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Development and Use of an Economic Evaluation Model to Assess Establishment of Local Centralized Rural Biogas Plants in Greece

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Abstract

An economic evaluation model was developed in the Laboratory of Agricultural Structures (LAS) of the Agricultural University of Athens—the Modified Basic Economic Evaluation Model (MBEEM). This model is an improved version of the original Basic Economic Evaluation Model, available in LAS, and it is used to assess the cost-effectiveness of biogas production systems. Because of the parameters involved, a computer model was developed to facilitate the application of the MBEEM. The model was used in this work to determine the cost-effective size of a local centralized biogas production system fed with pig wastes.

Index Entries: Pig wastes; centralized biogas plant; economic evaluation model.

Introduction

During the past 20 yr, the application of anaerobic systems to treat pig wastes has been extensively studied in Greece in the Laboratory of Agricultural Structures (LAS) of the Agricultural University of Athens (AUA) *(1)*. In particular, the anaerobic lagoon concept and biogas production in

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plug-flow digesters were the systems studied and applied more extensively. The mild climate of Greece and the simple and low-cost operation of the anaerobic lagoon system has led to its adoption by the majority of Greek farmers and especially pig meat producers.

The efficient treatment and longtime storage of the wastes provided by an anaerobic lagoon system, as it is applied in Greece, and the low oil prices, following the energy crisis of 1973, could be considered the main reasons for the lack of rural biogas production systems in Greece. The sophisticated construction and operation of these systems, as well as the high investment and know-how costs, have pushed farmers to adopt the cheaper and simpler anaerobic lagoon system.

The research and development efforts of LAS *(2)* have been focused on optimizing the size of the biogas plants by settling pig wastes and using the settled sludge to feed the anaerobic digester. It was found that a daily biogas volumetric production rate of 1.16 m^3/m^3_R and a maximum net biogas volumetric production rate (daily biogas production minus that required to heat the digester) were obtained when a sludge volume equal to about one-fifth of the daily waste volume was loaded to the digester. At this loading rate, the optimum size of the digester resulted.

The settled sludge from different pig farms in a rural region could be collected and transported to a nearby local centralized biogas plant. The output of such a plant could normally be biogas and compost. The latter is the result of digested effluent mixing with solid wastes from the mechanical separation systems applied in Greek pig farms.

The supernatant (about 4/5 of the daily waste production volume) from the settling basin can be stored and treated in anaerobic lagoons, *in situ*, in each farm. The idea of a local centralized biogas production plant, which would collect, at a gate fee, the settled sludge from nearby pig farms for biogas and compost production and utilization, seems to be a very promising and reliable solution for most Greek pig farms in the future.

Experience in LAS has shown that due to their small- to medium-scale farms and inadequate technoeconomical status, individual farmers in Greece cannot optimally operate biogas production systems. The need for a reliable economic evaluation of a local centralized biogas production system is therefore obvious, in order to select the optimum size of such a plant, thus successfully promoting biogas technology in Greece.

To cope with this need, a Basic Economic Evaluation Model (BEEM) had initially been developed at LAS, in cooperation with the Faculty of Agricultural Economics and Rural Development of AUA *(3)*. In this work, an updating and improvement of the BEEM was developed, leading to the Modified Basic Economic Evaluation Model (MBEEM) discussed next.

Modified Basic Economic Evaluation Model

The MBEEM, as well as the original model (BEEM), is based on the Net Present Value Concept and determines the net present value (NPV) of the investment cost *(4)*. NPV for an investment is defined here as the difference between the present value of annual income and expenses. If the NPV is >0, then the investment is economically efficient. The value of the compound interest, whose NPV becomes zero, is called the internal rate of return. This value is the maximum compound interest discount rate, which is cost-effective. NPV is calculated by Eq. 1:

$$\text{NPV} = \sum_{j=1}^{n} [\text{NCF}_j \times (1 + r)^{-j}] - I \tag{1}$$

in which NPV = net present value (euro); NCF = net cash flow = $B - C$ (euro); B = annual income from the installation (euro); C = annual operational and maintenance cost of the installation (euro); r = discount rate (%); j = operation life-span of the installation (yr); and I = required capital investment cost (euro).

If the net initial capital investment cost of the installation is known, the application of NPV indicates whether the investment is cost-efficient (NPV > 0) or not (NPV < 0). The capital investment cost for which NPV becomes zero is the maximum one for the installation to pay its cost, during its operation life-span. Its value depends on the values of the different parameters of Eq. 1.

