ECONOMY OF BIOGAS PLANTS

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Abstract

At a time when worldwide energy demand grows, the care for greener environment grows as well. Due to the extremely high energy potential, along the safety and cleanness of its operations, the biogas plant as an energy solution is deemed a great investment in the future. Frequently in that regard we face the question concerning the scope of the investment and the time needed for its return.

This paper gives an example of an investment in a biogas plant and the exploitation of renewable sources, which is simultaneously an example of circular economy. The biogas plant has a power of 1 MW, which along the existing concession prices and the resulting economy justifies the validity of the decision to invest while ensuring a cleaner environment. Invested funds shall be returned within a maximum of 6 years, reflecting the extremely dynamic business process.

Keywords: Biogas plant; Costs; Forecast; Profit; Electrical energy

1. Introduction

The current energy policy requires a constant technology development towards more sustainable energy transformation systems. Cogeneration and the use of renewables are two important solutions available to achieve this goal [1]. To analyse such systems from the point of view of resource efficiency, the pure energy analysis is not sufficient since the quality of particular energy carriers is not evaluated. Biogas projects demand high investments. Biogas plants are still experiencing harsh economic conditions [2]. Financing is therefore one of the key elements in order to ensure project viability. The financing scheme of a biogas plant project differs from country to country, but in general, low interest long-term loans are used. Ordinary mortgage loans are not frequently used. The index-regulated annuity loans are low-interest loans, which secure the investor against inflation through a re-evaluation of the unpaid debts according to the inflation rate. The pay-back period is more than 20 years. This type of loans proved to be the most suitable for financing the construction of biogas plants, meeting the demands for long maturity, low interest and low initial instalments. The disadvantages of such loans are that they are raised by ordinary sales of bonds at the stock exchange market price, implying a depreciation risk that may induce some uncertainty in the planning phase [3, 4]. In countries like Denmark, biogas projects are e.g. financed by means of index-regulated annuity loans, guaranteed by the municipalities. Most of the past biogas projects received also supplementary government subsidies, representing up to 30 % of the investment costs of the project.

A single farmer, a consortium of farmers or a municipality are usually the entrepreneurs likely to implement successful biogas projects. The success of the project depends on some factors that can be controlled and influenced by strategic decisions concerning investment and operational costs. Very few research studies exist on the positive effects of biogas production on the socio-economics of rural areas [5]. Considerable changes occur regarding the employment level. Additionally, in the majority of areas there is a significant potential for further development of biogas production, which would likewise be reflected in the effects of added value and employment opportunities. Farmers have heterogeneous investment thresholds. Their investment decisions are mainly driven by capital costs and the subjective perception of the risk resulting from the investment. Other decision parameters like sustainability and non-monetary objectives play only minor roles [6]. Choosing the best technology in respect of level of investment and operational costs is very difficult. If tendering a biogas plant, it is important receive offer on operational cost like:

- Operational cost of combined heat and power plant (CHP) incl. all services and spare parts (amount/kWh),
- Maintenance costs of biogas plant in total (% of investment/year),
- Own electrical energy demand, including demand of CHP (kWh/year),
- Average working hours/day of staff (maintenance and feeding the system).

The success of the project is also influenced by some factors that cannot be controlled such as:

- Interest terms,
- Grid access and feed in tariffs,
- World market prices for feedstock (e.g. energy crops),
- Competition for feedstock from other sectors.

Industrial waste collectors face problems securing long term availability of the feedstock. This could be a problem because the waste recycling market is highly competitive and contracts with waste producers are rarely for periods longer than five years.

Quite often, before a bank offers to finance the biogas plant project, the economical long term success of the project must be proven by a study/ calculation of profitability [7]. The calculation is normally done within the preliminary planning by an experienced planning/consulting company, but in many cases, especially in the case of single based biogas projects, this work can be done by the project developer, with two consequently advantages: the project developers/partners are forced to have a very close view to the different aspects of the project and, in case of cancelling the project, no external costs have occurred.

2. Economic forecast of a biogas plant project

In a case of a biogas plant treating municipal waste, it is recommended to mandate an experienced consulting company. Waste treatment plants are much more complex regarding handling of feedstock, biological stability of the system and the whole plant design, compared to a farm based plant (Fig. 1).

