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Techno-Economic Evaluation of Biogas Production from Organic Waste Using SuperPro Designer

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Abstract

The growing emphasis on sustainable energy has intensified interest in producing biogas from organic waste, recognized as a renewable and environmentally friendly alternative. This study focuses on the economic analysis and evaluation of biogas generation from cow dung through anaerobic digestion, utilizing the SuperPro Designer software. The process model encompasses key stages such as waste handling, slurry preparation, anaerobic digestion, and biogas recovery. Material and energy balances, along with equipment sizing and economic assessments, were conducted using the software's integrated tools. Essential economic metrics including total capital investment, operating costs, net profit, payback period, and return on investment were calculated based on practical assumptions. The findings reveal an annual methane output of approximately 6.16 million kilograms, generating estimated revenue of USD 1.85 million. The total capital investment required was assessed at USD 2.37 million, paired with annual operating costs of approximately USD 1.25 million. This yields an annual net profit of around USD 0.39 million, a payback period of 6 years, and a return on investment (ROI) of 16%. These outcomes validate both the technical feasibility and the economic sustainability of biogas production from cow dung. Furthermore, they highlight the effectiveness of SuperPro Designer as a valuable decision-support tool for the design and optimization of sustainable biogas systems.

Keywords: Biogas; Anaerobic digestion; Cow dung; Techno-economic analysis; SuperPro Designer; Renewable energy

1. Introduction

Energy lies at the heart of global economic development, but the heavy reliance on fossil fuels has given rise to pressing challenges such as climate change, environmental degradation, and risks to public health. With a growing energy demand, particularly driven by rapidly industrializing nations, the need to shift toward sustainable and alternative energy sources has become increasingly urgent. [1, 2]. Biogas is gaining recognition as a promising renewable energy solution due to its environmental advantages and often cost-competitiveness when compared to other renewable technologies.[3]. Thanks to the vast availability, diversity, and flexible applications of biomass, energy systems utilizing it are anticipated to play a pivotal role in the future energy landscape by providing heat, electricity, biofuels, and even chemicals.[4]. In addition, biological waste, once deemed low-value, is now being repurposed as a valuable resource for producing eco-friendly fuels, marking an essential step toward reducing petroleum dependency and embracing more sustainable, bio-based energy systems. [1, 5]. Extensive research has explored the techno-economic and environmental performance of biogas plants, incorporating evaluations rooted in circular economy (CE) principles. A comparative

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analysis of economic viability and environmental emissions was conducted for various scenarios involving biogas production and digestate utilization. Focusing on a system that uses animal manure as feedstock, the findings revealed that the combined approach of using biogas for cogeneration and processing digestate into compost delivered the most favorable outcomes in terms of profitability and environmental benefits. [6]. The implementation of large-scale waste management technologies like anaerobic digestion (AD) requires a comprehensive economic assessment, as their practicality heavily depends on regional technical and geopolitical factors. As a result, techno-economic analysis (TEA) becomes essential in determining the viability of such projects and should be customized to the specific context of each location. TEA generally combines process modeling, engineering design, and economic evaluation to analyze economic performance while identifying critical cost factors and potential risks during the development and execution stages [7-10]. Techno-economic evaluation serves as a critical approach for examining the technical performance and economic viability of biogas production systems prior to their large-scale deployment. By combining aspects like process efficiency, energy outputs, capital expenses, and operating costs into a comprehensive framework, it provides a thorough assessment essential for informed decision-making. This analysis helps determine whether a biogas project can sustain operations under practical industrial conditions while minimizing financial uncertainty. By evaluating key factors such as feedstock availability, system configuration, conversion efficiency, and cost dynamics, techno-economic studies offer a practical foundation for comparing different technologies and refining system designs. As a result, this form of evaluation is instrumental in shaping investment choices, supporting policy development, and ensuring the effective implementation of biogas technologies for renewable energy generation and managing organic waste. [11]. Process simulation tools are essential in contemporary chemical and biochemical engineering, facilitating detailed and cohesive analysis of mass and energy balances, equipment design, and process optimization within a single computational framework. These tools empower engineers to simulate intricate process flowsheets, analyze material and utility demands, estimate both capital and operational expenditures, and evaluate the technical and economic viability of various process alternatives prior to implementation. By integrating thermodynamic modeling, libraries of unit operations, and advanced optimization techniques, process simulators enable data-driven decisions, minimize design risks, and improve overall process efficiency and sustainability. [12, 13, 14]. SuperPro Designer facilitates the structured assessment of various process scenarios, plant capacities, and operating conditions for biogas production from organic waste within a unified simulation environment. The platform enables users to evaluate alternative feedstocks, digestion methods, and utility setups while analyzing their effects on material and energy balances, equipment dimensions, and economic outcomes. Through scenario and sensitivity analyses, it aids in optimizing plant throughput, operational parameters, and cost-efficiency. This functionality helps minimize technical risks and enhances decision-making during the design and scale-up of biogas systems. [12, 14]. The study performs a comprehensive techno-economic assessment of biogas production from organic waste using SuperPro Designer. Its objectives include modeling the process, evaluating profitability and sensitivity, and identifying areas for improvement to enhance overall feasibility.

