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COST ANALYSIS OF ENERGY PRODUCED FROM BIOGAS AND BIOSYNGAS

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Abstract. This paper deals with the livelised cost of electricity from gaseous biofuels, such as biogas and bio-syngas, produced from biodegradable waste, using different technologies (internal combustion engines, gas turbine, fuel cells) at different capacities in the conditions of the Republic of Moldova, in case of non-use and use of thermal energy. The levelized cost of electricity was compared with the levelized energy supply tariff. Thus, it was demonstrated the feasibility of electricity production from biogas using internal combustion engines at any installed power, gas turbines with installed power starting from hundreds of kW and high power fuel cells, and the use of the bio-syngas for energy production is attractive in internal combustion engines and gas turbines with power greater than 1 MW. The technology of internal combustion engines proves to be more attractive, compared to gas turbine and fuel cells installations.

Keywords: *livelised costs of electricity energy, gaseous biofuels, biogas, bio-syngas.*

Rezumat. În acest articol este determinat costul nivelat al energiei electrice produse din biocombustibili gazoși, precum biogazul și bio-singazul, produse din deșeuri biodegradabile, utilizând diferite tehnologii (motor cu ardere internă, turbine cu gaze, pile de combustie) la diferite capacități, fără valorificarea energiei termice și cu valorificarea parțială a ei, în condițiile Republicii Moldova. Costul nivelat al energiei electrice produse a fost comparat cu tariful nivelat de furnizare a energiei electrice. Astfel, a fost demonstrată fezabilitatea producerii energiei electrice din biogaz, utilizând motoare cu ardere internă de orice capacitate, turbine cu gaze cu puteri instalate ce încep de la câteva sute de kW și pile de combustie de puteri mari, iar producerea energiei electrice din bio-singaz este atractivă în cadrul motoarelor cu ardere internă și turbine cu gaze de puteri mai mari de 1 MW. Tehnologia motoarelor cu ardere internă se dovedește a fi mai atractivă comparativ cu turbinele cu gaze și pilele de combustie.

Cuvinte-cheie: *cost nivelat al energiei electrice, biocombustibili gazoși, biogaz, bio-singaz.*

Introduction

The challenges of the last decade related to climate change [1], security of energy supply, including electricity, in the context of importing of about 75% consumed electricity [2], the Republic of Moldova requires a profound change in terms of energy sources, how energy is delivered and consumed and require the search for alternative solutions to meet energy needs. Our country needs such a change, by promoting distributed production energy sources, as well as renewable energy sources.

Our country being one with an agricultural based economy denotes the abundant existence of biomass, so the generation of energy from gaseous biofuels, produced from biodegradable waste, by applying modern technologies, could be one of the solutions, all the more so because the regional distribution of biodegradable waste allows this [3].

This paper deals with an analysis of economic performance of internal combustion engines technologies (*MAI*), gas turbine (*ITG*) and fuel cells (*FC*) for the energy generation from biogas and silas, produced from biodegradable waste, by assessing the levelized cost of electricity (*CNAE*) in the conditions of the Republic of Moldova. For this, the static-equivalent model of expenditure determination [4 - 6] will be used and the results will be compared with the levelized electricity supply tariff.

1. Calculation methodologies and common parameters considered

The basic criterion in assessing the competitiveness of energy sources, as a rule, is the minimum levelized cost of energy produced during the study period. The cost of produced electricity will be determined by reporting all the expenses recorded during the study period, expressed in present value, *CTA*, to the total present volume of the energy produced, *ETA*.

It is proposed to analyse the cost of energy produced in the thermoelectric power plant (CTE) and in the cogeneration regime (CET). For the energy produced in cogeneration, its cost is determined based on the remaining expenses method [4 - 6].

