmarking value is 30 LVL/tCO_2, only two installed capacities of 0,5 and 1 MW have lower cost efficiency.

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Dagnija Blumberga, Ģirts Kuplais, Ivars Veidenbergs, Elīna Dāce, Jūlija Gušča, Poligonu elektrostacijas jaudas izvēles modelēšana

Arvien vairāk tiek attīstīti atkritumu poligoni, kuros tiek ražota un uzkrāta biogāze, kuru iespējams izmantot elektroenerģijas ražošanai. Šobrīd tehnoloģisku iemeslu dēļ elektroenerģijas ražošana, izmantojot biogāzi, elektrostacijās notiek ar zemu lietderības koeficientu. Lai šādas enerģijas ražošanu varētu attīstīt, nepieciešams rast atbildes uz dažādiem inženiertehniskiem, ekonomiskiem un ekoloģiskiem jautājumiem.

Rakstā izklāstīti rezultāti, kas iegūti, izveidojot modeli poligonu elektrostaciju jaudas noteikšanai un to aprobējot cieto sadzīves atkritumu poligonā „Daibe". Izveidotais biogāzes matemātiskā modeļa algoritms sastāv no četriem pamata moduļiem:

- *izejas datu modulis;*
- *inženieraprēķinu modulis;*
- *tarifa aprēķinu modulis;*
- *klimata aprēķinu modulis.*

Rezultātā noteikta poligona „Daibe" optimālā elektrostacijas jauda, kā arī veikta poligona datu ekonomiskā un izmaksu efektivitātes analīze.

Dagnija Blumberga, Girts Kuplais, Ivars Veidenbergs, Elina Dace, Julija Gusca, Modelling of the installed capacity of landfill power stations

More and more landfills are being developed, in which biogas is produced and accumulated, which can be used for electricity production. Currently, due to technological reasons, electricity generation from biogas has a very low level of efficiency. In order to develop this type of energy production, it is important to find answers to various engineering, economic and ecological issues.
The paper outlines the results obtained by creating a model for the calculations of electricity production in landfill power stations and by testing it in the municipal solid waste landfill "Daibe". The algorithm of the mathematical model for the operation of a biogas power station consists of four main modules:
- *initial data module,*
- *engineering calculation module,*
- *tariff calculation module, and*
- *climate calculation module.*

As a result, the optimum capacity of the power station in the landfill "Daibe" is determined, as well as the analysis of the landfill's economic data and cost-effectiveness is conducted.

Дагния Блумберга, Гиртс Куплаис, Иварс Веиденбергс, Елина Даце, Юлия Гуща, Моделирование установления мощности в электростанциях свалок

В настоящее время все больше и больше разрабатываются свалки, производящие и накапливающие биогаз, который может быть использован для производства электроэнергии. В настоящее время из-за технологических причин, производство электроэнергии с использованием биогаза, имеет очень низкую эффективность. В целях развития этого вида производства энергии, важно найти ответы на различные инженерные, экономические и экологические вопросы.
В работе излагаются результаты, полученные путем создания модели для расчетов производства электроэнергии в электростанциях свалок и апробирования созданой модели на основе муниципальной свалки твердых отходов "Daibe". Алгоритм математической модели для действия биогазовой электростанции состоит из четырех основных модулей:
- *модуль исходных данных,*
- *модуль инженерных расчетов,*
- *модуль тарифных расчетов,*
- *модуль расчета климата.*

В результате определена оптимальная мощность электроэнергии для свалки твердых отходов "Daibe", а так же произведен анализ экономических данных и эффективности затрат свалки.