2. Materials and Methods

2.1. Materials

The main raw material used in this study is organic waste, such as animal manure. These wastes are rich in biodegradable organic matter and suitable for biogas production through anaerobic digestion. Water is used to adjust the moisture content and facilitate pumping and mixing. In addition, basic utilities such as electricity and process water are considered in the economic evaluation. No hazardous chemicals are required, making the process environmentally friendly.

2.1.1. *Equipment*

The biogas production process requires several main units. These include a waste receiving and storage unit, a mixing tank for slurry preparation, and an anaerobic digester where biogas is produced under controlled temperature conditions. A gas holder is used to collect and store the produced biogas, while a biogas upgrading or cleaning unit removes impurities such as carbon dioxide and hydrogen sulfide if needed. Other auxiliary equipment includes pumps, heat exchangers, and separators. All equipment sizes and specifications are modeled and selected using SuperPro Designer based on process capacity.

2.2. Methods

A detailed economic assessment of biogas production from cow dung via anaerobic digestion was performed using the integrated costing tools of SuperPro Designer. The evaluation generated key financial indicators, including total capital expenditure (CAPEX), annual operating expenditure (OPEX), and the unit cost of biogas production. To improve the reliability of the analysis, assumptions related to equipment lifetime, labor costs, and utility prices were refined in accordance with internationally accepted benchmarks.

Through anaerobic digestion was evaluated using the built-in economic analysis tools of SuperPro Designer. The assessment was based on the developed process flowsheet and the specified operating parameters. The main steps of the analysis included setting the prices of raw materials and products, estimating equipment purchase and installation costs, and defining key economic parameters such as plant lifetime and discount rate. Finally, SuperPro Designer was used to generate a comprehensive financial report, including total capital investment, annual operating costs, and the unit cost of biogas production.