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 was accepted for all the considered technologies:

- *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.
- *Capacity factor*. In the calculations, for all the technologies, it was considered the same duration of use of the maximum electric power, of 5,000 h·year^{-1} ($T_{M,W}$), and in using heat case it is considered that it will be produced for a duration of 2,000 h·year^{-1} ($T_{M,Q}$).
- *Low heat value of fuels* was accepted an average value for biogas: 18-22 MJ·m^{-3} and for syngas - 4-6 MJ·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.
- *The cost of thermal energy at the reference source* is an important indicator on which the cost of produced electricity depends on cogeneration. In order not to disadvantage one of produced energies, its cost was accepted at the level of 90 Euro·Gcal^{-1} in the reference year for the units with powers of up to 100 kW, a tariff of 70 Euro·Gcal^{-1} for powers of up to 500 kW, 50 Euro·Gcal^{-1} for powers up to 1000 kW and 40 Euro·Gcal^{-1} for powers over 1,000 kW.

These values correspond to the current tariff in national public thermal networks [7 - 10], for which an annual rate of evolution of 0.7% was accepted.

- *The levelized costs of biofuels*, used for energy production, are prezented in Table 1 for biogas and in Table 2 for biosyngas.

Table 1

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

Table 2

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

2. Technologies considered to use gaseous biofuels

Gaseous fuels are very convenient to use in energy production plants. First of all, their state of aggregation allows their transport from the collection container to the energy installation without making a significant effort, it is sufficient to install a pipe with a tap at the end. Second, the complete chemical combustion of these fuels offers an advantage over solid and liquid fuels, which require intervention to remove ash and slag, resulting from the combustion process. In view of the above, an important conclusion emerges: gaseous biofuels can be used in a wide variety of installations based on various technologies.

The modern society needs four forms of energy: thermal energy for heating homes, electricity for supplying electric receivers, fuels for preparing food and fuel for transportation. Biogas and syngas can meet any of these needs. Following, briefly there will be presented the possible facilities for their use for energy purposes.

In this paper, technologies for the use of biogases will be considered for the purpose to produce energy: the internal combustion engine, the fuel cells and gas turbine installations. Once the obtained gases are clean fuels, it would be appropriate to analyze their use also in cogeneration plants, for the technologies considered.

The internal combustion engine is the most attractive, accessible and proven technology for the conditions of the Republic of Moldova. The unitary powers of these installations are available in a very wide range, from tens of kW to thousands of kW.

Biogas and syngas can be introduced into the cylinders of the plant, where the ignition of the fuel takes place. The explosion produced causes the moving of pistons - rotational motion, which is transmitted to the shaft of the electric generator.

A gas turbine is a thermal turbine, which uses the enthalpy drop of a gas or gas mixture to produce by means of blades that rotate around an axis a quantity of mechanical energy available at the turbine coupling. The gas turbine is also known as the gas turbine installation. Gas turbines are a mature technology for power generation, with capacities ranging from a few kW to tens of MW. They allow the use of different types of fuels, even their combined use.

Still a modern cogeneration technology, it is based on the use of fuel cells. In this case, the biogas is continiously introduced into the compartment from the anode, and the oxidant, the atmospheric oxygen, continuously supplies the compartment located on the cathode side. At the level of the electrodes an electrochemical reaction takes place, after which the electric current is produced. The heat dissipated by the battery can be used to heat the water. This technology is still expensive but still promising. With its cheapness, in the future it can get a very wide use.

3. Technical-economic parameters of biofuel technologies

Technologies for using biogas

For cogeneration plants (CET) with MAI the investments range are between 820 and 2,100 Euro·kW^{-1} [11 - 15], the biogas purification system is at the level of 500 Euro·kW$_{el}$ [16]. These power plants are an electric efficiency of about 28÷43 % [11, 13 - 19], operating and maintenance expenses were accepted at 4÷5.5 % [18-22], the capacity degradation rate of production, as well as the annual increase rate of fuel consumption, according to the analysis of the evolution of these indicators at the existing plants, constitutes about 0.5%, as are presented în Table 3.