Fig. 1. Main components and general process flow of biogas production

For case specific calculation of the economic forecast, a calculation model was elaborated, allowing the preliminary estimation of costs, plant size, dimensioning, technical outline etc. finding an independent and reliable planning partner is mandatory. The framework conditions of organic biogas generation and its monetary implications on production economics must be carefully analysed [8] and [9], with risks evaluation [10]. Renewable energy production is not economically viable by its own, without considering the wastewater treatment function and the associated incomes [11].

3. Project case

For the purpose of construction of the biogas plant, land in area of 1.4 ha is being purchased. The Ministry of economy has issued a preliminary electricity permission needed in order to construct the plant with bio power of 1 MWh based on prior economic and technological analyses.

Collection of waste from farms represents an ecological problem because raw manure cannot be immediately (due to its high concentration and / or vegetation period) used on arable land as fertilizer. The waste is therefore collected or deposited along the fields in inadequate (usually permeable) reservoirs / disposal sites / lagoons from where they penetrate into the surface and ground waters, polluting them. Stench and even more important pollution from glass gases (NH₃, CO₂, CH₄, H₂S), that destroy the ozone layer, are expanding.

3.1. Project goals

Three main goals need to be achieved:

- Tackling environmental problems and at the same time exploiting "waste" traits as a renewable source of energy,
- Exploitation of processed and fermented residue as a high caloric organic fertilizer,
- Development of energy crops (silages) with the aim of improving the energy efficiency with partial exploitation of fertilizer produced on site.

The raw material for the biogas plant will be purchased in the environmental field on approximately 10,000 hectares of arable land, which provides a minimum of 10,000 tons of biomass with the price of 17 €/tonne. The production itself is agreed for a reason that it should not endanger food production and should take the arable land. Deficiencies of the contracts for inbounds are identified as price hikes of the raw materials required for the upcoming biogas plant and the price hikes of the agricultural products, corn in particular. In absence of price hikes regarding the biogas production, long-term contracts for period of 10-12 years are suggested to be signed. In terms of the biomass price the following formula is applied:

$$C_{Goie} = C_{Goie-1} \times ICM_{Goie-1} \quad (1)$$

- C_{Goie} is the purchase price for the current year,
- C_{Goie-1} is the purchase price for the previous year,
- ICM_{Goie-1} is an annual index of growth of the retail prices in terms of the previous year,
- $Goie$ is an annual index, the minimum value in the year.

Plants connected to the distribution network with installed electrical power up to 1 MW, which use renewable sources of energy for its production, sell such energy under the price of 0,174 €/kWh, with no value added tax (VAT) calculated.

The raw material is delivered to the cleaver and the blender by pressure pipeline and/or tanks, where it is mixed with silage, other biodegradable substrates (waste material) and hot water (heated with the surplus of the heat already generated), after what it is dosed in an equalization pool, mixed with a submerging device. The liquid is being pumped from the pool into a hydrolyser, where for 2-3 days a hydrolysis is commencing on temperature of approx. 55 °C. The heating is carried out by heat exchanger of the water heated with the surplus of the produced heat (hot water). The hydrolysate is pumped onwards into a digester – 1, where for 15-20 days a thermophilic conversion of hydrolysed organic substances into biogas is commencing on temperature of approx. 55 °C [12]. The heating is carried out by heat exchanger of the water heated with the surplus of the produced heat (hot water). Ferment thickens by passing through the separator and thus condensed, pumps through the reservoir, where the conversion into biogas continues, accumulating in the gas tank / in the dome above the reservoir. In that gas tank, the biogas is dosed from the dome of the digester – 1. Reservoir – ferment will be soon built for the phase II as well, thus the initial period of retention of the ferment shall take approx. 30 days, whilst in the second phase it shall decrease [13].

The obtained biogas is purified by aerobic biological conversion of sulphide into elementary sulphur at the top of the dome and by removing the moisture by passing through the capacitors and the filters. Later on the obtained biogas is used for drive of CHP units which are used in the production of electrical and thermal energy.

Processed and fully stabilized fermenter (without odour) is transported through the same reservoirs, which are used for delivery of the substrate to the smaller reservoirs (container, metal or terrestrial), mounted on arable areas as high calorific organic fertilizer with corresponding tractor hitch. Optionally it can be one of the larger reservoirs (which holds fermenter for approx. 90 days, during the vegetation period), from which the fertilizer can be deprived if necessary.

