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Profitability Evaluation of Investments in CHP Technologies: a Case Study of Varna Wastewater Treatment Facility, Bulgaria

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Abstract: *In this paper, profitability evaluation of investments in the cogeneration system installed in Varna Wastewater Treatment Facility (Varna WWTF) was performed, and information from previous study [15] is used. For this purpose, the annual total revenues for the cogeneration system that must be collected to ensure sound economic plant operation are calculated. Then, the levelized unit cost of produced electricity and the cogeneration system by-products are determined, as well as the levelized costs associated with carrying charges, fuel, and operation and maintenance for different economic life period of the plant. In this study, the profitability evaluation of investments is achieved by introducing of the following key economic parameters – Net Present Value (NPV), Internal Rate of Return (IRR) and payback period (PB). The results from the investigation demonstrate that investments in cogeneration systems driven by biogas engine are not only profitable projects on location of Bulgaria, but also technological solutions for power generation having responsibilities relevant to environmental protection.*

Keywords: *Biogas engine, Cogeneration, Internal rate of return, Net present value, Profitability, Revenue requirements.*

1. Introduction

When a cogeneration system is defined as “optimal maintained”, it must mean that the system has not only optimal thermodynamic efficiency parameters, but also its operation will bring the most favorable profits of the exploiters. Since net profit represents total income minus costs incurred for the system, it is essential the determination of all expenditures involved in manufactured processes, such as: total capital investments, fuel costs, raw material cost, operating and maintain costs and etc.

Furthermore, referring to the similar studies [1-4], it can be argued that the equipments used in cogeneration system and their purchased costs are standard on European market, but the same cannot be claimed about the profitability of the investments – it strongly depends on location of the investigated system through differences in the system economic and financial environment. For instance, the authors of [2] investigated the profitability of investments in two well-established combined heat and power (CHP) technologies - combined-cycle gas turbine CHP (CCGT-CHP) and engine-CHP. These two types of identical systems are located in different European Union countries and the results confirmed the statement that the profitability of CHP investments varies significantly between different markets. Therefore, two complete identical CHP systems can have dissimilar economical optimum due to their site-specifics.

So far, however, in reviewed studies it has not been found in-depth discussion about total revenue required which a cogeneration system located in Bulgaria must realize to be profitable. Moreover, to our knowledge, little is known about profitability of investments in internal combustion engine (ICE) based cogeneration systems for use with biogas from wastewater treatment plants sited in Bulgaria. To address this niche in the global research work, the purpose of this investigation is to provide an opportunity to advance our knowledge of what are the revenue requirements of the system, the levelized costs of main products and the profitability of the investments in cogeneration system with biogas engines on site of Bulgaria. In addition, this study seeks to obtain data which will help to determine the thermo economic optimum of the analyzed CHP system.

2. System Description and Operating Conditions

The present study is made for a cogeneration plant installed in the Varna Wastewater Treatment Facility, Bulgaria (Varna WWTF). The plant consists of two CHP modules, each of which is driven by internal combustion engines burned biogas - model Cento T300 SP BIO+ZP (Tedom). The biogas fuel is obtained in the Varna WWTF. The plant produced electrical energy and hot water. The electricity is generated by two, biogas engine actuated generator set. Each of the biogas engines – generators sets produce 320kW electricity at 100% of output. In the heat exchanger of the plant (HEX), high temperature exhaust gas energy is used to heat water. Thus, the produced hot water has mass flow rate 7.6 kg/s and maximal heat rate is 2 x 322 kW. The flow diagram of the cogeneration plant is illustrated in **Figure 1**.