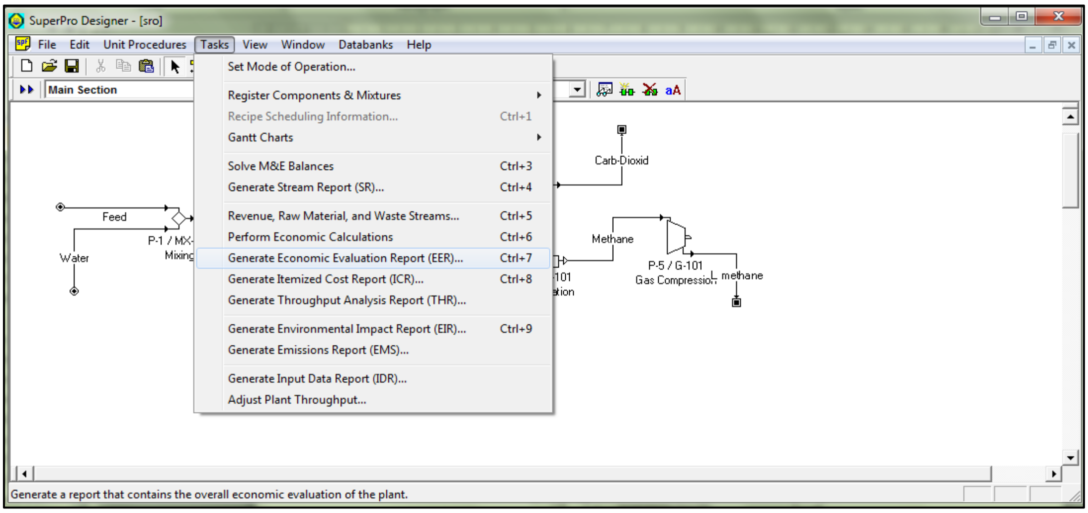

Figure 1 Reports dialog box

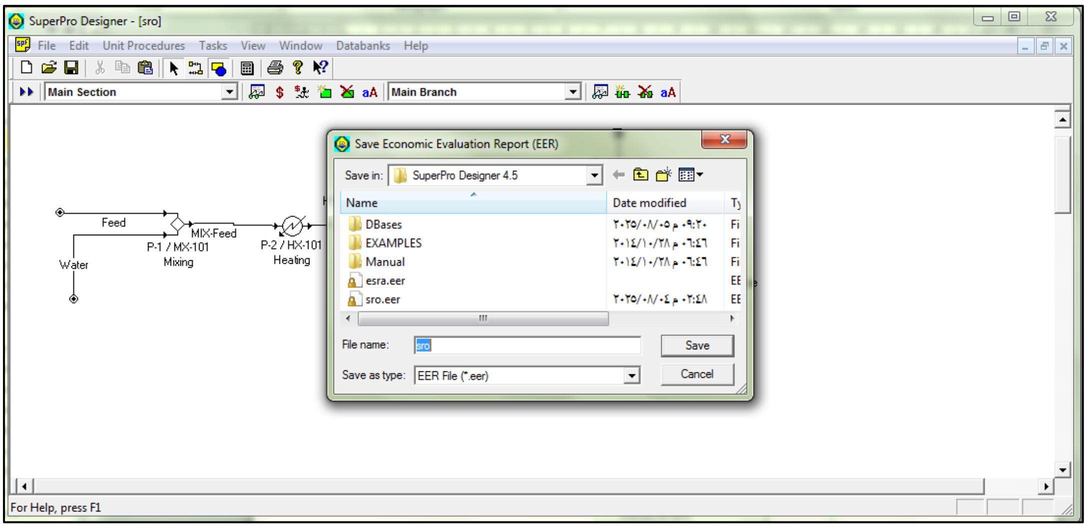

Figure 2 Save economic evaluation report

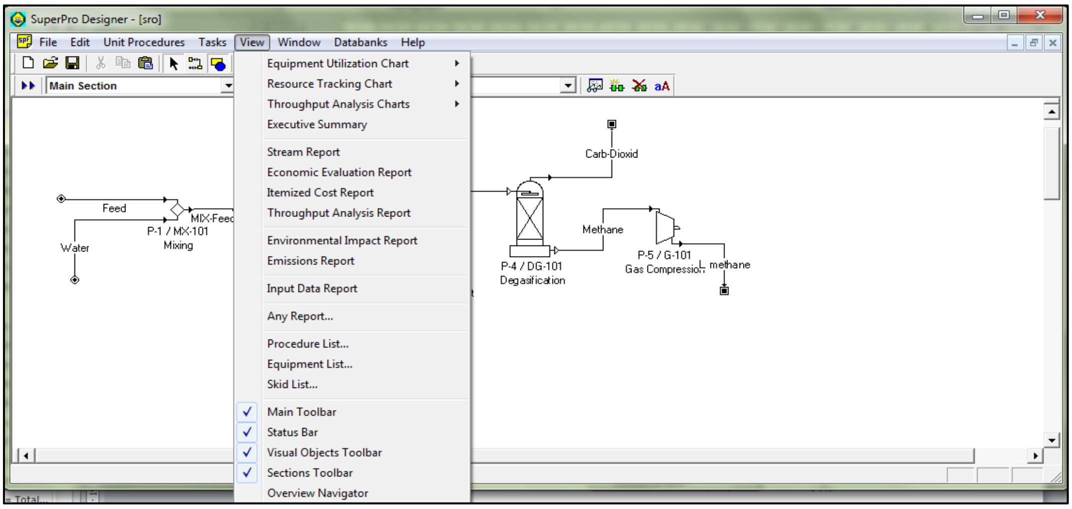

Figure 3 View of the Reports

Estimation of Total Capital Investment:

The total capital investment for the proposed plant is estimated:

TCI = Fixed Capital Investment + Working Capital Investment……………..……(1)

Fixed Capital Investment (FCI):

Fixed Capital Investment (FCI) = Direct Costs + indirect costs……..……......….(2)

= 1072000 + 900000

= 1972000 $/year

Working Capital Investment (WCI):

Working Capital Investments (10- 20) % of FCI

= 1972000 * 0.2 = 394400 $/year

TCI = 1972000 + 394400 = 2366400 $/year

Annual Revenue:

According to the simulation output, the annual production of methane is:

6163902.4464 kg/year

Market selling price = 0.3 $/kg

Revenue = Market selling price * annual production of methane …………..…... (3)

=6163902.4464 * 0.3 = 1849170.73392 $/year

Annual Operating Costs:

Based on realistic estimations from SuperPro Designer and industrial data, the total operating costs are:

Operating Costs= 1252000 $/year

Profit Calculation:

Gross Profit = Revenue − Operating Costs ………………….…………………..………. (4)

= 1849170.73392 - 1252000

= 597170.73392 $/year

Accounting for a 35% corporate tax:

Net Profit = 597170.73392 × (1−0.35) = 388160.977048 $/year

Payback Period Calculation:

The Payback Period is the time needed to recover the initial investment from net profits.

Payback Period = Total Investment / Net Profit ……………………..…….……… (5)

= 2366400 / 388160.977048

= 6 years

The Return on Investment (ROI):

ROI = Net profit / TCI *100……..………………………………………………………..….. (6)

= (388160.977048 /2366400)*100 %

= 16 %

3. Results and Discussions

Table 1 The major equipment specification and cost

Major equipment specification and fob cost (2025 prices)			
Quantity /stand -by	**Description**	**Unit cost $**	**Cost $**
1/0 MX-101	Mixer Rated throughput = 8000 Kg/h	8000	8000
1/0 HX-101	Heat exchanger Area = 0.34 m/s	2000	2000
1/0 V-101	Stirred Jacket Vessel Volume = 8969.08 L Diameter = 1.66 m	120000	120000
1/0 G-101	CF Compressor power = 189.98 KW	10000	10000
1/0 DG-101	Degasifier Diameter = 0.00 m Height = 0.00 m	100000	100000
Cost of unlisted equipment			60000
Total equipment purchase cost			299000

Table (1) presents the major equipment specifications and associated costs for the biogas production process, with a total equipment purchase cost of $299,000, as estimated using SuperPro Designer. The Stirred Jacket Vessel (V-101) is the most significant capital item, costing $120,000, due to its large volume (8969.08 L) and jacketed structure, which is essential for maintaining optimal fermentation temperatures. The Degasifier (DG-101) follows at $100,000, despite having unspecified dimensions, indicating it may be a customized or high-efficiency unit. Other components include the CF Compressor (G-101) at $10,000 (189.98 kW), the Mixer (MX-101) at $8,000 (throughput of 8000 kg/h), and the Heat Exchanger (HX-101) at $2,000 (0.34 m^2 surface area). An additional $60,000 accounts for unlisted equipment such as instrumentation, valves, or minor units. This distribution reflects standard cost trends in medium-scale bioprocessing plants, where vessels and gas-handling systems typically dominate capital expenses.

Table 2 The costs

Fixed capital estimate summary (2025 prices)	
A. Total plant direct cost (TPDC) (physical cost)	**$**
1.Equipment purchase cost	299000
2. Installation	210000
3. Process piping	105000
4. Instrumentation	120000
5. Insulation	9000
6. Electricals	30000
7. Building	135000
8. Yard improvement	45000
9. Auxiliary facilities	120000
TPDC = 1072000	
B. Total plant indirect cost (TPIC)	
10. Engineering	268000
11. Construction	375000
TPIC = 643000	
C. Total plant cost (TPDC+ TPIC)	TPC = 1715000
12. Contractor’s fee	86000
13. Contingency	172000
(12+13) = 257000	
D. Direct fixed capital	TPC +12+13 = 1972000