Fig. 2. Technological process of the biogas plant

The biogas plant will be installed at a location with good infrastructure in terms of logistical point of view. At 500 m distance from the bioplant there is a transformer-station with an option to connect to the network.

Possible impacts of the construction of biogas plant on the surrounding area can affect the soil, underground and groundwater, the air and the "production" waste. Negative impact can occur on soil and subsoil in case of outlet of the liquid manure. In that case the liquid manure will penetrate into the underground, in particular into the underground water or it will reach the recipient on the surface, where it can destroy the living world due to lack of oxygen. In order to prevent such negative impact, the manure is deposited into closed reservoirs.

The impact on air is unfavourable odour-stench from the biogas plant because of the silage, the livestock faeces, aggregate pits for wastewater from the silages and the reservoirs for the fermented manure. It is considered that the stench reaches an area of 500 m, whilst in terms of unfavourable weather conditions it can reach an area of up to 1 km. Closest living areas are 1 km away, which means that it shall not affect the area of residential neighbourhoods.

In order to monitor the state of the environment, regular controls and analyses on the underground water shall be performed, whilst once in two years' time analyses on the soil, which are fertilized by the fermented liquid manure from the plant shall be commenced as well. The construction of the biogas plant creates jobs, new values and raises the awareness of the usage of renewable sources.

4. Economic and financial analysis

The input data and the results of the analysis for the observed 10 years are summarised in tables 1 to 8. We have developed the cost model considering all fixed values of parameters (some of them are fixed by the government regulation or market situation) and some cost components giving us some optimisation possibilities.

Description	Equipment value	Amortization period	Annual depreciation
Construction works	707.616 €	20	35.381 €
Equipment	2.153.164 €	10	215.316 €
Cogeneration unit	739.220 €	7	105.603 €
Total	3.600.000 €		356.300 €

Table 1. Total investment costs

Description	Price (€)
Construction works	707.616
Electro-mechanical equipment and works	2.672.384
Engineering	220.000
Silage purchase in first year of business	220.000
Total	3.820.000

Table 2. Total infrastructure costs

No.	Service / Equipment	Capacity	Value
1.	Design / Construction		135.000 €
2.	Commissioning (Momentum)		65.000 €
3.	Design of plans for location permit		20.000 €
4.	Static budget		V
5.	Apparatus for receiving solids		149.838 €
6.	Reception reservoir of liquid manure		16.977 €
7.	Digester charging room		105.596 €
8.	Digester 1	3.115 m ³	406.403 €
9.	Digester 2	3.115 m ³	406.403 €
10.	Post reservoir with associated gas-tank		230.792 €
11.	CHP	Approx. 999 kW _{el}	739.220 €
12.	Safety torch		
13.	Desulfurization of biogas		
14.	Scale (quantity: 1)	30 t	
15.	Measuring, monitoring and control equipment		284.625 €
16.	Dehydration of sludge		53.590 €
17.	Laguna for post-fermented mass		100.000 €
18.	Condensing pool		
19.	Design of pipelines		117.300 €
20.	Insurance, transport		61.640 €
	Plant expenses		2.892.384 €
	Infrastructure expenses		707.616 €
1.	Silage silo		274.700 €
2.	Earthworks and asphalt bases (quantity: 2000)	40 €	80.000 €
3.	Other earthworks		54.000 €
4.	Foundations		138.966 €
5.	Substation		125.000 €
6.	Starting cost		34.950 €
	Total investment		3.600.000 €

Table 3. Detailed specification of equipment, material and labour

Structure \ Year	1	2	3	4	5	6	7	8	9	10
Revenue										
Thermal energy	0	31.906	32.864	33.850	34.865	35.911	36.988	38.098	39.241	40.418
Electricity	730.037	1.417.548	1.460.074	1.502.601	1.545.127	1.587.654	1.630.180	1.672.707	1.715.233	1.757.760
Value of the organic fertilizers										
Total revenue	730.037	1.449.455	1.492.938	1.536.450	1.579.992	1.623.565	1.667.169	1.710.805	1.754.474	1.798.178
Costs										
Loan repayment										
Interest										
Depreciation	178.150	356.300	356.300	356.300	356.300	356.300	356.300	356.300	356.300	356.300
Maintenance of the plant		16.802	16.802	33.605	33.605	33.605	33.605	33.605	50.407	50.407
Maintenance of the CHP	47.875	119.689	123.280	126.870	130.461	134.052	137.642	141.233	144.824	148.414
Insurance	10.000	10.000	10.300	10.609	10.927	11.255	11.593	11.941	12.299	12.668
Fuel	5.833	10.000	10.300	10.609	10.927	11.255	11.593	11.941	12.299	12.668