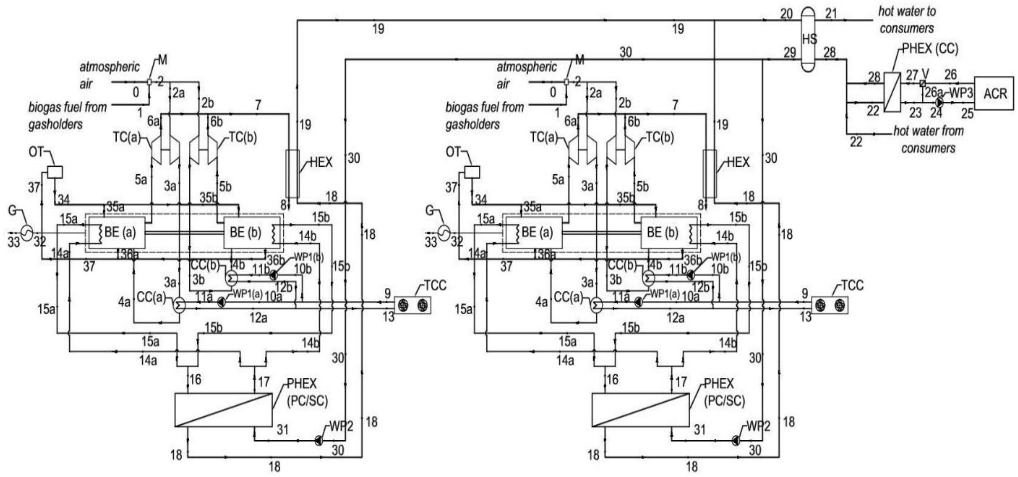

Fig1. *A schematic representation of the analysed cogeneration system*

M – mixer; TC(a), TC(b) – turbochargers; BE(a), BE(b) – internal combustion engines; CC(a), CC(b) – charge coolers; WP1(a), WP1(b) – technological circuit water pumps; TCC – technological circuit cooler; PHEX (PC/SC) – plate heat exchanger from secondary circuit; WP2 – secondary circuit water pump; HEX - heat exchanger; G – generator, OT – oil tank; HS – hydraulic separator; PHEX (CC) – plate heat exchanger from cooling circuit; V – 3 –way valve; WP3 - cooling circuit water pump; ACR – air – cooled radiator

The following economic and financial model of the cogeneration plant is made for typical operation conditions of the system, namely 75% of total electrical output. For these conditions each CHP modules produces 240kW electricity. The heat energy consumption depends on thermal needs of mesophilic fermentation process, occurring within the digesters.

In considered system operating condition, the produced heat rate is 279.976 kW. The overview of technical parameters of the CHP plant is presented in **Table 1**. The data from this table, as well as from **Table 2** are obtained by energy and exergy analysis of the cogeneration system, conducted in previous study [15].

Table1. *Technical parameters of the analyzed cogeneration plant*

Parameter	Unit	Value
Biogas mass flow rate	kg/s	2 x 0.035
Combustion gases mass flow rate	kg/s	2 x 0.2235
Energy efficiency	%	53.347

The Varna WWTF produces 1300 nm^3/day biogas fuel with LHV=20.2048 MJ/kg and the following volumetric composition: 65% CH_4 and 35% CO_2. The biogas fuel is burned in internal combustion engine (BEa,b) and in consequence of that an amount of carbon dioxide (CO_2) is emitted into the atmosphere. In **Table 2** are summarized the annual amounts of produced biogas fuel and total amount emissions due to its combustion in internal combustion engines of the CHP modules.

Table2. *Annual amounts of the produced biogas fuel and combustion gases*

Flow	Component	Value, t/year
Biogas fuel	CH_4	220.884
	CO_2	325.858
Combustion gases	$CO_2 + O_2 + N_2 + H_2O$	8457.955

3. Economic and Financial Model of the Cogeneration System

All paragraphs must be justified alignment. With justified alignment, both sides of the paragraph are straight. In this study, the assumptions made include:

- The present profitability evaluation of investments is performed using economic parameters corresponding to the beginning of design and construction period, i.e. March, 2009;
- The economic criteria are determined by net cash flow in current euro, i.e. by including the effect of inflation in projections of capital expenditures, fuel costs and O&M costs;
- The escalation of all costs occurs in the middle of the year;
- Straight – line deprecation is used for depreciating the value of an asset;
- Depreciation cost of the asset is 100%;
- Working capital appears as a common equity at the end of system book life;
- The depreciation funds are assumed to be used to pay back investors for the principal;
- Since property tax increase with time and insurance costs decrease with time, the sum of the two remains constant.

