CO-GENERATION POTENTIALS OF MUNICIPAL SOLID WASTE LANDFILLS IN SERBIA

by

Goran B. BOŠKOVIĆ**, Mladen M. JOSIJEVIĆ, Nebojša M. JOVIČIĆ, and Milun J. BABIĆ

Faculty of Engineering, University of Kragujevac, Kragujevac, Serbia

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Waste management in Serbia is based on landfilling. As a result of many years of practice, a large number of municipal waste landfills has been created where landfill gas has been generated. Landfill gas, which is essentially methane (50-55%), and CO_2 (40-45%) (both green-house gases), have a great environmental impact which can be reduced by using landfill gas in co-generation plants to produce energy. The aim of this paper is to determine economic and environmental benefits from such energy production. For that purpose, the database of co-generation potentials of 51 landfills in Serbia was created. Amount of landfill gas generated at each municipal landfill was calculated by applying a first order decay equation which requires the data about solid waste production and composition and about some landfill characteristics. For all landfills, which have over 100,000 m^3 each, a techno-economic analysis about building a combined heat and power plant was conducted. The results have shown, that the total investment in 14 combined heat and power plants with payback period of less than 7 years amounts 11,721,288 €. The total nominal power of these plants is 7 MW of electrical power and 7.9 MW of thermal power, and an average payback period is about 61 months. In addition, using landfill biogas as energy source in proposed plants would reduce methane emission for 161,000 tons of CO_2 equivalent per year.

Key words: *landfill gas, methane emissions, combined heat and power, green energy*

Introduction

Waste, as an inevitable product of daily activities of the humankind, may have a negative impact on the environment and human health. Consequently, during the last few decades, experts have been emphasizing the importance of reducing this impact through the improvement of solid waste management. Thus, different waste management models have been developed. In countries with developed economies there are waste technologies including modern recycling, incineration or anaerobic digestion, while waste management in developing countries still relies on landfilling.

The production of municipal solid waste depends on several factors including economic and cultural aspects of a community, industrial development of a municipality, environmental awareness level, manner and place of living, a season of a year, *etc.* [1]. Consequently, waste production does not only vary between different countries but also within one

* Corresponding author; e-mail: goran.boskovic@kg.ac.rs

country, even within the same city. Different regions can differ significantly in terms of waste production [2, 3]. The data about the quantity of waste generated is not available for every country in the world or the data given are not completely reliable. However, it has been determined that at the global level the amount of waste was about 2 billion tons per year at the beginning of the 21th century [4].

During the period ranging from the establishment of an organized waste management to the eighties of the twentieth century, landfilling represented the most economical and the most acceptable method of waste management worldwide. In Europe, landfilling is still present to a considerable extent. It has been estimated that in the countries of the central and eastern Europe landfilled 83.7% of generated waste in 1995 [5]. During the same year, the European Union (EU) landfilled over 60% of municipal waste while around 14% of waste was treated in incinerators, about 10% was recycled, and less than 6% of waste was treated by other means [6]. Also, according to Eurostat data [6] for 2012, the EU landfilled 33% of municipal waste, about 23% of waste was treated in incinerators, 27% was recycled, 15% was composited, and about 2% was treated by other technologies. Among the European countries, landfilling is the lowest in the Netherlands, Germany, and Austria where less than 3% of waste is landfilled [5, 6].

After landfilling, the decomposition of waste starts, which results in biogas production. Landfill gas (LFG) is essentially CH_4 (50-55%) and CO_2 (40-45%). More than hundred other compounds can be found in it, but only in small traces [4, 7]. The CH_4 and CO_2 are both gases that cause green-house effect and thus they have a negative impact on the environment [8, 9]. In addition, CH_4 has 25 times higher global warning potential compared to CO_2 [10]. Consequently, more attention is being paid to CH_4 generation.

The average emission of CH_4 to atmosphere is estimated at about 34 million tons per year [11]. It has been also determined that CH_4 emissions from municipal waste landfills contribute to total global CH_4 emission with 3-19% [12]. The share of landfill CH_4 in total emission of gases leading to green-house effect amounts 50% and the remaining half originates from the emissions of CH_4, N_2O, and CO_2 in communal waters and CO_2 generated during the process of incineration [13].