Table 3

Indicators used in calculation of cost of energy produced in the CET with MAI

Power, kW	Indicators					
	i_{sp}, Euro·kW^{-1}	η_{el} , %	η_{gl} , %	$k_{O\&M}$, %	$T_{M,W}$, h·year^{-1}	$T_{M,Q}$, h·year^{-1}
< 50	1 540 - 2 100	26-30	56-67	4,0-5,5	5 000	2 000
50-100	1 475 – 1 860	31-40	77-85	4,0-5,5	5 000	2 000
100-500	1 100 – 1 400	34-37,5	84,6-86,4	4,0-5,5	5 000	2 000
500-1000	980 – 1 270	32,2-40,2	78,3-86,6	4,0-5,5	5 000	2 000
> 1000	820 – 1 150	37-40,5	76,7-87,8	4,0-5,5	5 000	2 000

In the case of ITG, the investments vary between 800 and 2 250 Euro·kW^{-1} [11 - 15], the electric efficiency between 22 and 34%, and the global one, in the case of cogeneration - between 59 and 86% [11-19, 23, 24], operating and maintenance expenses are considered at the level of 5-6% of the investment, Table 4.

Table 4

Indicators used in calculation of cost of energy produced in the CET with ITG

Power, kW	Indicators					
	i_{sp}, Euro·kW^{-1}	η_{el} , %	η_{gl} , %	$k_{O\&M}$, %	$T_{M,W}$, h·year^{-1}	$T_{M,Q}$, h·year^{-1}
< 50	1 650 – 2 250	22 - 28	59 - 62	5- 6	5 000	2 000
50-100	1450 – 2 000	23 - 30	60 - 66	5- 6	5 000	2 000
100-500	1250 – 1750	24 – 31	62 - 72	5- 6	5 000	2 000
500-1000	1000 – 1500	24– 32	64 -78	5- 6	5 000	2 000
> 1000	800 – 1 200	26 - 34	66 -86	5- 6	5 000	2 000

For fuel cells an investment of 3,600 - 6,000 Euro·kW^{-1} has been identified [11 - 15, 25, 26], the electric efficiency has values between 30 and 45%, and the global one, in the case of cogeneration - between 70 and 85% [11 - 19], the operating and maintenance expenses are considered at the level of 3.6 - 4.5% of the investment, Table 5.

Table 5

Indicators used in calculation of cost of energy produced in the CET with FC

Power, kW	Indicators					
	i_{sp}, Euro·kW^{-1}	η_{el} , %	η_{gl} , %	$k_{O\&M}$, %	$T_{M,W}$, h·year^{-1}	$T_{M,Q}$, h·year^{-1}
< 50	5 000 - 6 000	30 - 35	70 - 75	3,6 – 4,5	5 000	2 000
50-100	4720 – 4 900	33 - 38	73 - 77	3,6 – 4,5	5 000	2 000
100-500	4 440 – 4 600	35 – 40	75 - 80	3,6 – 4,5	5 000	2 000
500-1000	3 900 – 4 250	36 – 43	78 -83	3,6 – 4,5	5 000	2 000
> 1000	3 600 - 3 800	38 - 45	80 -85	3,6 – 4,5	5 000	2 000

Technologies for using syngas

In the case of MAI operating on the syngas, common values for electrical efficiency, between 25 and 30%, with a global one, in the case of cogeneration, of 70-80% [11, 13-21], operating and maintenance costs of 10-15 Euro·MWh^{-1} [16-21] and the cost of the investment varying from 550 up to 1,900 Euro·kW^{-1} [11, 13-16, 20].

ITG involve investments of about 550 - 1,700 Euro·kW^{-1} [11, 13-16], can develop an electric efficiency of 30-35% and a global one, in the case of cogeneration, of 70-80%, operating and maintenance expenses constitute about 10-15 Euro·MWh^{-1} [19-24].

FC, being a young technology and at an early stage of commercialization, have a higher investment value, compared to ITG and MAI. In the case of syngas using, the same costs are admitted as in the case of biogas using.

4. The levelized cost of energy produced from gaseous biofuels

Electricity produced from biogas has different values, both for the same technology applied to different values of installed power, as well as produced by different technologies, as it is shown in Table 6.