The values obtained from calculation of the cogeneration system total capital investment (TCI) are input data for the current profitability evaluation of investments. A method described in detail in [5] is used in the determination of the TCI components.

Table3. *The estimate of total capital investment for the cogeneration system (all costs are expressed in thousand euros).*

I. Fixed capital investments	
A. Direct costs	
1. Onsite costs	
Purchased – equipment costs (PEC)	430.480
Purchased – equipment installation	59.624
Piping	253.241
Instrumentation and controls	160.484
Electrical equipment and materials	50.378
Total onsite costs	**954.207**
2. Offsite costs	
Land	0
Civil, structural and architectural work	29.220
Service facilities	31.412
Total offsite costs	**60.633**
Total direct costs	**1014.840**
B. Indirect costs	
Engineering and supervision	124.897
Construction costs and contractor's profit	56.581
Contingency	94.302
Total indirect costs	**275.780**
Fixed capital investment	**1290.619**
II. Other outlays	
Startup costs	30.214
Working capital	138.842
Allowance for funds used during construction	25.112
Total other outlay	**194.169**
Total capital investments	**1484.788**

It is important to note that the purchased – equipment costs are assigned according to the manufacturing company price lists, and in case of the hydraulic separator, the charge cooler and the oil tank the purchased – equipment costs (PEC) are obtained by the six-tenths rule [5,6]. The values of the PEC and the remaining components of direct costs and the indirect costs are presented in **Table 3** and it is clear that the investments made are in amount of 3093€/kWe.

In order to formulate a complete economic and financial model of the CHP plant, information from public available database of the Energy and Water Regulatory Commission is used [7] and it is showed in the table below.

Table4. *Parameters used in profitability evaluation of investments in the cogeneration system*

№	Parameter (units)		Value
1a.	Average general inflation rate (2009-2036), %		4.2
b.	Average nominal escalation rate of all costs (2009-2036), %		4.2
c.	Average nominal escalation rate of biogas costs (2009-2036), %		2
2a.	Beginning of design and construction period		March, 2009
b.	Date of commercial operation		December, 2011
3a.	Plant economic life, (years)		20
b.	Plant life for tax purposes, (years)		10
4.	Plant financing fractions and required returns on capital		
	Type of financing Financing fraction, (%) Required annual return, (%)	Common Equity and Free Financial Aid 100 4.53	
5a.	Corporate income tax rate (2009-2036), (%)		10
b.	Average insurance rate (2009-2036), (% of PFI in end- 2011 EUR)		0.39
c.	Average property tax rate (2009-2036), (% of PFI in end- 2011 EUR)		0.27
6.	Average capacity factor, (%)		60
7.	Labor position for operating and maintenance		15
8.	Average labor rate, (EUR/h)		3.49
9.	Annual fixed O&M costs, (EUR/year)		20436
10.	Annual variable O&M costs at 75% output, (EUR/year)		797.11
11.	Unit cost of biogas fuel, (EUR/1kg)		0.086
12.	Allocation of plant facilities investments to the individual years of design and construction, (%) March – December, 2009 January – December, 2010 January – November, 2011		 20 40 40

4. Methodology for Profitability Evaluation of Cogeneration System Driven by Biogas Engine

4.1. Calculation of Revenue Requirements

For investigated cogeneration system is adopted that the annual total revenue requirement (TRR) is a sum of the following six terms: total capital recovery (TCR), minimum return on investment (ROI_{ce}), income taxes (ITX), other taxes and insurance (OTXI), fuel costs (FC) and operating and maintenance costs (O&M). The calculation method for each of these components of the total revenue requirement is detailed described in [5].

4.2. Levelized Costs and Costs of Main Products

The levelized annual total revenue requirement can be expressed by the following equation [5]:

$$TRR_{L,cu} = \frac{TRR_1}{1 + r_n} \cdot \frac{k \cdot \left(1 - k^n\right) \cdot CRF}{1 - k} \qquad (1)$$

Where

$$k = \frac{1 + r_n}{1 + i_{eff}} \qquad (2)$$

The levelized annual fuel costs ($FC_{L,cu}$) and operating and maintenance costs ($O\&M_{L,cu}$) are defined as similar way.