The negative impact of LFG on the environment can be reduced through its collection, adequate processing and further usage as fuel for running co-generation gas plants. In this way, waste can be used to achieve economic gains through the sale of produced energy. This method of using LFG as renewable energy source is usually subsidized, which is the same in the case of Serbia. However, despite the defined subsidies [14], the fact that waste management in Serbia is based on landfilling [15] and that morphological composition of waste, with more than 60% of biodegradable contents, is liable for CH_4 production, there are still no plants for utilization of LFG in Serbia. The aim of this paper is to determine potentials for constructing such plants, the investments needed for such undertakings and the payback period for the investments needed in case of Serbia.

Methodology

Serbia belongs to developing countries. Taking into consideration that the country is preparing to join the EU, one of the important steps is to take certain actions in the domain of solid waste management. The directives and the initiatives of the EU will have a major impact on solid waste management and the development of legislation in this area. Serbia also has an obligation to increase the share of energy from renewable sources in total energy consumption. According to the national plan, the use of renewable energy sources must amount 27% of the total consumption by 2020 [16]. In order to accomplish this goal, the sector of electricity must install additional 1092 MW with 10 MW derived from LFG [16]. Given that it is best to use LFG in co-generation plants with combined production of electricity and heat, in this paper the focus will be on the possibilities to build such plants at the existent municipal waste landfills in Serbia. Based on EU Landfill Directive [17] a new Serbian waste landfill regulation was adopted [18] as a part of national waste management (WM) strategy [19]. According to regulations, the share of biodegradable waste that can be landfilled is decreased by 25%, 50%, and 65% till the years 2016, 2019, and 2026, respectively, so this type of waste has to be collected and treated separately.

The data basis for co-generation potentials

Without the relevant data, any evaluations about the municipalities in which co-generation plants should be built first are impossible. Serbia has a huge co-generation potential. In order for this potential to be used properly, it must be recorded first. At this moment, there are no data if any institution has developed a system for logistic support for developing co-generation plants. Consequently, the first task of this study was to develop an active platform for data collection, data sorting, and data analysis which would serve as a logistic support for the construction of co-generation plants. The PHP programming language in combination with MySQL data basis was used in creating the platform. The data basis is now available online. Accessing the web portal one can easily check co-generation potentials at local and regional levels or at a state level. Figure 1 presents the regions of Serbia for WM, named as leading city in the region, in accordance to national WM strategy [19]. After selecting a region, user can select a municipality in a given region. When a municipality is selected, the basic data about it becomes available such as: the population, the area, important information about the climate, *etc.*

Figure 1. The WM regions in Serbia

The data basis of co-generation potentials does not only include co-generation potential of landfills, but also of existing power plants and plants for waste water. However, since this paper focuses only on co-generation potential of LFG, only the evaluation procedure for this option will be presented.

Modeling the process of LFG production

The starting point for the evaluation of the landfill potentials is to determine a rate of LFG generation. In order to obtain relevant results, an adequate mathematical model must be selected. According to the literature available on the topic, the amount of LFG generated per mass unit of waste ranges from 40 to 250 m^3 per ton of landfilled waste [20, 21]. The most popular software tools for modeling generation of LFG (LandGEM, Ukrain, and IPCC) use a first order equation to calculate the rate of waste decomposition. The first order models incorporate the effect of age (of waste) on the production of LFG [22]. Taking into consideration that LFG production is also influenced by climate characteristics [23], as well as management practices, the equation of first order can be extended to include these factors. This equation was applied in Ukrain model, which was developed by the US Agency for Environmental Protection through the Global Methane Initiative. Considering that this extended equation provides the best results, it is implemented in the data basis of co-generation potentials in Serbia. Based on the data for each municipality, this equation calculates the amount of generated LFG. The calculation is based on the formula:

$$Q_{\mathrm{LFG}} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} 2kL_0 \left(\frac{M_i}{10}\right) \mathrm{e}^{-kt_{i,j}} MCF \cdot F \tag{1}$$

where Q_{LFG} is the maximum expected LFG generation flow rate [m^3 per year], i – the one year time increment, n – the year of the calculation, j – the 0.1 year time increment, k – the CH_4 generation rate [per year], L_0 – the potential CH_4 generation capacity [m^3t^{-1}], M_i – the mass of solid waste disposed in the i^{th} year [t], $t_{i,j}$ – the age of the j^{th} section of waste mass M_i disposed in the i^{th} year (decimal years), MCF – the CH_4 correction factor, and F – the fire adjustment factor.

By applying the previous formula we get the amount of LFG generated in a year on the basis of landfilled waste quantity. Thus, to perform this kind of calculation the amount of waste landfilled per year must be determined for the time period beginning with its establishment as well as morphological composition of waste.

The evaluation of investments and their payback period

In order to simplify the evaluation, the capital total investments (TI) in a co-generation plant are calculated as the sum of investments in engines, investments in systems for biogas collection and processing, investments in electrical equipment and finally, investments in control system. The smaller investments are not taken into consideration since they are negligible in respect to capital TI.

The choice of proper engine model was carried out based on consumption of engine models available on the market, so that consumption per hour of an engine corresponds to hourly production of biogas at municipal waste landfills. Due to improper treatment of waste landfilled (lack of compaction or the corresponding landfill covers), the CH_4 oxidation in landfill cover soil often happens [24], and thus decreasing the amount that can be used for energy purposes. In addition, it is not possible to collect all LFG produced and use it in energy production. The efficiency of gas collection systems usually ranges from 50-75% [11]. Therefore, in this research, the adopted level of efficiency of gas collection system of 60% is considered as realistic. We also took into account decrease of biodegradable waste that will be landfilled according to Serbian Landfill Directive [18]. Since the certain share of biodegradable waste must be treated separately, the amount of LFG will also be decreased, which was affected on engines that have been chosen in our paper. The proper choice of an engine leads to a maximum level of efficiency and consequently to a more favorable payback period (PBP). For all landfills analyzed in this paper, the selection of two Otto engines was made according to the previously determined criteria.

The nominal power values of an engine, efficiency and its price are taken from the catalogues of manufacturers. These values are used to estimate the investments in engines.

The investments in systems for gas collection and gas processing depend on an area and a depth of a landfill but also on its contour. Landfill shape has an effect on the number of gas collection wells which should be installed at a landfill. According to some sources [12], the highest efficiency of a biogas collection system is achieved when collection wells whose diameter is 90 mm and whose coverage has a radius, R, of 25 m are installed at the distance of 1.73 R. The recommended diameter of pipes used in a pipeline for gas collection equals 160 mm. In addition to the investments in gas collection system, the calculations also take into account the investments in all those systems necessary for gas processing and preparations for its efficient use in engines.

The payback period (PBP) of investments is calculated according to eq. (2):

$$PBP = \frac{TI}{ANP} \tag{2}$$

where TI [€] is the total investment, and ANP [€ per year] – the net profit per year.

Based on the nominal power of an engine, ANP is calculated, taking into consideration the costs of system maintenance, eq. (3):

$$ANP = (APEE \cdot PE) - AMC \tag{3}$$

where $APEE$ is the electric energy production per year, PE – the price of produced electric energy, and AMC – the maintenance costs.

The $APEE$ per year is calculated for 8000 work hours while the PE in co-generation plant is determined based on the FEED-In tariff and equals 0,0691 €/kWh [14].

The maintenance costs depend on engine's electric power and they are calculated:

$$AMC = 4.9406 \cdot EP^{-0.2219} \cdot 10 \tag{4}$$

where EP [€ per MWh] is the nominal electric power of an engine.

Results and discussions

Since LFG generation rate depends on several parameters, such as amount of accumulated waste and its morphological composition, age, size, and height of a landfill, the first step in determining of the rate is to collect all the relevant information about these parameters.