Fermented mass supply costs		38.245	39.010	39.790	40.586	41.398	42.226	43.070	43.932	44.810
Raw materials costs (Silage)	110.000	220.000	226.600	233.398	240.400	247.612	255.040	262.692	270.572	278.689
Monitoring of the biological process		2.340	2.410	2.483	2.557	2.634	2.713	2.794	2.878	2.964
Workforce	12.775	21.900	22.557	23.234	23.931	24.649	25.388	26.150	26.934	27.742
Spare parts	9.946	19.893	20.091	20.292	20.495	20.700	20.907	21.116	21.327	21.541
Total costs	374.579	815.169	827.650	857.190	870.190	883.460	897.007	910.841	941.771	956.203
EBITDA	355.458	634.285	665.288	679.261	709.803	740.105	770.162	799.964	812.703	841.974

Table 4. Profit and loss statement (part 1)

Structure \ Year	1	2	3	4	5	6	7	8	9	10
I. Revenue	730.037	1.449.455	1.492.938	1.536.450	1.579.992	1.623.565	1.667.169	1.710.805	1.754.474	1.798.178
1. Total revenue	730.037	1.449.455	1.492.938	1.536.450	1.579.992	1.623.565	1.667.169	1.710.805	1.754.474	1.798.178
2. Rest of project	0	0	0	0	0	0	0	0	0	0
2.1. Fixed assets										
II. Expenditures	319.979	787.306	798.688	822.059	833.899	845.909	858.234	870.813	895.414	908.522
3.Fixed assets investments										
4. Operating costs	200.596	458.869	471.350	500.890	513.889	527.159	540.707	554.541	585.471	599.903
4.1.Tangible costs	177.821	426.969	438.493	467.047	479.031	491.255	503.726	516.450	546.239	559.494
4.2. Service costs	10.000	10.000	10.300	10.609	10.927	11.255	11.593	11.941	12.299	12.668
4.3. Intangible costs										
4.4. Gross salaries	12.775	21.900	22.557	23.234	23.931	24.649	25.388	26.150	26.934	27.742
5. Profit tax	79.589	218.958	218.225	214.112	213.340	212.499	211.685	210.848	206.628	205.746
6. Reserves	39.794	109.479	109.113	107.056	106.670	106.250	105.842	105.424	103.314	102.873
III. Net revenue	410.058	662.148	694.250	714.392	746.093	777.656	808.935	839.992	859.060	889.656

Table 5. Profit and loss statement (part 2)

Structure \ Year	1	2	3	4	5	6	7	8	9	10
I. Revenue	4.330.037	1.449.455	1.492.938	1.536.450	1.579.992	1.623.565	1.667.169	1.710.805	1.754.474	1.798.178
1. Total revenue	730.037	1.449.455	1.492.938	1.536.450	1.579.992	1.623.565	1.667.169	1.710.805	1.754.474	1.798.178
2. Funding sources	3.600.000	0	0	0	0	0	0	0	0	0
2.1. Own resources	720.000									
2.1. Loans	2.880.000									
3. Rest of project	0	0	0	0	0	0	0	0	0	0
3.1. Fixed assets										
II. Expenditures	200.596	883.634	896.115	925.655	938.655	951.925	965.472	979.306	1.010.237	1.024.669
4. Investments in fixed assets										
5. Operational costs	200.596	458.869	471.350	500.890	513.889	527.159	540.707	554.541	585.471	599.903
5.1. Tangible costs	177.821	426.969	438.493	467.047	479.031	491.255	503.726	516.450	546.239	559.494
5.2. Services costs	10.000	10.000	10.300	10.609	10.927	11.255	11.593	11.941	12.299	12.668
5.3. Intangible costs	0	0	0	0	0	0	0	0	0	0
5.4. Gross salaries	12.775	21.900	22.557	23.234	23.931	24.649	25.388	26.150	26.934	27.742
6. Profit tax 20 %	0	0	0	0	0	0	0	0	0	0
7. Reserves	0	0	0	0	0	0	0	0	0	0
8. Annuities	0	424.765	424.765	424.765	424.765	424.765	424.765	424.765	424.765	424.765
III. Net revenue	4.129.441	565.820	596.823	610.795	641.338	671.640	701.696	731.499	744.237	773.509
IV. Cumulative net revenue	4.129.441	4.695.261	5.292.084	5.902.880	6.544.217	7.215.858	7.917.554	8.649.053	9.393.290	10.166.799