The levelized annual carrying charges are then calculated as [5]:

$$CC_{L,cu} = TRR_{L,cu} - FC_{L,cu} - O\&M_{L,cu} \tag{3}$$

Since the cogeneration system produce heat energy as a by-product, the levelized unit cost of the main product (electrical energy) for a given period can be expressed as [5]:

$$MPUC_L = \frac{TRR_L - BPV_L}{MPQ} \tag{4}$$

4.3. Profitability Evaluation

4.3.1. Economic and Financial Profitability of the Investments in the Cogeneration System

Once defining the interest rate at which the investments are returned (entry 4 of **Table 2**), as well as the average general inflation rate (entry 1a of **Table 2**) and determining the net cash flow, the net present value (NPV) of the investment in the cogeneration system driven by biogas engines is calculated as follow [5, 6]:

$$NPV = \frac{A_0}{(1+r)^0} + \frac{A_1}{(1+r)^1} + \dots + \frac{A_n}{(1+r)^n} = \sum_{n=1}^{BL} \frac{A_n}{(1+r)^n} \tag{5}$$

In addition to NPV as an assessment criterion, in order to evaluate the profitability of the investments in the cogeneration system, the internal rate of return (IRR) is used. The IRR is defined as the discount rate that makes the NPV equal to zero [5, 6]:

$$NPV = \sum_{n=1}^{BL} \frac{A_n}{(1+IRR)^n} = 0 \tag{6}$$

Here, the internal rate of return is found iteratively.

In this paper, the length of time required to accumulate to savings equal to the initial investments, i.e. the payback period is determined. This profitability criterion is calculated as follow [5, 6]:

$$\tau_{PB} = \frac{TDI}{ANCF} \tag{7}$$

4.3.2. Social Benefits of the Investments in the Cogeneration System Driven by Biogas Engines

In this paper, social aspects of benefits of investments in cogeneration systems driven by biogas engines are also evaluated. It is assumed that the main component of the social benefits of the investments is the environmental benefits.

In order to demonstrate the social benefits from putting into operation of cogeneration technology in Varna WWTF, first, the case without a utilization of the obtained biogas and generated emission CO_2 when the biofuel is discharged directly into the atmosphere is investigated. It is important to note that the non-CO_2 emissions such as CH_4 emission are expressed as tons of carbon dioxide equivalent (tCO_2eq) using the global warming potential (GWP) [8]. The obtained values are compared with CO_2 emissions generated in a case of the utilization of the biogas fuel in CHP modules.

Moreover, the technology for utilization of obtained biogas fuel in Varna WWTF is assessed from ecological point of view by introducing of parameter called ecological efficiency [9]. The ecological efficiency (ε) is indicator for estimating the environmental impact of gaseous emissions by comparing emissions in CO_2 equivalent emissions with the existing for air quality patterns [9]. The ecological efficiency is determined by Eq. (8) [9]:

$$\varepsilon = \left[\frac{0.204 \cdot \eta}{\eta + \Pi_g} \cdot \ln\left(135 - \Pi_g\right) \right] \quad (8)$$

As can be seen, the value of ε is a function of energy efficiency, η, of the equipment or process responsible for emission and pollution indicator, Π_g. The pollution indicator is defined as follow:

$$\Pi_g = \frac{(CO_2)_{eq}}{LHV} \quad (9)$$

5. Results and Discussion

In this paper, the revenue requirement method of economic analysis was applied to existing cogeneration system. The results obtained from the calculations of the components constituting revenue requirements are summarized in **Table 5**. From the data in column 7 in **Table 5**, it is apparent that the total annual revenue requirements (expressed in current euro) increases with decreasing the number of years of system operation. Therefore, the CHP plant users will pay fewer charges in the first years than the last year of the operation due to the annual general inflation rate. However, if TRR is considered without inflation rate, i.e. TRR are expressed in constant euro (column 8 in **Table 5**), it is clear that the trend is opposite: TRR decreases with the increasing number of years of plant operation.

