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FEASIBILITY PRODUCTION OF GASEOUS BIOFUELS FROM WASTE IN THE REPUBLIC OF MOLDOVA

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Abstract. This paper deals with the cost of biogas and syngas produced from biodegradable waste was determined, at different capacities, which correspond to the powers of gas recovery plants for the purpose of electricity production in the conditions of the Republic of Moldova. The evolution rates of the annual cost of gases were determined. There were determined the levelized cost of biogas and syngas, which was compared with the levelized cost of natural gas. In order to ensure the comparability of these costs with that of natural gas, there are considered the levelized costs of biogases equivalent to the combustion heat of natural gas and the cost of natural gas which is one levelized for the same period. The cost of the syngas is higher than the biogas, this is due to the higher production technology cost and the lower heat value of syngas compared to the biogas. The production of gaseous biofuels, from biodegradable waste, in conditions of our country, proves to be profitable in the case of biogas, and of syngas - it is profitable at high powers.

Keywords: *biogas and syngas from biodegradable waste, annual costs, levelized cost, cost evolution rate.*

Rezumat. În lucrare este analizat costul biogazului și singazului produs din deșeuri biodegradabile pentru diferite capacități de producere, care corespund puterii generatoarelor utilizate în scopul producerii de energie electrică în condițiile Republicii Moldova. A fost determinată evoluția anuală a costului gazelor produse. A fost determinat costul nivelat al biogazului și singazului, care a fost comparat cu costul nivelat al gazelor naturale. În scopul asigurării comparabilității costurilor biogazului și singazului cu cel al gazelor naturale, a fost considerat un cost al biogazelor echivalent căldurii de ardere a gazelor naturale. Costul gazelor naturale este unul nivelat pe aceeași perioadă pentru care este determinat și costul nivelat al biogazelor. Se obține un cost al singazului mai ridicat decât cel al biogazului, lucru datorat costului majorat al tehnologiei de producere, precum și căldurii de ardere mai scăzute a singazului față de biogaz. Producerea biocombustibililor gazoși din deșeuri biodegradabile în condițiile țării noastre poate fi rentabilă în cazul biogazului, iar a singazului – doar la puteri mari.

Cuvinte-cheie: *biogaz și singaz din deșeuri biodegradabile, cost anual, cost nivelat, rata de evoluție a costului.*

Introduction

The Republic of Moldova is dependent on imported fossil energy resources [1]. In recent years, their cost is constantly increasing [2].

In these conditions, it is appropriate to focus on indigenous energy resources. The economy based on agriculture [3] implies the availability of biodegradable waste, coming from agriculture, food industry and municipal waste, suitable for biogas and syngas production [4].

Currently, environmental concerns [5] and rising prices for traditional fuels make this raw material valuable by converting it into gaseous biofuels. These can be used for the subsequent generation of electricity through mature technologies, such as the internal combustion engine [6-8].

In this paper, the problem of assessing the cost of biogas and syngas produced from biodegradable waste, in conditions of the Republic of Moldova is being discussed. For this, the method of the dynamic model of expenditure determination [6, 8, 9] will be used. Also, based on the obtained data, the annual rate of produced gases cost increase will be determined. The levelized cost of gaseous biofuels will be compared with the cost of imported natural gas.

1. The powers of gasification farms

Having established the availability of a significant quantity of biodegradable wastes, there could be converted into biogas and bio-syngas and, subsequently, used in cogeneration units on biogas of about 600 MW_{el} and on the singas - of about 250 MW_{el} [4].

The geographical distribution of the waste determines the possibility to install at the local level cogeneration units on biogas with powers between 50 and 100 kW_{el}, and on the syngas - installations with values of the powers between 100 and 200 kW_{el}.

The present work will operate with capacities of the gas generating units, which would cover the gas needs of the energy generating plants, which have powers corresponding to the specific ones at the locality and rayon level, function of waste available potential. In this context, there were accepted installations with powers of 50, 100, 500, 1000 and 5000 kW_{el} for the energy conversion of biogas, and for those for the conversion of the bio-syngas - of 50, 150, 750 and 1300 kW_{el}. For these capacities there will be estimated the costs of biofuels.