Table 6

Cost of electricity produced from biogas in MAI, ITG and FC, cEuro / kWh

Installed power	50 kW		100 kW		500 kW		1000 kW		5000 kW	
	CTE	CET	CTE	CET	CTE	CET	CTE	CET	CTE	CET
MAI										
$CNAE_{biog}$ -	15,16	11,62	10,15	6,55	7,87	5,62	6,91	5,53	5,71	4,96
$CNAE_{biog}$ +	30,54	28,32	20,86	11,12	13,69	11,12	12,46	10,78	9,32	8,77
ITG										
$CNAE_{biog}$ -	17,15	14,18	11,79	9,31	9,53	8,15	8,01	7,33	6,30	5,61
$CNAE_{biog}$ +	34,99	31,22	26,06	22,43	17,96	16,02	14,89	13,87	11,74	10,72
FG										
$CNAE_{biog}$ -	27,71	25,62	22,49	19,38	21,02	18,57	18,41	17,66	16,62	15,60
$CNAE_{biog}$ +	43,	41,29	33,13	30,15	27,68	25,18	24,32	23,26	21,14	20,09

MAI is supplied with biogas product in the volume digestion which provides the required volume of gas to supply the electric generator with considerable power. For this technology there is a variation of electricity costs from 5.71 cEuro·kWh^{-1} for 5 MW power up to 30.54 cEuro·kWh^{-1} for 50 kW power, in case of non-thermal energy use and from

4.96 cEuro·kWh^{-1} up to 28.32 cEuro·kWh^{-1}, for the same powers, but in case of partial recovery of thermal energy, in CET.

ITG is less attractive compared to that of MAI. For this technology there is a variation of electricity cost from 5.61 cEuro·kWh^{-1} for high powers up to 31.22 cEuro·kWh^{-1} in case of partial recovery of the thermal energy and the value between 6.3 and 34, 99 cEuro·kWh^{-1} in case of non-use of thermal energy.

The data obtained allow us to observe that the production of energy with fuel cells leads to an average leveled cost of about 16.62 cEuro·kWh^{-1} (electricity production only) and 15.60 cEuro·kWh^{-1} (cogeneration) - in the optimistic scenario for 5 000 kW. In the conservative scenario, the average level cost of electricity produced results at a level of 21.14 (electricity only) and 20.09 cEuro·kWh^{-1} (cogeneration), all for the same power.

The cost of electricity produced by syngas through the technologies considered, being similar to those of biogas recovery, is presented in Table 7.

MAI being a mature technology has low investment costs, but due to the low heat of syngas, the cost of electricity produced within it is quite high. Thus, we observe an average cost of electricity ranging from 19.64 cEuro·kWh^{-1} for powers of 1 300 kW in case of partial recovery of the thermal energy in the conservative scenario, up to values of 69.03 cEuro·kWh^{-1} for powers of 50 kW for the conservative scenario. In the case of non-use of thermal energy, the cost of electricity is higher ranging from 21.71 to 73.73 cEuro·kWh^{-1} for the same scenarios and powers.

Table 7

Cost of electricity produced from syngas in MAI, ITG and FC, cEuro / kWh

Installed power	50 kW		150 kW		750 kW		1300 kW	
	CTE	CET	CTE	CET	CTE	CET	CTE	CET
MAI								
$CNAE_{sing}$ -	44,29	40,15	37,21	33,05	27,41	25,64	21,71	19,64
$CNAE_{sing}$ +	73,73	69,03	64,38	58,61	50,96	47,92	42,83	39,08
ITG								
$CNAE_{sing}$ -	38,20	35,07	32,01	30,28	23,78	24,85	19,05	18,43
$CNAE_{sing}$ +	62,39	59,10	54,16	52,99	43,12	47,31	36,43	36,24
FC								
$CNAE_{sing}$ -	53,05	53,13	43,65	42,44	31,99	32,08	26,96	26,52
$CNAE_{sing}$ +	79,51	79,53	64,75	62,66	49,51	49,13	41,73	40,87

ITG appear to be more attractive compared to syngas MAI, the data obtained show that at 1.3 MW, the single-source ITG can produce electricity at a cost of 18.43 cEuro·kWh^{-1} in cogeneration regime and 19.05 cEuro·kWh^{-1} without using the heat.