The maximum capital investment cost, for which NPV becomes zero, is given by Eq. 2:

$$I = \sum_{j=1}^{n} [\text{NCF}_j \times (1 + r)^{-j}] \tag{2}$$

The input data (different parameter values) to the MBEEM have been selected to fit biogas utilization for cogeneration of thermal energy and power.

The total annual income (benefit, B) and the total annual expenses (cost, C) of the installation are determined by Eqs. 3 and 4:

$$B = B_{ther} + B_{el} + B_{comp} \tag{3}$$

in which B = total annual income (total benefits from biogas use) (euro); B_{ther} = income from thermal energy production utilization: $(V_R \times \gamma_v - L) \times P_{ther} \times 0.9 \times T_{ther} \times a \times Pr_{ther}$ (in which a = unit conversion coefficient, 0.8759 L of diesel oil/m^3 of CH_4, at standard temperature and pressure; P_{ther} = percentage of net methane utilized for thermal energy production [%]/100; Pr_{ther} = price of diesel oil [euro/L]; and T_{ther} = time period of utilizing the thermal energy produced [d]); B_{el} = income from the power utilization: $b \times P_{el} \times Pr_{el} \times T_{el} \times 0.9 \times (V_R \times \gamma_v - L)$ (in which b = unit conversion coefficient, 9.278 kWh$_{el}$/[d·m^3 of CH_4]; P_{el} = percentage of net methane utilized for power production [%]/100; Pr_{el} = selling price of the electric kWh$_{el}$ produced [euro/kWh$_{el}$]; T_{el} = time period of selling the power produced [d]; V_R = working volume of the digester [m^3]; γ_v = total daily methane production rate at steady-state conditions, m^3 of CH_4/[m^3_R·d]; and L = total daily methane utilization rate for digester heating m^3 of CH_4/[m^3_R·d]; and B_{comp} = income from selling the compost produced: $W_{comp} \times Pr_{comp}$ (in which W_{comp} = total annual compost production [t/yr]; and Pr_{comp} = net benefit (income-outcome) [euro/t]):

$$C = C_{dig} + C_{mec} + C_{inv} + C_{ins} + C_{misc} + C_{sal} \tag{4}$$

in which C = total annual expenses (euro); C_{dig} = total annual digester maintenance cost (euro/yr): $V_{wast} \times Pr_{dig}$ (in which V_{wast} = annual waste volume [m^3/yr]; and Pr_{dig} = maintenance unit cost [euro/t of wastes]); and C_{mec} = total annual cogeneration unit or biogas burner operation cost (euro): $E \times Pr_{mec}$ (in which E = annual energy production [kWh/yr]; and Pr_{mec} = operation unit cost, euro/[kWh·yr]); and C_{misc} = miscellaneous cost (euro/yr); and C_{sal} = personnel salaries (euro/yr).
(Note that in this work, the parameter B_{comp} is set as zero, since the cost of compost production from mechanical separation solids, for simplicity reasons, is assumed to be fully paid by the income from selling the compost to the market.)

Results and Discussion

The successful application of the MBEEM depends on the best estimates of the different input data required.

The following assumptions have been considered to determine the cost-effective size of a local centralized biogas production system installation, under the Greek pig farm reality *(5)*:

1. The average life-span of the biogas production system is 12 yr.
2. The time period of utilizing the thermal energy produced to heat young piglets and a nearby slaughterhouse is 250 d/yr.
3. The time period of selling the power produced to the national power company grid is 365 d/yr.
4. Total annual salaries from 30,000 up to 84,000 euro, depending on the size of the plant. All salaries are subjected to an average annual inflation rate increase of 2%.
5. The value of r is taken as 0.08 and gradually reduced to a final value of 0.06 during the 12-yr life-span of the biogas system.
6. The price of diesel oil substituted is taken as 0.704 euro, with an average annual increase of 2%, during the 12-yr life-span of the biogas system.
7. The price of each electric kilowatt-hour produced is taken as 0.059 euro, with an average annual increase of 2%, during the 12-yr life-span of the biogas system.
8. The annual operation and maintenance cost of the system is 0.20 euro/t of influent in the digester, with an average annual increase of 2%, during the 12-yr life-span of the biogas system.
9. The annual operation and maintenance cost of the cogeneration unit is 4.5 euro/MWh$_{el}$ produced, with an average annual increase of 2%, during the 12-yr life-span of the biogas system.