2. Calculation methodologies and common parameters considered

The cost of the produced gas ($c_{gas,t}$) will be determined by relating the annual calculation costs, CA_t, to the volume of gas produced in that year ($V_{gas,t}$) [10]. For the comparability of the obtained results, it will be operated with their levelized cost (*LCO)*, which is determined by reporting all the expenses recorded during the study period, expressed in present value (*CTA)*, to the total prezent volume of gases produced (*VTA),* [6, 8, 10].

The evaluation and comparison of gas generation instalations will be base on LCO. The solution for which it will present the minimum value will be the most attractive.

The uncertainty, of the initial data in the calculations, is provided by considering two scenarios: the optimistic (-) and the conservative scenario (+). The first scenario contains initial data leading to a minimum possible cost for the analyzed technology and the second scenario - with data leading to a maximum cost.

In the calculations a series of common parameters were accepted for all the considered powers of installations:

- *Duration of study*. For the technologies of energy production, the life span is 7 and 25 years. In the calculations, a single study duration was accepted for all technologies, equal to 15 years, provided for by the methodology for determining the tariffs for energy from renewable sources.
- *Low heat value of fuels*. Calculation values depend on the type of raw material, but it was accepted an average value for biogas: 18-22 $MJ \cdot m^{-3}$ and for syngas - 4-6 $MJ \cdot m^{-3}$.
- *The annual discount rate* for all technologies is 12%. This rate represents the weighted average value of the cost of the capital involved: 65% bank loan at the 8% rate and 35% equity at the 20% rate.

3. Initial data considered while determining the cost of biogas and syngas

For the conditions of our country, it is considered that the suitable option for biogas production is anaerobic fermentation under mesophilic thermal regime. This regime comprises temperatures between 20 and 45 °C and has the advantage of requiring a smaller amount of heat to ensure the stability of the fermentation process. The duration of the fermentation process is between 15 and 30 days.

It is admitted that the used biomas substrate in the biogas production has a cost equal to zero, the only cost being that of transporting it to the biogas plant, within the radius of the district in which the factory is established to be built.

The volume of the digester is chosen according to the density and the mass of the raw material used for biogas production and the retention time. The fermenter is sized so that the volume of the raw material does not exceed 80% of its total volume.

The costs considered for the production of biogas [11 - 18] are presented in the Table 1.

From the Table 1 it could be observed a variation of parameters that determine the cost of biogas depending on capacity of the digester, which, at its turn, depends on the power of electric generator operating on biogas.

Table 1

Initial data for calculating costs for different biogas generating units, kW

Nr.	Parameters	Notation	m.u.	50^-	50^+	100^-	100^+	500^-	500^+	1000^-	1000^+	5000^-	5000^+
1	Fermenter volume	V	m^3	98	127	184	230	849	1075	1702	2179	8465	10844
2	Fuel type							waste					
3	Fermenter specific investment	i_s	$€ \cdot m^{-3}$	450	600	230	400	150	220	95	150	50	90
4	Annual quota for operation and maintenance (O&M)	$k_{o\&M}$	$\% \cdot year^{-1}$	3	7	3	7	3	7	3	7	3	7
5	Annual growth rate of spending for O&M	$r_{o\&M}$	$\% \cdot year^{-1}$	5	7	5	7	5	7	5	7	5	7
6	Raw materials annual consumption	$V_{m.p.}$	$t \cdot year^{-1}$	829	1074	1555	1946	7171	9078	14379	18411	71509	91612
7	Vegetable mass cost in the reference year	$T_{m.p,0}$	$€ \cdot t^{-1}$	7	9	7	9	7	9	7	9	7	9
8	Annual growth rate of vegetable mass cost	$r_{m.p.}$	$\% \cdot year^{-1}$	3	5	3	5	3	5	3	5	3	5
9	Annual biogas production	V_t	thsd $m^3 \cdot year^{-1}$	59,5	90	130	163	601	761	1205	1543	5992	7677
10	Biogas low heat value	Q_{inf}	$M \cdot m^{-3}$	22	18	22	18	22	18	22	18	22	18
11	Annual growth rate of specific fuel consumption	r_b	$\% \cdot year^{-1}$	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
12	Annual degradation rate of the installation	r_{degr}	$\% \ year^{-1}$	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
13	Exchange rate	r_s	$€ \cdot \$^{-1}$	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2

It is worth mentioning that there was accepted the idea of feeding the digester in 80% with animal waste and 20% with vegetable mass, the cost of which is presented in the Table 1. At the same time, to generate units with capacities from 1000 kW, there will be considered a cost of waste transport of 1 Euro·tonne^{-1}, and to process the raw material and its loading in the digester it will be considered a cost of 1 Euro·tonne^{-1}.