Information about landfills in Serbia is taken from previously conducted research funded by the Ministry of Environment of the Serbian Government under the project entitled *Identification of landfills and dumping sites on the territory of the Republic of Serbia* [25]. By using the results of this project, the first cadaster of landfills was created and published in the report of Environment for the 2009 year by Serbian Environmental Protection Agency [25]. Beside the illegal dumping sites. all municipal landfill sites in 165 Serbian municipalities were identified and marked using proper global positioning system (GPS) equipment. For each landfill following parameters were determined:

– location (co-ordinates determined by using GPS equipment),
– extension of a site (landfill area),
– average height of a landfill,
– degree of waste compaction, and
– type of landfill cover.

Each landfill measured by GPS equipment was inserted into a digital map as a polygon, which was used in this study to determine the necessary infrastructure system for the collection of LFG. All the necessary information about the maintenance of landfills, also applicable to the calculation of the amount of generated gas, has been taken from previously conducted research [26].

According to eq. (1), LFG production rates are primarily affected by morphological composition and quantity of deposited waste. Municipalities in Serbia are required to conduct measurements of the amount and composition of municipal waste collected on their territory in accordance to the rulebook on the methodology for collection of data on composition and quantities of municipal waste at the territory of local self-government unit [27]. Therefore, in order to determine LFG generation rate, this study uses the only data available which is obtained through experimental measurements for ten municipalities in Serbia [28]. Within the study [28], the reference municipalities are associated with the respective municipalities of similar socio-economic characteristics. In this way, the resulting projections of amount and composition of communal waste by municipalities in Serbia were determined. For the period prior to 2008 measure, the trends of change in production of waste in the European countries, which have been keeping records for several previous decades, were used. Overall, nowadays 25-30% of additional waste is generated than in the 80's of the last century. The information on amount of waste produced in the previous period was obtained using data on gross domestic product and an algorithm of artificial neural networks. For projections of the amount of waste in the future, we used the recommendations established by the strategy of Serbia according to which the expected annual increase in waste quantity generation is 2%.

According to Stanisavljević *et al.* [15], 91% of total landfilled waste is placed on 51 locations. The volume of these landfills is more than 100,000 m^3 each and for each one of them techno-economic analysis for the construction of co-generation plants was carried out.

Table 1 shows the results of the analysis obtained using the previously described methodology. The table contains the data for 14 municipal landfills with acceptable PBP of less than 7 years. This PBP was chosen taking into account that an engine is an element of an installation that has the shortest service life. Consequently, for service life of an installation we have chosen service life of an engine. Most manufacturers guarantee service life of about 60,000 hours with 8,000 operating hours annually. The fact is that these engines could operate twice or even more times as long as guaranteed service life with proper maintenance. Still, we consider that only service life period is guaranteed.

Table 1 also presents data for selected co-generation units like their consumption of biogas, electric, and heat capacity as well as the overall efficiency of the plant for utilization of biogas from municipal waste landfills. Investment costs, maintenance costs, and the value of the annual production of electricity as well as the *ANP* from the sale of generated electricity are presented too. The last column of the table shows the PBP for the investment in the construction of the proposed plant.