FC also in the case of the conversion of the syngas into electricity proves to be less attractive, the costs being significant - with an average value level of approx. 26.96 cEuro·kWh^{-1} (CTE) and 26.52 cEuro·kWh^{-1} (CET) - in the optimistic scenario for 1.3 MW.

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 [5]. Thus, in order to ensure the comparability of electricity cost produced from biogas and syngas with that of electricity tariff supply, there are considered levelized costs of energy, and the levelized supply electricity tariff ($CNAT_W$) for the same period.

Analyzing the evolution of supply electricity tariff for the last 15 years, [28], as they are presented in Table 8, it is observed an increase of 5,67%·$year^{-1}$, for monetary units expressed in Euro·kWh^{-1}. Maintaining this evolution for a period of 15 starting with 2020, it obtains a 17.24 cEuro·kWh^{-1} levelized supply electricity tariff from the medium voltage public grid.

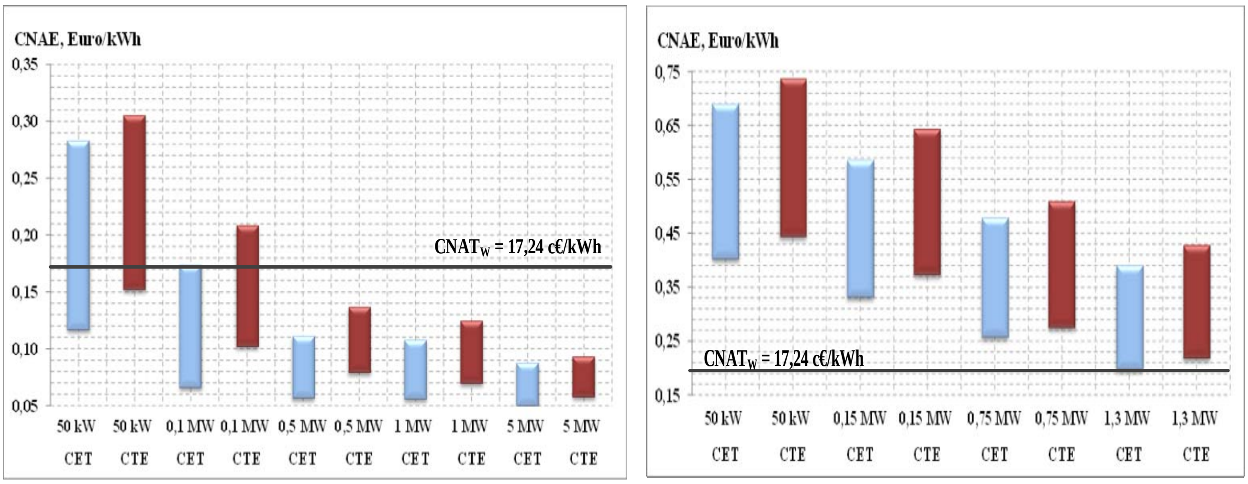
Table 8

Dynamics of the supply electricity tariff 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	bani·kWh^{-1}	74,00	74,00	74,00	84,14	107,81	115,00	133,80	145,72	155,96	160,00	156,86	167,76	195,28	193,77	193,77
Model cost	bani·kWh^{-1}	68,04	73,60	79,62	86,13	93,16	100,78	109,01	117,92	127,56	137,99	149,26	161,46	174,66	188,93	204,38
The approximation equation Tarif =68,042e0,0788t , Annual growth rate - 8,17%																
Real cost	cUSD·kWh-1	6,00	5,87	5,64	6,93	10,38	10,35	10,82	12,42	12,88	12,71	11,17	8,92	9,80	10,48	11,53
Model cost	cUSD·kWh-1	6,54	6,84	7,16	7,48	7,83	8,19	8,57	8,96	9,37	9,80	10,25	10,72	11,22	11,73	12,27
The approximation equation Tarif = 6,5401e0,0451t , Annual growth rate - 4,60%																
Real cost	cEuro· kWh-1	4,83	4,71	4,49	5,07	7,05	7,41	8,16	8,92	10,02	9,57	8,42	8,03	8,85	9,30	9,76
Model cost	cEuro· kWh-1	4,73	5,00	5,28	5,58	5,90	6,23	6,59	6,96	7,36	7,77	8,21	8,68	9,17	9,69	10,24
The approximation equation Tarif = 4,7325e0,0553t , Annual growth rate - 5,67%																