Table 6. Economic flow of project

Month	Monthly production	Own consumption	Energy for sale	Rest
January	662.400	198.720	463.680	0
February	662.400	198.720	463.680	0
March	662.400	198.720	463.680	0
April	662.400	158.976	302.054	201.370
May	662.400	0	264.960	397.440
June	662.400	0	0	662.400
July	662.400	0	0	662.400
August	662.400	0	0	662.400
September	662.400	0	198.720	463.680
October	662.400	59.616	361.670	241.114
November	662.400	99.360	563.040	0
December	662.400	198.720	463.680	0
Total per annum	7.948.800	1.112.832	3.545.164	3.290.804

Table 7. Production balance of thermal energy (in KWh)

Consumption of thermal energy for own needs is 55 %.

Month	Monthly production	Capacity (kW)	Daily production (h)
January	674.505	999	21,78
February	609.230	999	21,78
March	674.505	999	21,78
April	652.747	999	21,78
May	674.505	999	21,78
June	652.747	999	21,78
July	674.505	999	21,78
August	674.505	999	21,78
September	652.747	999	21,78
October	674.505	999	21,78
November	652.747	999	21,78
December	674.505	999	21,78
Average	661.813	999	21,78
Total per annum	7.941.750	-	7949,7

Table 8. Production of electricity (in KWh)

Consumption of electricity for own needs of the biogas plant is 6 % or 476.505 kWh. During operation, we have a computer control loop, which indicates that we are running within planned costs, within the achievement of the planned objectives and within other technical parameters. All technical parameters and costs, eventual failures are controlled by dedicated software. Any deviations are displayed using visual warning signal, overall control can also be remotely controlled and synchronized with the network. This ensures a stable economic operation of the plant.

5. Conclusion

Production and consequently sales of energy derived from biogas production devices offers economic opportunity for treatment and recycling of many agricultural residues and by-products, a variety of bio-waste, organic waste water from industry and sewage in a sustainable and environmentally friendly manner.

Having done the pre-calculations using the calculation tool as recommended in the result is a model of the economy of the project. As stated before, the operational costs and the investment costs can be influenced by strategic decisions. For example by choosing the best adapted technology. So, if labour is cheap in your country, than it might be cheaper engaging more people than spending money for automation of a plant.

The revenue side of a project is difficult to influence. The feed in tariffs are set by the government. In case of waste treatment plants, the tipping fees are market prices. There are other possibilities of improve the revenue side:

- Using/selling the produced heat,
- Selling digestant as a fertilizer.

If the project obtains an internal rate of return (*IRR*) lower than 9 %, you should reconsider all the project premises, and improve some of them. If the *IRR* rate is higher than 9 %, the premises are good and it is worth continuing the project and moving to the next planning phase. It is important to compare the assumptions with the material reality. This helps to get a realistic idea of the biogas plant itself, the needed space, the true mass current and the real building costs. The calculation model is useful for providing the rough information which is necessary to kick start the actual planning phase. Also the earnings before interest, taxes, depreciation and amortization (*EBITDA*) are very prosperous. For the next steps of project, finding an independent and reliable planning partner is mandatory.

According to the economic indicators, return on the whole investment is anticipated in 5-6 years. The lifetime of the biogas plant is 20 years. The plant itself delivers 5 jobs, whilst it indirectly ensures 20 jobs including production of biomass on the fields. The utilization of the fermented mass as organic fertilizer improves crops contribution for 15-25 % and reduces the application of artificial fertilizers, which as a result improves the total quality of the agricultural production and decreases the artificial fertilizers expenses. In the biogas plant, the waste is used as bio-renewable source of energy.

The main paper contribution is the development of new structure of cost calculation applying a wide list of influencing parameters which consider the actual state and conditions. Another achievement is the modified system of evaluation of the eligibility of investment. In future research some model expansions are planned, including the generalization of implemented (combined) energy sources.

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