10. Thirty percent of the annual operation and maintenance (including salaries) costs have been added for new investments, insurance, and miscellaneous costs.

It is assumed that only 75% of the total annual heat production is actually utilized plus 10% for heat transfer and other heat losses. Twenty-five percent of the total pure methane production is converted to power. Ten percent for any kind of power losses has been calculated.

Because of the complexity of the parameters involved, a computer program has been developed to fit the MBEEM. The program uses Visual Basic Language, operating in a Windows environment. A general flow diagram of the program is shown in Fig. 1.

The MBEEM, through the aforementioned computer program, has evaluated a series of digester capacities corresponding to different pig farm sizes. The proper parameter values have been used as the input and the maximum required capital investment cost (I_{max}) for a cost-effective biogas production system, as the output. Figure 2 illustrates a detailed sample MBEEM calculation sheet, similar to those used by the computer program. All digester sizes, relevant pig farm sizes, and $I_{\max}$ are given in Table 1, compared to the installation cost estimate of the corresponding centralized biogas production systems.

The installation cost estimate (C_{tot}) of the different size centralized biogas production systems of Table 1 is based on the following cost range assumptions, depending on the size of the plant, which can be considered reliable for operations in Greece *(5)*:

1. Reinforced concrete construction, including thermal insulation and equipment: 600–850 euro/m^3 of reinforced concrete of the digester.
2. Temporary biogas storage facility: 30,000–200,000 euro.
3. Thermal energy and power cogeneration unit: 100,000–500,000 euro.
4. Miscellaneous: 80,000–250,000 euro.

In Table 2, several subsidy levels are used, at up to 60% of the installation cost, thus reducing the cost-effective size of the biogas production system to 600 m^3.

Conclusion

The MBEEM was developed from the initial BEEM available in LAS of AUA and used to determine the cost-effective size range of local centralized biogas production and utilization systems fed with settled pig wastes in Greece. The cost-effective size range of such a system was shown to be 800 m^3 and up, under the assumptions set for Greek pig farming. At these sizes, the required maximum investment cost ($I_{\max}$) becomes greater than the corresponding installation cost (C_{tot}). The higher the difference between $I_{\max}$ and C_{tot}, the sooner the invested capital will be paid, thus allowing some profit. By subsidizing the installation cost, a size range from 600 m^3 and up becomes cost-effective and profitable.