The cost of electricity, produced from the gaseous biofuels considered, at the specific costs of their recovery units, has different values both for technology and installed power, as illustrated below.

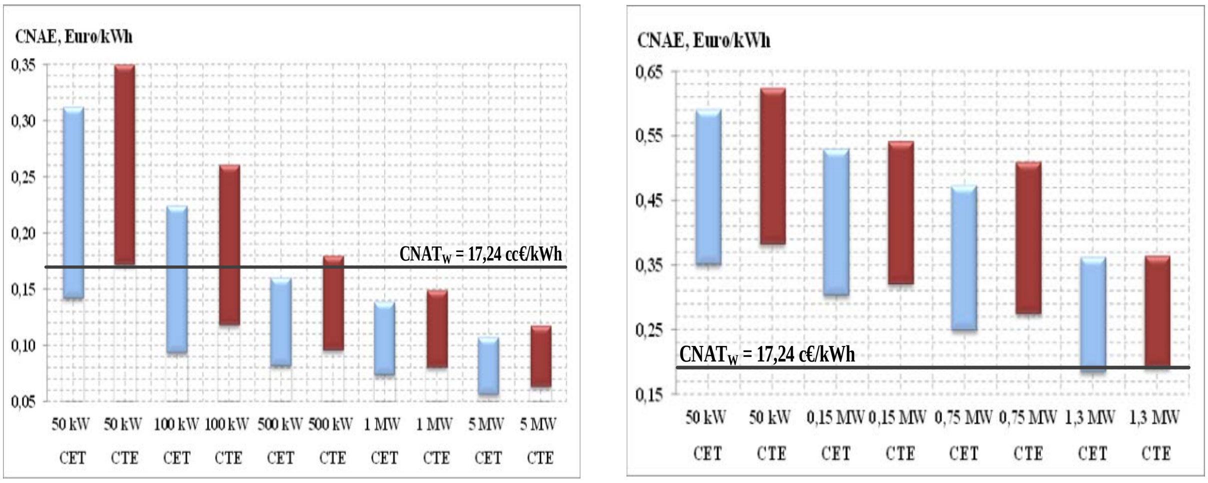
Figure 1 shows the profitability of electricity produced from biogas, compared to that produced from syngas. Electricity produced from biogas is attractive both for the use and non-use of thermal energy in the entire range of considered powers, for small powers being attractive only under the optimistic scenario. The electricity produced from the syngas is close to the predicted cost of electricity delivery only for the high powers under the optimistic scenario.



a) biogas b) syngas

Figure 1. Comparative analysis of MAI technology.

The ITG technology is more attractive, for the electricity production from syngas, compared to that of MAI, approaching the cost of electricity delivered in the case of high powers, both in thermoelectric power station and in cogeneration regime and use of thermal energy, (Figure 2). In the case of biogas, this technology is attractive in all power ranges, except the 50 kW in case of non-use of thermal energy, being more attractive in the case of large powers of 1 and 5 MW installed power.