Table 2 presents the financial characteristics of the gasifiers, [17 - 22].

Table 2

Initial data for calculation of the cost syngas

Nr.	Parameters	Notation	m.u.	Values							
1	Installed power of the generating unit	P	kW	50-	50+	150-	150+	750 -	750+	1300-	1300+
2	Fuel type			Biomass sawdust							
3	The efficiency of the installation	η	%	72	70	75	72	78	75	80	78
4	Specific investment in the unit	i_s	thsd €·MW^{-1}	2000	2200	1600	1800	1000	1200	700	900
5	Annual quota for O&M	$k_{O\&M}$	%·year^{-1}	4	5	4	5	4	5	4	5
6	Annual growth rate of spending for O&M	$t_{O\&M}$	%·year^{-1}	5,0	7,0	5,0	7,0	5,0	7,0	5,0	7,0
7	Vegetable mass cost in the reference year	$T_{m.p.}$	€·t^{-1}	80	100	80	100	80	100	80	100
8	Annual growth rate of vegetable mass cost	$r_{m.p.}$	%·year^{-1}	3,00	5,00	3,00	5,00	3,00	5,00	3,00	5,00
9	Low heat value of biomass	Q_{inf}	GJ·t^{-1}	18	13	18	13	18	13	18	13
10	Annual growth rate of specific raw material consumption	r_b	%·year^{-1}	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
11	Annual degradation rate of the installation	r_{degr}	%·year^{-1}	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
12	Exchange rate, €·$$^{-1}$	r_s	€·$$^{-1}$	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2
13	Exchange rate, lei·€$^{-1}$	$r_{s,*}$	lei·€$^{-1}$	19,8	19,8	19,8	19,8	19,8	19,8	19,8	19,8
14	Syngas low heat value	$Q_{inf,\ SN}$	MJ·m^{-3}	6	4	6	4	6	4	6	4

Similar to determine the biogas cost, two scenarios were considered for the syngas, conservative and optimistic, gasification plant efficiency between 65 and 80%, a combustion heat of the raw material of 13 and 18 MJ·kg^{-1} and an investment between 700 and 2 200 Euro·kW^{-1} and a transport cost of raw material of 1 Euro·tonne^{-1} was considered.

4. The annual and levelized cost of gaseous biofuels

The cost of biogas, as mentioned, is determined for each year of the study period ($C_{biog,t}$), as is presented in Table 3. It is worth mentioning that, 80% of agriculture residues and 20% corn silage mixing of raw material was considered.

Table 3

Biogas current cost of, Euro·thousand m^{-3}

Installed power	50 kW		100 kW		500 kW		1000 kW		5000 kW	
The year t	$C_{biog,t}$ -	$C_{biog,t}$ +	$C_{biog,t}$ -	$C_{biog,t}$ +	$C_{biog,t}$ -	$C_{biog,t}$ +	$C_{biog,t}$ -	$C_{biog,t}$ +	$C_{biog,t}$ -	$C_{biog,t}$ +
0	141,04	217,18	86,09	155,92	66,11	100,79	61,91	88,90	50,67	70,52
1	143,06	223,34	87,37	160,39	67,11	103,73	62,74	91,25	51,34	72,36
2	145,16	229,90	88,69	165,14	68,16	106,85	63,59	93,73	52,04	74,30
3	147,33	236,89	90,06	170,19	69,24	110,16	64,47	96,37	52,75	76,36
4	149,59	244,32	91,48	175,56	70,35	113,68	65,37	99,16	53,49	78,53
5	151,94	252,24	92,96	181,27	71,51	117,41	66,31	102,12	54,25	80,83
6	154,38	260,67	94,49	187,36	72,71	121,37	67,29	105,25	55,04	83,26
7	156,91	269,67	96,08	193,83	73,96	125,58	68,30	108,58	55,85	85,83
8	159,54	279,26	97,73	200,73	75,25	130,05	69,34	112,11	56,69	88,55
9	162,29	289,48	99,44	208,07	76,58	134,81	70,42	115,86	57,56	91,44
10	165,14	300,40	101,21	215,90	77,97	139,86	71,53	119,84	58,46	94,49
11	168,10	312,04	103,06	224,25	79,41	145,24	72,69	124,06	59,39	97,72