Table5. *Year-by-year revenue requirement analysis for the cogeneration system driven by biogas engines (all costs are expressed in thousand euros)*

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Year	Calendar Year	TCR	ROI_{ce}	ITX	OITX	FC	O&M Costs	TRR (constant EUR)	TRR (current EUR)
1	2012	79.40087	72.1791	1.89378	17.8636	146.708	24.0224	342.068	302.3492
2	2013	79.40087	68.5822	1.89378	17.8636	149.642	25.0314	342.414	290.4561
3	2014	79.40087	64.9854	1.89378	17.8636	152.635	26.0827	342.861	279.1128
4	2015	79.40087	61.3885	1.89378	17.8636	155.688	27.1782	343.413	268.2933
5	2016	79.40087	57.7917	1.89378	17.8636	158.801	28.3196	344.071	257.9728
6	2017	79.40087	54.1948	1.89378	17.8636	161.977	29.5091	344.839	248.1277
7	2018	79.40087	50.5979	1.89378	17.8636	165.217	30.7484	345.722	238.7355
8	2019	79.40087	47.0011	1.89378	17.8636	168.521	32.0399	346.720	229.7747
9	2020	79.40087	43.4042	1.89378	17.8636	171.892	33.3856	347.84	221.225
10	2021	79.40087	39.8074	1.89378	17.8636	175.33	34.7877	349.083	213.0668
11	2022	65.22509	36.2105	14.4945	17.8636	178.836	36.2488	348.879	204.3591
12	2023	65.22509	33.256	14.4945	17.8636	182.413	37.7713	351.023	197.3275
13	2024	65.22509	30.301	14.4945	17.8636	186.061	39.3577	353.303	190.6038
14	2025	65.22509	27.346	14.4945	17.8636	189.782	41.011	355.723	184.1738
15	2026	65.22509	24.3917	14.4945	17.8636	193.58	42.7332	358.286	178.024
16	2027	65.22509	21.4370	14.4945	17.8636	197.45	44.5279	360.998	172.1414
17	2028	65.22509	18.4823	14.4945	17.8636	201.399	46.3981	363.862	166.5138
18	2029	65.22509	15.5276	14.4945	17.8636	205.427	48.3468	366.884	161.1293
19	2030	65.22509	12.5729	14.4945	17.8636	209.54	50.377	370.069	155.9768
20	2031	65.22509	9.61822	14.4945	17.8636	213.726	52.4933	373.420	151.0456

According to the calculating procedure described in Section 4.2 of this study, the total revenue requirements in current euro are used to determine the levelized costs associated with carrying charges, operation and maintenance and fuel, and the levelized cost of the main product for levelization time periods of 20 and 10 years. Table 6 shows the breakdown of this estimation. As can be seen from the table below, the change of the levelization time period from 20 to 10 years leads to a slight decline in the value of carrying charges and a rise in fuel costs. Since the TRR for 20 years period is higher than those for 10 years, this tendency is also reflected in the levelized unit cost of the produced electrical energy. It is important to note, that the obtained units costs are on the base of unit electrical energy, and not on unit exergy. Moreover, these values are similar to those found in literature [4].

Table6. *Levelized annual costs in current euro and levelized unit cost of the main products for levelization time periods of 20 and 10 years for cogeneration system (all costs are in euro)*

	Levelization time period of 20 years		**Levelization time period of 10 years**	
	Value	Percentage, %	Value	Percentage, %
Carrying charges	282081.7	57.614	220180.8	53.921
Fuel costs	173141.3	35.363	159484.6	39.057
O&M costs	34383.7	7.023	28676.7	7.023
Total revenue requirement	489606.7	100	408342	100
Levelized unit cost of the produced electrical energy	0.175402 €/kWh		0.143191 €/kWh	

The financial results for the cogeneration system (NPV, IRR and τ_{PB}) presented in **Table 7** are satisfactory. It is apparent from this table that the calculated value of NPV is a positive number, i.e. NPV > 0. Moreover, according to the statistical data of Bulgarian National Bank, the nominal interest rate of loans in November, 2014 is 5.76% [10] and the data in **Table 7** indicates that the determined IRR is highest than the interest rate.