Table 1. Techo-economic analysis of economically feasible CHP plants in Serbia

Municipality	LFG production [m^3h^{-1}]	Proposed engines	Consumption of an engine [m^3h^{-1}]	Electric power [kW]	Heat power [kW]	Efficiency [%]
Belgrade	4 800	BIEM 1130	420	1 130	1 124	83.8
		BIEM 1130	420	1 130	1 124	83.8
Subotica	470	MGW 260 BG	112	258	353	84.6
		FMB-230-BSM	75.7	185	215	81.9
Novi Sad	1 200	SEVA-DE 800C	290	800	752	83
		2G J526 B	202	526	553	82.9
Sabac	198	ENER-G 100B	48	100	151	81.1
		GS R6 75 BG	32	75	91	80.1
Arandlelovac	237	eco 125 BG	56	125	185	85.5
		eco 80 BG	37	80	125	85.7
Uzice	385	BG	91.4	265	218	82
		2G 150 BG	61.9	150	208	87.1
Kragujevac	570	ET 340 MA BG	141	340	410	81.9
		BG	90	250	232	83
Kraljevo	200	2G 120 BG	50	120	178	85.7
		FMB-100-BSM	39	81	128	84.1
Jagodina	260	2G 150 BG	61.9	150	208	87.1
		2G 100 BG	40.8	100	126	85.5
Krusevac	206	ENER-G 100B	48	100	151	81.1
		GS R6 75 BG	32	75	91	80.1
Aleksandrovac	255	2G 150 BG	62	150	208	87.1
		2G 100 BG	41	100	126	85.5
Novi Pazar	211	eco 110 BG	50	110	167	85.6
		CHP CE 75 B	33	75	104	83.6
Prokuplje	201	ENER-G 100B	48	100	151	81.1
		GS R6 75 BG	32	75	91	80.1
Nis	350	2G A206 BG	84	220	229	83.6
		eco 150 BG	65	150	183	79.57

Table 1. (Continuation)

Municipality	Investments in engines [€kW^{-1}]	Investments in systems for collection and processing [€]	Total investment [€]	Maintenance costs [€ per year]	Annual production of electric energy [MWh per year]	Annual net profit [€ per year]	Payback period [years]
Belgrade	446.4 446.4	1 513 383	2 522 306	187 715	18 080	1 061 613	2.38
Subotica	730 815.6	508 849	848 082	52 700	3 544	192 191	4.41
Novi Sad	500.8 575.9	1 055 377	1 758 961	123 509	10 608	609 503	2.89
Sabac	1001 1102	274 078	456 797	25 598	1 400	71 142	6.42
Arandjelovac	929 1078	303 626	506 043	28 881	1 640	84 443	5.99
Uzice	734 875	484 395	807 326	49 869	3 320	179 543	4.5
Kragujevac	666 738	616 292	1 027 153	65 886	4 720	260 266	3.95
Kraljevo	942 1074	300 022	500 036	28 468	1 608	82 645	6
Jagodina	875 1001	346 921	578 202	33 728	2 000	104 472	5.53
Krusevac	1001 1102	274 078	456 797	25 598	1 400	71 142	6.42
Aleksandrovac	875 1001	346 921	578 202	33 728	2 000	104 472	5.53
Novi Pazar	970 1102	283 933	473 222	26 693	1 480	75 575	6.26
Prokuplje	1001 1102	274 078	456 797	25 598	1 400	71 142	6.42
Nis	769.8 874.6	450 820	751 366	45 775	2 960	158 761	4.73

According to the results for the analyzed landfills, in 14 cases (out of 51) the investments in co-generation plants are economically feasible. The shortest PBP of 29 months would be at the landfill with the highest generation of LFG. The necessary investment there would be 2,522,306 €, while the annual electricity consumption of selected engines would reach 18,080 MWh. At the same time, the aforementioned engines could have the potential to produce 17.984 MWh of heat annually. It must be noted that the potential profit from the sale of produced heat energy was not taken into account when economic viability was being determined. The problem here exists in consumer demands. The energy produced by LFG could be distributed to citizens during the winter period or to consumers from industrial sector that have certain needs for heat energy throughout the year. Thus, the calculation would need to include a huge number of other important factors such as distance from locations where energy must be supplied, total demands for energy from users, possibilities for constructing heating distribution networks, *etc.* Taking into consideration the complexity of such calculations, the possibility of selling energy was completely neglected.

Among the proposed co-generation plants with satisfactory PBP, the one with the longest PBP generates 198 m^3 of LFG per hour. All the other landfills, which have the unsatisfactory PBP, generate less LFG. The amount of generated gas is insufficient to provide economic benefits from its utilization.

The TI for constructing co-generation units in 14 proposed landfills would reach 11,721,288 € while achieved *ANP* from the sale of produced electricity would amount 3,127,000 €. The overall investment PBP would be 61 months.