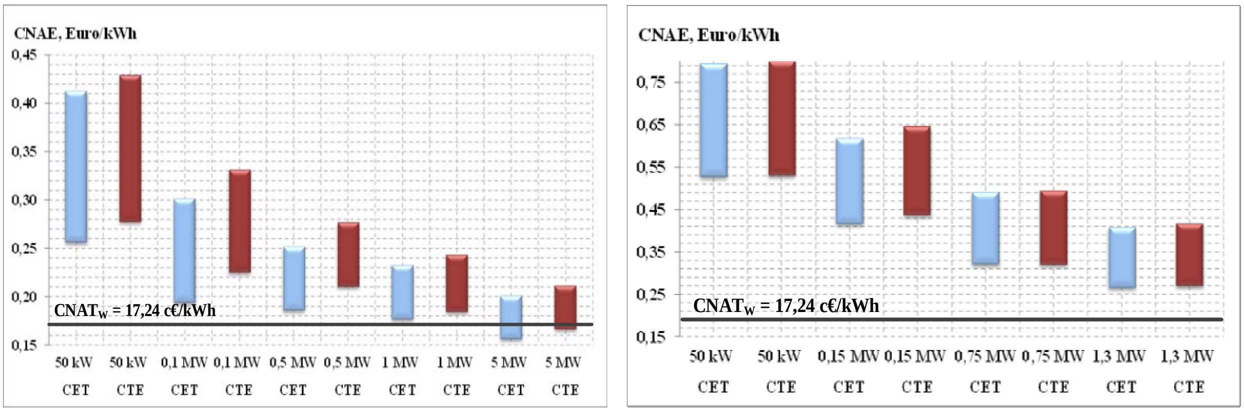


a) biogas b) syngas

Figure 2. Comparative analysis of ITG technology

The technology of internal combustion engines is more attractive, compared to gas turbine installations, for the first one resulting in a cost of electricity with values between 5 cEuro·kWh^{-1} and 30.5 cEuro·kWh^{-1}, and for the second - between 5.6 and 35 cEuro·kWh^{-1}.

Figure 3 illustrates that the FC technology is competitive only in the case of biogas recovery, within the 5 MW power plants, for the optimistic scenario conditions. For installed power of 1 MW, in the case of cogeneration under the optimistic scenario, the cost of energy is close to the levelized supply cost of electricity. Thus, in the case of syngas use, the resulting electricity cost is much higher than the cost of the supplied electricity.



a) biogas b) syngas

Figure 3. Comparative analysis of FC technology

Electricity generation from biogas is attractive for all considered technologies, and from syngas - only in MAI and ITG at high powers, and FC being a new technology is currently less applied because of the high investment costs.

Conclusions

1. An evaluation of the electricity cost from gaseous biofuels, obtained from waste, under 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 paper proposes the use of biogas and syngas by applying different technologies (MAI, ITG, FC), in cogeneration regime and separately, on medium and small scale. For the technologies listed, the levelized cost of energy was determined, this being the most important indicator of the economic performance of the energy sources. The calculations were performed for two scenarios: optimistic and conservative.

3. Electricity produced from biogas, within MAI, has the lowest cost, showing a variation of the cost price from 5.71 cEuro·kWh-1, for powers of 5 MWe, up to 30.54 cEuro·kWh-1 for powers of 50 kWe, in case of non-use of thermal energy and from 4.96 to 28.32 cEuro·kWh-1, for the same powers, but in case of partial use of thermal energy.

4. The highest cost of electricity is obtained, from syngas within the fuel cells, showing a variation of the price cost from 26.52 cEuro·kWh-1, for 1.3 MWe power, up to 79.53 cEuro·kWh-1 for powers of 50 kWe, in the case of thermal energy recovery and from 26.96 cEuro·kWh-1 up to 79.51 cEuro·kWh-1, for the same powers, but in case of partial non-use of the produced thermal energy.

5. This paper demonstrates that, the production of electricity from biogas is profitable for the MIA technologies, for the entire considered power chain, the ITG becomes attractive at powers starting from 100 kW, and the PC are only competitive at powers greater than 5 MW, under the conditions of the optimistic scenario. The production of electricity from syngas proves to be attractive only in MAI and ITG with powers greater than 1.3 MW, in case of thermal energy recovery and under the optimistic scenario conditions.

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