Continuation Table 3

12	171,19	324,48	104,98	233,15	80,90	150,96	73,89	128,55	60,35	101,15
13	174,41	337,75	106,97	242,65	82,45	157,05	75,14	133,31	61,34	104,78
14	177,77	351,94	109,05	252,78	84,06	163,54	76,42	138,38	62,37	108,63
15	181,26	367,09	111,20	263,59	85,73	170,44	77,76	143,76	63,43	112,71

Noting a change in biogas cost, for the scenarios and powers considered, the annual cost evolution rate ($r_{C.biog}$), for the study period, was determined, Table 4.

Table 4

Evolution rates of biogas cost, %·year^{-1}

Powers, kW	50	100	500	1000	5000
$r_{C.biog}$ -	1,69	1,72	1,75	1,54	1,52
$r_{C.biog}$ +	3,58	3,58	3,58	3,27	3,18

At the same time, in order to obtain a single cost for the entire study period, below, in Table 5 is presented the levelized cost of biogas (LCO_{biog}), for the admitted capacities.

Table 5

Levelized cost of biogas, Euro·thousand m^{-3}

Installed power, kW	50	100	500	1000	5000
LCO_{biog} -	154,93	94,81	72,95	67,47	55,17
LCO_{biog} +	264,56	190,09	123,07	106,55	84,21

The obtained biogas has a low heat value of 18-22 MJ·m^{-3}, but if it had a one equivalent to the natural gas, of 33.5 MJ·m^{-3}, the cost of equivalent, to natural gas (NG), biogas ($LCO_{biog,\ ech}$) would be that indicated in Table 6 and would have a variation between 84.01and 492.38 Euro·thousand m^{-3}.

Table 6

Levelized cost of biogas equivalent NG, Euro·thousand m^{-3}

Installed power, kW	50	100	500	1000	5000
$LCO_{biog,\ ech}$ -	235,92	144,37	111,08	102,74	84,01
$LCO_{biog,\ ech}$ +	492,38	353,78	229,05	198,30	156,72

The cost of any finished product represents the economic efficiency indicator of its production process, so in the case of producing the syngas, its cost indicates the efficiency of the gasification plant and allows its comparison with the traditional fuel. Table 7 presents the cost of the syngas obtained for the years of the study period.

Table 7

Syngas current cost of, Euro·thousand m^{-3}

Installed power	50 kW		150 kW		7 500 kW		1 300 kW	
The year t	$C_{sing,t}$ -	$C_{sing,t}$ +	$C_{sing,t}$ -	$C_{sing,t}$ +	$C_{sing,t}$ -	$C_{sing,t}$ +	$C_{sing,t}$ -	$C_{sing,t}$ +
0	161,69	210,39	135,27	182,29	96,94	140,95	76,96	118,27
1	164,95	217,33	138,10	188,54	99,13	146,15	78,82	122,89
2	168,35	224,69	141,03	195,15	101,40	151,66	80,75	127,77
3	171,88	232,49	144,08	202,15	103,75	157,49	82,75	132,95

Continuation Table 7

4	175,55	240,76	147,25	209,58	106,20	163,66	84,83	138,42
5	179,38	249,52	150,54	217,44	108,75	170,20	86,99	144,21
6	183,36	258,82	153,98	225,78	111,40	177,12	89,24	150,34
7	187,50	268,68	157,55	234,63	114,15	184,45	91,57	156,83
8	191,81	279,14	161,26	244,00	117,01	192,22	93,99	163,70
9	196,30	290,25	165,13	253,95	119,98	200,46	96,51	170,98
10	200,99	302,04	169,16	264,51	123,08	209,18	99,12	178,69
11	205,86	314,56	173,36	275,72	126,30	218,44	101,84	186,86
12	210,95	327,86	177,73	287,61	129,65	228,25	104,67	195,51
13	216,25	341,99	182,29	300,24	133,13	238,65	107,61	204,69
14	221,78	357,00	187,04	313,66	136,76	249,69	110,66	214,41
15	227,55	372,96	191,99	327,90	140,54	261,39	113,84	224,71

For the obtained values there was determined the annual evolution of the cost of the syngas (r_{Csing}), Table 8.