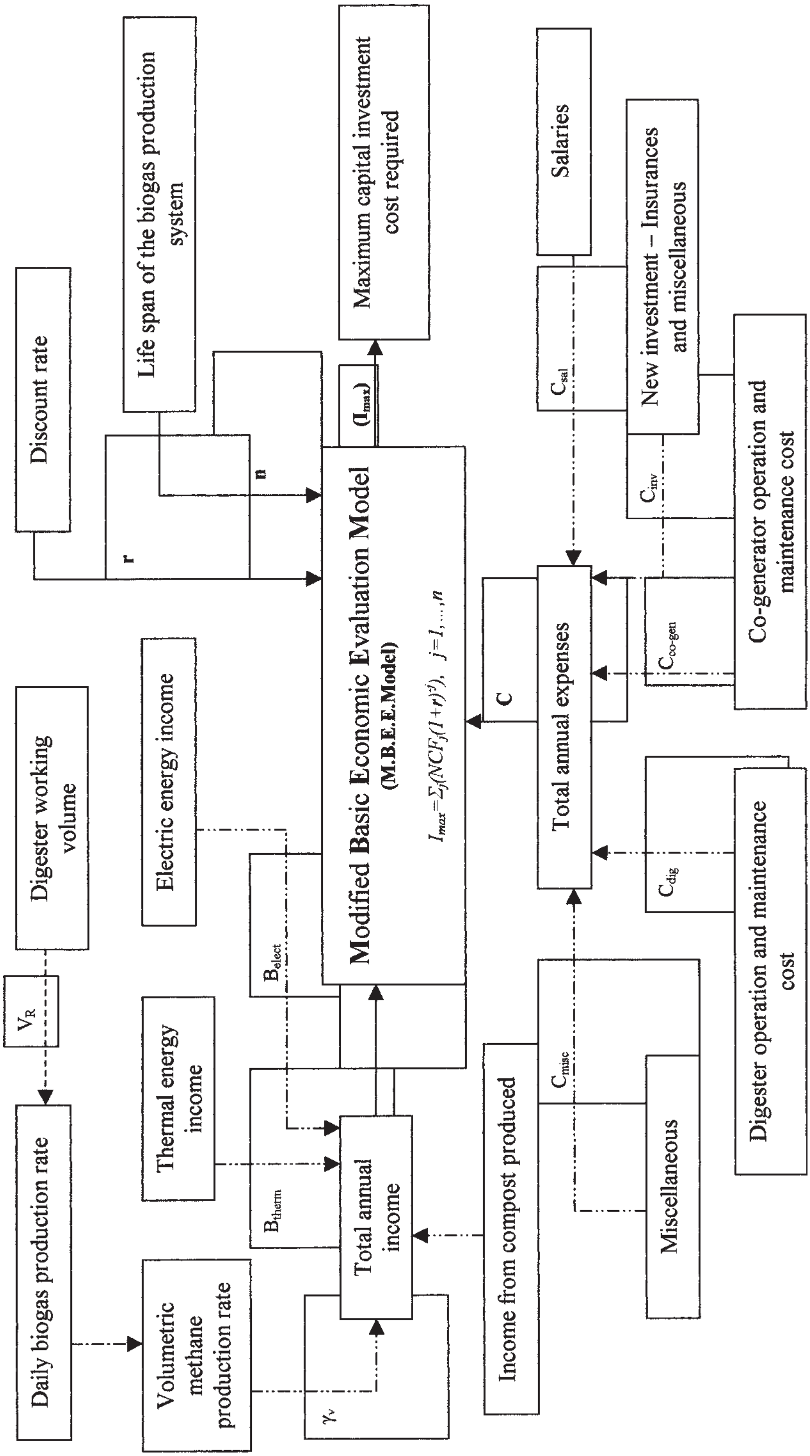

Fig. 1. General flow diagram of computer program developed to fit MBEEM.

		YEAR											
	j	1	2	3	4	5	6	7	8	9	10	11	12
INCOME	THERMAL ENERGY *(Liters of diesel oil equivalent)*	119,736	122,131	124,573	127,065	129,606	132,198	134,842	137,539	140,290	143,095	145,957	148,877
	DIESEL OIL PRICE	0.704	0.718	0.733	0.747	0.762	0.778	0.793	0.809	0.825	0.842	0.859	0.876
	POWER PRODUCTION *(Electric kWh)*	26,412	26,941	27,479	28,029	28,590	29,161	29,745	30,339	30,946	31,565	32,196	32,840
	Euro/electric kWh	0.059	0.060	0.061	0.062	0.064	0.065	0.066	0.067	0.069	0.070	0.072	0.073
	TOTAL ANNUAL INCOME ***(Euro)***	146,148	149,071	152,053	155,094	158,196	161,359	164,587	167,878	171,236	174,661	178,154	181,717
EXPENSES	DIGESTER OPERATION AND MAINTENANCE COST *(Euro)*	3,650	3,723	3,798	3,873	3,951	4,030	4,111	4,193	4,277	4,362	4,449	4,538
	Euro/t influent	0.200	0.204	0.208	0.212	0.216	0.221	0.225	0.230	0.234	0.239	0.244	0.249
	CO-GENERATOR OPER. AND MAINT. COST *(Euro)*	2,025	2,066	2,107	2,149	2,192	2,236	2,281	2,326	2,373	2,420	2,469	2,518
	Euro/electric kWh	4.500	4.590	4.682	4.775	4.871	4.968	5.068	5.169	5.272	5.378	5.485	5.595
	NEW INVESTMENT INSURANCES MISCELLANEOUS *Euro)*	18,218	18,582	18,954	19,333	19,719	20,114	20,516	20,926	21,345	21,772	22,207	22,651
	SALARIES +25% *(Euro)*	46,375	47,303	48,249	49,214	50,198	51,202	52,226	53,270	54,336	55,422	56,531	57,662
	TOTAL ANNUAL EXPENSES ***(Euro)***	70,268	71,673	73,106	74,568	76,060	77,581	79,133	80,715	82,330	83,976	85,656	87,369
NCF	NET CASH FLOW *(Euro)*	75,881	77,398	78,946	80,525	82,136	83,778	85,454	87,163	88,906	90,684	92,498	94,348
r	DISCOUNT RATE	0.080	0.078	0.076	0.075	0.073	0.071	0.069	0.067	0.066	0.064	0.069	0.060
K	$(1+r)^{-j}$, j=1,2,…12 years	0.935	0.876	0.825	0.778	0.737	0.701	0.669	0.640	0.614	0.592	0.573	0.556
PRESENT VALUE	NCF*K *(Euro)*	70,917	67,831	65,099	62,688	60,572	58,727	57,133	55,772	54,631	53,697	52,961	52,417
I_{max}	**MAXIMUM CAPITAL INVESTMENT COST REQUIRED** ***(Euro)***	**712,445**											