It should be noted that in addition to landfills that were analyzed in this research, there are seven regional sanitary landfills in Serbia that have been put into operation recently. These landfills are better suited for the utilization of LFG due to their better treatment of deposited waste. However, since the landfills began to work relatively recently it is necessary to deposit a certain amount of waste that could lead to waste decomposition and that could ensure the generation of LFG in amounts which are sufficient for its profitable use. Therefore, the analysis of LFG utilization on sanitary landfills will be a subject of future research.

Conclusions

Waste management in Serbia is based on landfilling. As a result of such year-long practice, a huge number of municipal waste landfills have been created where LFG has been generated. On one hand, this kind of gas is a major threat to the environment, while on the other it can be a valuable energy source if it is properly utilized.

In the present research, the database on co-generation potentials of municipal landfills on the territory of Serbia was created. In addition, techno-economic analysis of the possibilities of building co-generation plants on the existing landfills was performed. Based on the obtained results it is evident that 14 co-generation plants can be built with a total electrical nominal power of 7 MW and 7.9 MW of heating nominal power. Total investment for the construction of these plants would reach 11,721,288 € while the average payback period would be 61 months. It should be mentioned that the interest rates of any bank loans were not taken into consideration, as well as profit from the sale of heat energy.

The construction of the proposed plants, in addition to economic benefits, would reduce the pressure on the environment. Combustion of LFG in co-generation plants would reduce CO_2 equivalent emissions to 161,000 tons per year.

However, the implementation of waste-to-energy projects, in addition to meeting the technical conditions is also facing with socio-cultural problems [29]. Therefore, future research will be focused to finding solutions to these problems, as well as to finding funds for financing the projects of this kind.

Nomenclature

F – fire adjustment factor
i – year time increment
j – 0.1 year time increment
k – CH_4 generation rate [year^{-1}]
L_0 – potential CH_4 generation capacity [m^{3}t^{-1}]
MCF – CH_4 correction factor
M_i – mass of solid waste disposed in the i^{th} year [t]
n – year of the calculation
Q_{LFG} – maximum expected LFG generation flow rate [m^3 per year]
$t_{i,j}$ – age of the j^{th} section of waste mass M_i disposed in the i^{th} year (decimal years)

Acronyms

AMC – annual maintenance costs, [€ MWh^{-1}]
ANP – annual net profit, [€ per year]
APEE – annual production of electric energy, [€ per year]
CHP – combined heat and power
EP – nominal electric power of an engine [kW]
GPS – global positioning system
LFG – landfill gas
PBP – payback period [year]
PE – price of produced electric energy [€]
TI – total investment [€]
WM – waste management

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References

[1] Christensen, T., *Solid Waste Technology & Management*, Wiley Publication, London, UK, 2011
[2] Purcell, M., Magette, W. L., Prediction of Household and Commercial BMW Generation According to Socio-Economic and other Factors for the Dublin Region, *Waste Management, 29* (2009), 4, pp. 1237-1250
[3] Williams, I. D, Guton, H., Waste Minimization Using Behavior Change Techniques: a Case Study for Students, *Proceedings,* in: Waste Matters (Ed., P. Lechner), Integrating Views of the 2nd BOKU Waste Conference, Vienna, 2007, pp. 303-314
[4] Tchobanoglous, G., Kreith, F., *Handbook of Solid Waste Management, 2nd ed.*, The McGraw--Hill Companies Inc., New York, USA, 2002
[5] Giusti, L., A Review of Waste Management Practices and Their Impact on Human Health, *Waste Management, 29* (2009), 8, pp. 2227-2239
[6] ***, Eurostat Data Centre on Waste, http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/data//database, accessed September 1, 2014
[7] Young, P. J., Heasman, L. A., An Assessment of the Odour and Toxicity of the Trace Compounds of Landfill Gas, *Proceedings,* 8th International Landfill Gas Symposium, GRCDA Government Refuse Collection and Disposal Association, San Antonio, Tex., USA, 1985, pp. 93-113
[8] Zuberi M., Ali S., Greenhouse Effect Reduction by Recovering Energy from Waste Landfills in Pakistan, *Renewable and Sustainable Energy Reviews, 44* (2014), Apr., pp. 117-131
[9] Leme, M., *et al.*, Techno-Economic Analysis and Environmental Impact Assessment of Energy Recovery from Municipal Solid Waste (MSW) in Brazil, *Resources, Conservation and Recycling, 87* (2014), June, pp. 8-20
[10] Singh, B. K., *et al.*, Microorganisms and Climate Change: Terrestrial Feedbacks and Mitigation Options, *Nature Reviews Microbiology, 8* (2010), Nov., pp. 779-790
[11] Rubio-Romero, J. C, *et al.*, Profitability Analysis of Biogas Recovery in Municipal Solid Waste Landfills, *Journal of Cleaner Production, 55* (2013), Sep., pp. 84-91
[12] Martin, S., Fernandez, S., *Management of Biogas in Landfills of Municipal Solid Waste*, Government of the Principality of Asturias, Service Publica in Asturias, Oviedo, Spain, 2000
[13] Metz, B., *et al.*, The Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, N.Y., USA, 2007