Table 8

Evolution rates of biosyngas cost, %·year^{-1}

Power, kW	50	150	7500	1300
r_{Csing} -	2,32	2,37	2,52	2,66
$r_{C.sing}$ +	3,91	4,02	4,22	4,39

It was determined the levelized of syngas cost(LCO_{sing}), Table 9, a value that may be compared with the levelized cost of natural gas for the same period.

Table 9

Levelized cost of biosyngas, Euro·thousand m^{-3}

Installed power, kW	50	150	7500	1300
LCO_{sing} -	205,08	175,56	139,25	110,5
LCO_{sing} +	285,83	244,64	194,7	168,2

To be able to perceive the value of the produced biosyngas, Table 10 presents its cost expressed in the energy equivalent of natural gas.

Table 10

Levelized cost of biosyngas equivalent NG, Euro·thousand m^{-3}

Installed power, kW	50	150	7500	1300
$LCO_{sing, ech}$ -	1 029,06	864,24	625,33	500,99
$LCO_{sing, ech}$ +	1 466,52	1 279,70	1 004,39	852,91

From the above table it can be observed that the cost of the syngas is higher than the biogas, this is due to the higher production technology cost and the lower heat value of syngas compared to the biogas.

5. Comparative analysis of the obtained results

The comparability of results, as well as investment projects, implies the assurance of similar conditions, which meet the same comparison criteria [10]. Thus, in order to ensure the comparability of the cost of biogas and syngas with that of natural gas, there are considered levelized costs of biogases equivalent to the combustion heat of natural gas, and the cost of natural gas is one levelized (LT_{NG}) for the same period, for which the levelized costs of biogases was determined.

Analyzing the evolution of the import cost of natural gas for 15 years [23], as it is presented in Table 11, it can be observed an increase of 9.12%·$year^{-1}$, for monetary units expressed in Euro·thousand m^{-3}. Maintaining this evolution for a period of 15 starting with 2020, it can be obtained a 608 Euro·thousand m^{-3} levelized import cost for natural gas.

Table 11

Dynamics of the import cost of natural gas in the Republic of Moldova 2004-2018

Year	u.m.	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Real cost	USD·thsd m^{-3}	66.20	68.48	120.01	155.61	209.06	237.47	225.10	305.40	354.58	341.62	377.07	244.40	193.5	165.50	245.66
Model cost	USD·thsd m^{-3}	106.01	114.49	123.65	133.54	144.23	155.77	168.23	181.69	196.22	211.92	228.88	247.19	266.96	288.32	311.39
The approximation equation Cost = $106{,}01e^{0.0772\,t}$, Annual growth rate - 8.00%																
Real cost	lei·thsd m^{-3}	816.11	862.85	1576.02	1888.47	2172.07	2639.05	2783.71	3584.47	4294.69	4301.18	5293.61	4598.65	3855.26	3060.13	4127.85
Model cost	lei·thsd m^{-3}	1103.0	1231.95	1375.97	1536.82	1716.49	1917.15	2141.28	2391.61	2671.20	2983.47	3332.26	3721.81	4156.91	4642.88	5185.66
The approximation equation Cost = $1102e^{0{,}1109t}$, Annual growth rate - 11.69%																
Real cost	Euro·thsd m^{-3}	53.24	54.97	95.56	113.77	142.04	169.99	169.74	219.41	275.95	257.18	284.11	220.05	174.80	146.92	208.01
Model cost	Euro·thsd m^{-3}	76.71	83.71	91.34	99.66	108.75	118.66	129.47	141.28	154.15	168.20	183.54	200.27	218.52	238.44	260.17
The approximation equation Cost = $76{,}714e^{0{,}0875t}$, Annual growth rate - 9.12%																

Figure 1 presents the results of the comparison of these two costs, which have highlighted the comparability and the biogas production profitability, including at low powers in the conditions to maintain the recorded evolution of the import cost of natural gas.