As the **Table 7** shows, the payback period of the investments in the cogeneration system is approximately 11 years. It means that after this number of years are required to recover project's cost.

Table7. *The results obtained from calculation of the profitability criteria in case of the cogeneration system*

Parameter	**NPV, €**	**IRR, %**	**τ_{PB}, years**
Value	2741770.33	11.446	10.705

Comparing the results of the conducted financial analysis of the cogeneration system with findings from the studies of the other authors makes the following point: the IRR and NPV values in case of ICE based cogeneration system fuelled biogas and located in Slovakia [4] do not differ significantly from the calculated in this paper results - the investments are determined to be 3559€/kWe, while the IRR and payback period are 15.42% and 11 years, respectively; the payback period of biogas powered cogeneration system financed from the investors own funds and located in Serbia is 9.8 years [1]. Kabouris, J., Forbes, B. et al. [11] investigate a biogas fueled cogeneration system and equipped with two ICE, but sited in USA. The findings in this paper show that by investing in such a technology, the payback period is 12 years. As can be seen, the obtained data and the references cited above are similar, but not identical, and this is mainly due to the different price levels for power and fuels, and to the differences in CHP promotion in the respective countries.

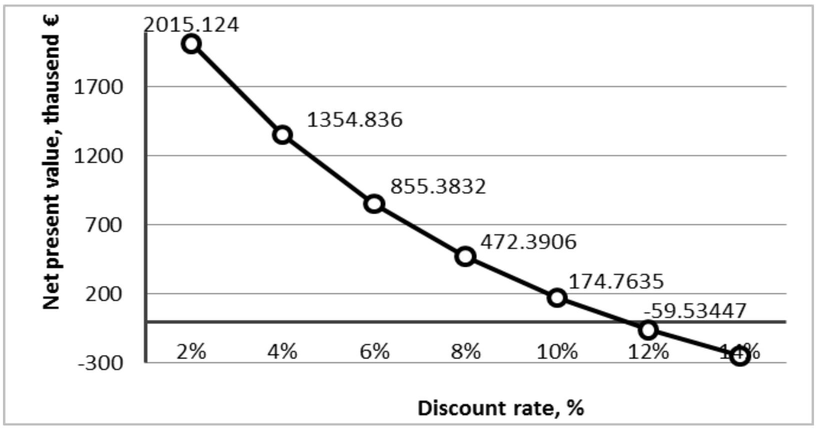

Fig2. *A graphical determination of the IRR*

From special interest are the calculated economic criteria in [12, 13]. Kumar, S., Abbi, Y.P. et al. [12] showed that ICE based cogeneration system, but fuelled natural gas and located in India is financial attractive: in this paper the payback period and IRR are determined to be 20 months and 68.5%, respectively. The payback period of a cogeneration system located in Sichuan Province, China is similar - 2.65 years [13]. These results can be explained by the peculiarities of Asian markets cogeneration technologies: low capital investments and relatively high price of the produced electrical energy.

In this paper, in order to assess the social benefits of investments in the cogeneration system, the amounts of the emissions in the base case (without utilization of the biogas fuel) and in case of biogas utilization in CHP modules are determined. The results are listed in **Table 8**.

Table8. *Amounts of the emissions in the base case (without utilization of the biogas fuel) and in case of biogas utilization in CHP modules*

Base Case		A Case of Biogas Utilization	
Emission	Amount, tCO_2/year (tCO_2e/year)	Emission	Amount, tCO_2/year (tCO_2e/year)
CO_2	325.858	CO_2	1141.82
CH_4	4638.5640		
Total	**4964.422**	**Total**	**1141.82**

As can be seen, it is expected decreasing of the emissions with more than 4 times less by putting into operation of the analyzed cogeneration technology in Varna WWTP. At the same time, this abatement option is assess through introducing of ecological efficiency. From **Table 9** is clear that the air pollutant with highest mass fraction in composition of exhaust gas is carbon dioxide, and ecological efficiency is calculated to be 75.9%. Such a result was obtained in [14], where the simulation with 100% load is applied to the micro turbine CHP system using biogas fuel.