Fig. 2. Detailed sample MBEEM calculation sheet for pig farm wastes.

Table 1
Maximum Capital Investment Required for Cost-Efficient, Local Centralized Biogas Production System

Digester construction volume (m^3)	Digester working volume (m^3)	Influent waste volume rate after settling (m^3/d)	Raw waste volume before settling (m^3/d)	Equivalent sow number (sows)	Maximum capital investment required (I_{max}) (euro)	Installation cost estimate (C_{tot}) (euro)
315	300	15.00	75.00	850	—	255,000
420	400	20.00	100.00	1100	38,000	274,000
525	500	25.00	125.00	1400	61,000	363,000
630	600	30.00	150.00	1650	191,000	382,000
735	700	35.00	175.00	2000	314,000	406,000
840	800	40.00	200.00	2200	450,000	423,000
945	900	45.00	225.00	2500	582,000	523,000
1050	1000	50.00	250.00	2750	712,000	620,000
1470	1400	70.00	350.00	3850	828,000	765,000
1890	1800	90.00	450.00	5000	1,356,000	930,000
2310	2200	110.00	550.00	6100	1,521,000	1,200,000

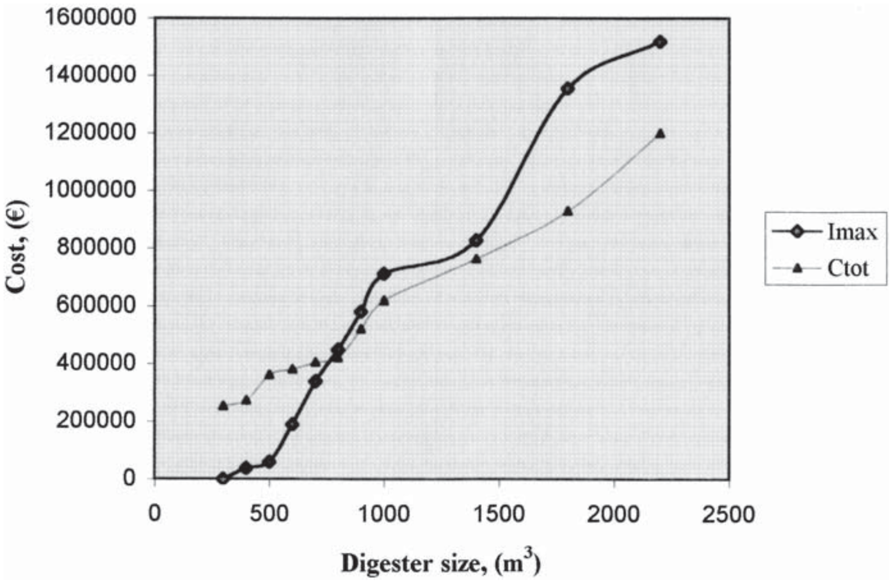

Fig. 3. Cost (I_{max}, C_{tot}) variation according to digester size.

Table 2
Cost-Effective Sizes of Local Centralized Biogas Production Systems at Different Subsidy Levels

Digester working volume (m^3)	Subsidy level[a]					
	0%	20%	30%	40%	50%	60%
300	–	–	–	–	–	–
400	–	–	–	–	–	–
500	–	–	–	–	–	–
600	–	–	–	–	+	+
700	–	–	+	+	+	+
800	+	+	+	+	+	+
900	+	+	+	+	+	+
1000	+	+	+	+	+	+
1400	+	+	+	+	+	+
1800	+	+	+	+	+	+
2200	+	+	+	+	+	+

[a]+, cost-effective size.

The MBEEM can be considered a useful and practical tool for the economic evaluation of a biogas production and utilization system, under appropriate parameter values. A computer program in Visual Basic Language is currently being developed at LAS to generalize and facilitate the application of the MBEEM.

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