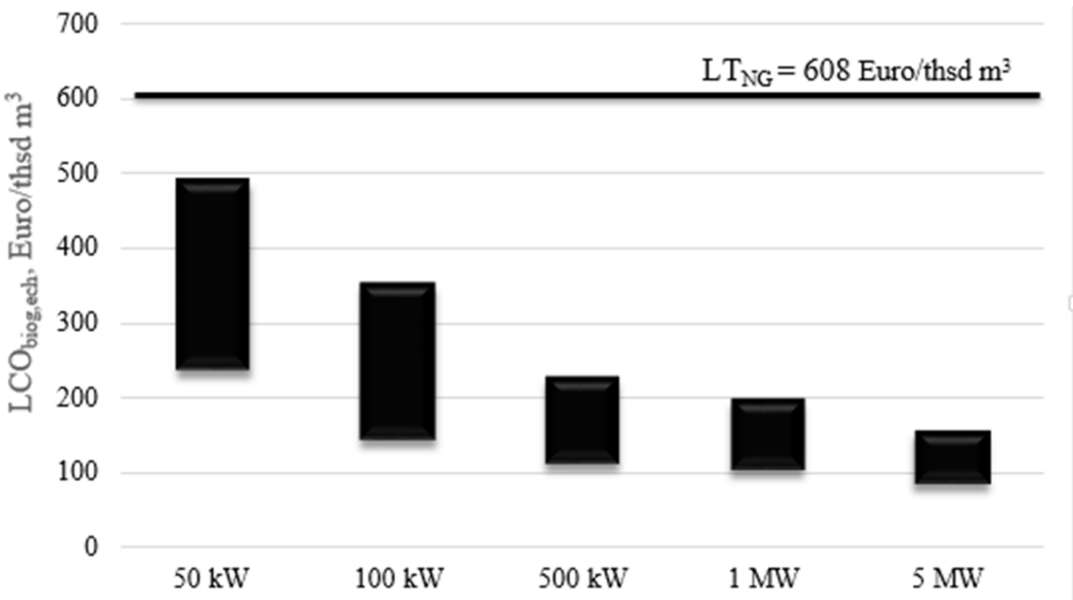

Figure 1. The equivalent levelized cost of biogas and import levelized cost of NG.

Figure 2 illustrates that the production of syngas is profitable only at high powers and under the conditiond of optimistic scenario. The cost of the production technology disadvantages it in front of natural gas and biogas, produced from waste under the conditions of our country.

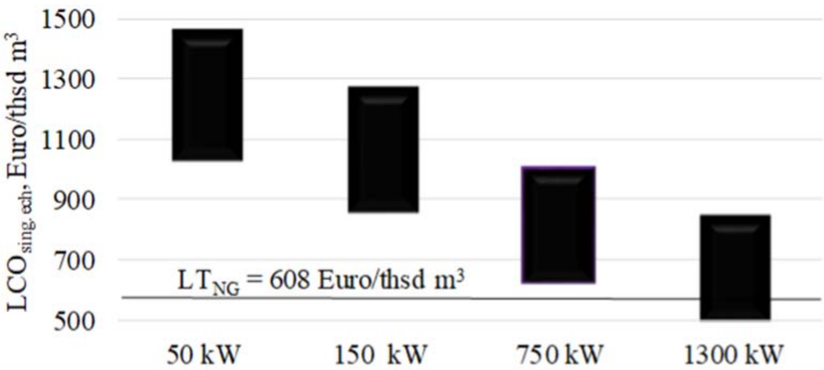

Figure 2. The equivalent levelized cost of syngas and import levelized cost of NG

Thus, the production of gaseous biofuels, from biodegradable waste, in conditions of our country, proves to be profitable in the case of biogas, and of syngas - it is profitable at high powers.

Conclusions

1. An evaluation of gaseous biofuels cost price, obtained from waste, within local conditions was carried out in the paper. The calculations were performed for two scenarios: an optimistic one, which includes values of the initial data leading to a minimum cost, and a conservative one, which implies values of the initial data leading to a maximum cost.
2. The data obtained show that the production of biogas is attractive in case of maintaining the natural gas cost evolution over the last 15 years, and of the syngas only for powers greater than 1 MW and within the optimistic scenario.
3. The levelized cost of biogas expressed in heat value equivalent to natural gas varies between 84 Euro/thousand m^3, for high powers within optimistic scenario, and 492 Euro/thsd m^3, and of the syngas between 501 and 1 466 Euro/thsd m^3.
4. Starting from the fact that there are technologies for the production of gaseous biofuels, which prove to be economically feasible, it would be advisable to orient the investors towards exploiting the potential of biodegradable waste existing in the country.

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