Table9. *Products of combustion of biogas fuel (kg/kg fuel), CO_2 equivalent of emission, pollution indicator and ecological efficiency*

Fuel	**CO_2**	**N_2**	**O_2**	**H_2O**	**$(CO_2)_{eq}$, kg/kg fuel**	**Π_g, kg/MJ**
Biogas	3.428	17.744	2.1324	2.082	3.428	0.1697
Ecological efficiency						**75.9%**

6. Conclusion

The objectives of this paper were to evaluate profitability of the investments in cogeneration technology in Varna Wastewater Treatment Facility and to determine the effectiveness of the analyzed technology from an environmental point of view, i.e. to assess the social profitability of the investments. For this purpose, a detailed methodology was introduced including the following main points: (i) application of the revenue requirement method to the cogeneration system installed in Varna Wastewater Treatment Facility; (ii) calculating of the levelized annual costs and levelized unit cost of the main products for different time periods; (iii) determining of economic criteria such as NPV, IRR and payback period in order to assess the economic profitability of the investments; (iv) assessment of social profitability of the investments through calculating of the ecological efficiency of the analyzed system.

The results from calculation of economic criteria (NPV, IRR and payback period) highlight that the Bulgarian market currently offers satisfactorily profitability of investments in CHP technology and it would be effective the enhanced promotion of the cogeneration systems installation in Bulgarian wastewater treatment plants. Moreover, the obtained value of the IRR is higher than the nominal interest rate of Bulgarian National Bank ($IRR = 11.446\ \%$). It can be conclude that if the investments in the cogeneration system were realized only by loan, they would be profitable.

Although the calculated value of the project payback period is in good agreement with the others [1, 4, 11], it can be claimed, that this results is relatively high and indicates the presence of the risks, arised from events outside the company and beyond its influence or control. Therefore, it is necessary to develop effective risk – management processes in Varna Wastewater Treatment Facility. Furthermore, the conducted economic study consist a number of assumptions and the sensitivity analysis is recommended to conduct in order to investigate the effect of the major parameters such as inflation and interest rate on results of economic criteria.

In terms of social profitability of the investments in biogas cogeneration plant, it can be noted that the investments in cogeneration technologies have a contribution to continuous pursuing of energy neutrality and job creation. In current investigation, however, is evaluating only ecological improvement of the project area as a form of social impact of the system. It can be conclude that the using of the biogas as a fuel in cogeneration system is better than the case of directly discharging into the atmosphere of the biofuel produced as a byproduct of the solids stabilization process at Varna WWTP. It is estimated that the realization of such an investment greenhouse gas emissions can be reduce with more than 3800 tCO_{2eq}. The statement that the biogas fuelled cogeneration system has responsibilities relevant to environmental protection is also conditioned by the high value of ecological efficiency obtained in this study. Therefore, the cogeneration systems are felicitous solution for energy supplying in urban area from ecological point of view and technology makes significant social sense.

Not withstanding the current analysis give us meaningful information about profitability of investment in cogeneration system in Varna Wastewater Treatment Facility, this evaluation not affected the quantity of product streams. The assessment of the cost per unit of the produced availability energy (or exergy) can be realized by conducting of exergo economic analysis of the system.

Finally, it is important to remark that the authors regarded the obtained results as input data for the following thermo economic evaluation and optimization of cogeneration system installed in Varna Wastewater Treatment Plant.

Nomenclature

Roman letters

A – net cash flow at the end of *n*th time period

b – inflation rate (%)

i – interest rate (%)

n – plant economic life (years)

r – real interest rate (%)

t - corporate income tax rate (%)

Greek letters

ε - ecological efficiency (%)

τ_{PB} - payback period (years)

Subscripts

ce – common equity

cu – current euro

eff - effective

L – levelized costs

n - nominal

Abbreviation

ANCI – average annual net cash inflow

CRF – capital - recovery factor

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