Table (2) summarizes the fixed capital investment for the biogas production facility, with a total Direct Fixed Capital (DFC) of $1,972,000 based on 2025 prices. The Total Plant Direct Cost (TPDC) amounts to $1,072,000, including major items such as equipment purchase ($299,000), installation ($210,000), buildings ($135,000), and auxiliary facilities ($120,000). The Total Plant Indirect Cost (TPIC) is $643,000, covering engineering ($268,000) and construction management ($375,000). Combined, these give a Total Plant Cost (TPC) of $1,715,000. Additional capital allowances include a contractor’s fee of $86,000 and a contingency reserve of $172,000, reflecting standard industrial practice to account for project uncertainties. These estimates were generated using SuperPro Designer's.

Table 3 The annual operating cost

Annual operation cost – summary (2025 prices)		
Cost item	**$/year**	**%**
Raw materials	325000	25.94
Labor – Dependent	305000	24.37
Equipment – Dependent	369000	29.49
Laboratory / QC/QA	46000	3.66

Consumables	0	0.00
Waste Treatment / Disposal	0	0.00
Utilities	207000	16.54
Transportation	0	0.00
Miscellaneous	0	0.00
Advertising and selling	0	0.00
Running royalties	0	0.00
Failed product disposal	0	0.00
Total	1252000	100.0
Profitability section and cash flow section are skipped since no main revenue stream has been defined		

Table (3) presents the annual operating cost breakdown for the biogas production process, totaling $1,252,000 per year based on 2025 prices. The largest cost component is equipment-dependent costs, amounting to $369,000 (29.49%), reflecting significant expenditures related to maintenance, depreciation, and energy consumption. Raw materials follow closely at $325,000 (25.94%), indicating a substantial input cost in the production process, while labor-dependent costs reach $305,000 (24.37%), highlighting the workforce's critical role in process operations. Utilities, particularly electricity and steam, contribute $207,000 (16.54%), which is typical for energy-intensive bioprocesses. Minor costs include laboratory and QA/QC operations at $46,000 (3.66%), while other categories such as consumables, waste treatment, transportation, and royalties are currently reported as zero, possibly due to process simplification or omission of certain downstream logistics in this evaluation. The profitability and cash flow analyses were excluded, as no defined revenue stream was input, which limits full economic assessment but provides a solid foundation for future profitability modeling.

Table 4 The summary of Key financial indicators

Indicator	Value million USD
Total Capital Investment	2366400
Fixed Capital Investment	1972000
Annual Operating Costs	1252000
Annual Revenue	1849170.73392
Net Profit	388160.977048
Payback Period	6 years
ROI	16%

Table (4) summarizes the key financial indicators for the proposed biogas production project, indicating a total capital investment of $2.366 million, of which $1.972 million represents fixed capital costs. The annual operating cost is estimated at $1.252 million, while the annual revenue reaches approximately $1.849 million, resulting in a net profit of $388,161 per year. These figures suggest that the project is financially viable, with a payback period of 6 years, which is within the acceptable range for medium-scale industrial investments. The Return on Investment (ROI) is 16%, reflecting moderate profitability relative to the capital invested. While the ROI is not exceptionally high, it indicates a positive return and potential for long-term financial sustainability. These results highlight the project's feasibility under the defined economic assumptions and reinforce its potential as a commercially justifiable operation.

4. Conclusions

This study conducted a techno-economic analysis of biogas production from bovine waste through anaerobic digestion, enhanced by process simulation using SuperPro Designer. The results demonstrate financial feasibility, with a total capital investment of USD 2.37 million, annual operating costs of USD 1.25 million, and projected revenues of approximately USD 1.85 million. The project achieves a net profit of around USD 0.39 million, a payback period of six years, and a return on investment (ROI) of 16%, indicating a commendable level of profitability for a renewable energy initiative. Capital costs are primarily allocated to digestion and gas-handling equipment, while operational expenses are driven by elements such as machinery, labor, raw materials, and utilities. Overall, the research confirms that biogas generation from cow dung is both an environmentally sustainable and economically viable option, with SuperPro Designer proving to be an effective tool for process and economic evaluation.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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