[14] ***, Official Gazette of RS 08/13, Decrete on Incentive Measures for Privileged Power Producers Feed-in--Tarrifs, 2013
[15] Stanisavljevic, N., *et al.*, Methane Emissions from Landfills in Serbia and Potential Mitigation Strategies: a Case Study, *Waste Management and Research, 3,* (2012), 10, pp. 1095-1103
[16] ***, National Renewable Energy Action Plan of the Republic of Serbia in Accordance with the Tempate as per Directive 2008/29/EC (Decision 2009/548/EC). Project: The Development of Renewable Energy Framework in Serbia Serbian-Dutch Govermant-to-Govermant (G2G10/SB/9/2)
[17] ***, Council Directive 1999/31/EC of 26 April 1999 on the Landfill of Waste
[18] ***, Official Gazette of RS 92/10, Regulation on Waste Disposal on Landfills, 2010
[19] ***, Official Gazette of RS 29/10, The National Waste Management Strategy for the Period 2010-2019, 2010
[20] Humer, M., Lechner, P., Alternative Approach to the Elimination of Greenhouse Gases from Old Landfills, *Waste Management and Research, 17* (1999), 6, pp. 443-452
[21] Themelis, N., Ullo, P., Methane Generation in Landfills, *Renewable Energy, 32* (2007), 7, pp. 1243-1257
[22] Bogner, J., *et al.*, Comparison of Models for Predicting Landfill Methane Recovery Publication, Report, No. GR-LG 0075, SWANA – The Solid Waste Association of North America, Silver Spring, Md., USA, 1998
[23] Vujić, G., *et al.*, Influence of Ambience Temperature and Operational-Constructive Parameters on Landfill Gas Generation – Case Study Novi Sad, *Thermal Science, 14* (2010), 2, pp. 555-564
[24] Vujić, G., *et al.*, Barriers for Implementation of „Waste to Energy“ in Developing and Transition Countries: a Case Study of Serbia, *Journal of Material Cycles and Waste Management*, published online on April 15th 2015
[25] ***, SEPA, The Report of Environment for the 2009, Serbian Environmental Protection Agency, 2010
[26] ***, Faculty of Technical Science, MOPRORK – Determination of Contamination from Landfills and Monitoring Models, Risk Assessment, Determination of Amount of Waste with Modern Satellite Information Technology to Support the Implementation of Legislation (in Serbian), Faculty of Technical Science, Novi Sad, Serbia, 2012
[27] ***, Official Gazette of RS 61/10, The Rulebook on the Methodology for Collection of Data on Composition and Quantities of Municipal Waste at the Territory of Local Self-Government Unit, 2010
[28] Vujic, G., *et al.*, Fast Method for the Analysis of Municipal Solid Waste in Developing Countries – Case Study of Serbia, *Environmental Engineering and Management Journal, 9* (2010), 8, pp. 1021-2019
[29] Ragossnig, A., Vujic, G., Challenges in Technology Transfer from Developed to Developing Countries, *Waste Management and Research, 33* (2015), 2, pp. 93-95

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