Economic and Environmental Assessment of Different Biogas Conversion Technologies for Cassava Pulp Treatment in Thailand: A Case Study

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Abstract. This research investigates the economic and environmental impact of various suitable biogas conversion technologies and their energy utilization options (electrical and thermal) on cassava pulp treatment. The results showed that the anaerobic cover lagoon (ACL), modified cover lagoon (MCL), and anaerobic baffled reactors (ABR) were the most suitable options in terms of the investment cost, which was the major factor influencing the selection of biogas technology. The ACL and MCL technologies had the highest values of NPV, a high IRR and a short payback period regardless of the energy utilization options due to their low investment and operating costs.

1. Introduction
Cassava pulp, which has high organic content, holds great potential as a feedstock for biogas production. Therefore, the use of cassava pulp for biogas production could provide an alternative solution for waste reduction and environmental improvement by reducing greenhouse gas (GHG) emissions [1]. Biogas can be used instead of fuel oil to produce heat and electricity, which can generate an equivalent value of 13.33 and 5.00 USD/t of cassava pulp, respectively.

To maximize the resource use efficiency, problems associated with the conversion of cassava pulp into biogas need to be overcome. However, the economic factor is the main concerning criterion when considering investing in biogas technology [2]. It can be seen that the more complex biogas conversion technology (BCT), the higher the investment and operating costs. Such costs depend not only on the chosen technology but also on the type of feedstock [3,4]. Therefore, biogas production from the cassava pulp requires higher costs compared to the biogas from wastewater.

The most popular biogas technology for wastewater treatment in Thailand is the ACL. There are approximately 300–400 systems of ACL implemented at swine farms, and some are found in cassava
starch production factories. The MCL, ABR, upflow anaerobic sludge blanket (UASB), anaerobic fixed film (AFF), and continuously stirred tank reactors (CSTR) technologies have also been widely used in cassava starch industries [5].

Most investors nowadays select the BCT and energy utilization strategy based on expert opinions [6]. This is due to the complexity of the feasibility study of biogas investment potential, especially if investors are not familiar with the process of biogas production from lignocellulosic materials. Therefore, this research investigated six scenarios of biogas production from cassava pulp using both economic and environmental impact analyses to identify the most suitable BCT and energy utilization option for treating cassava pulp.

2. Materials and methods
The case study was an industrial biogas production plant located in Northeast Thailand with a cassava pulp utilization capacity of 500 t/d. The boundaries were scoped gate-to-gate with a pulp-receiving capacity of 500 t/d (equivalent to cassava pulp from a 200-t starch factory) for biogas production at 300 working d/y. Calculations were based on a 10-y operational period. The BCT, environmental impact, and economic cost of each cassava pulp utilization alternative were analyzed in this study.

2.1. Selection of the optimal biogas conversion technology
The BCT was selected by the user based on the design criteria and operational guidelines such as the OLR, biogas plant area, investment cost, operating cost, and biogas production efficiency [3]. Under users’ concerns, the selected BCTs were shown as the three most preferable options. In terms of the operation and investment costs, which are the highest concerning factor for investors, ACL, MCL, and ABR were considered the most suitable and therefore were selected.

2.2. Economic assessment
Key indicators used for the economic analysis were the net present value (NPV), internal rate of return (IRR), and payback period (PBP) [7]. Depending on the scenario, in the first year of operation, there might be a major financial investment. The capital cost included costs of building construction, machinery, and equipment. The operating cost consisted of costs of raw materials, plant operation, labor, social fund, and depreciation cost. The material cost was calculated directly from the price of raw materials used for starch manufacturing.

2.2.1. Calculation of the net present value. The NPV was used to determine the value of the future project in terms of the present value. A positive NPV from the investment will add value to the company and benefit the company shareholders. The NPV of the investment project was calculated from eq. (1):

\[ \text{NPV} = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0 \]  

where NPV is the net present value (USD), \( C_t \) is the net cash inflow during the period t (USD), \( C_0 \) is the total initial investment cost (USD), \( r \) is the discount rate (USD/y), and \( t \) is the operational period (y).

2.2.2 Calculation of the internal rate of return. The IRR is used to evaluate the desirability of an investment or a project. The higher the IRR is, the more desirable it is to undertake the project. The IRR was calculated from eq. (2).

\[ 0 = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_0 \]  

2.2.3 Calculation of the payback period. The PBP is the period of time required to recoup the funds expended in the investment and was calculated from eq. (3).

\[ \text{PBP} = \frac{\text{Cost of investment}}{\text{Annual cash inflow}} \]  

2.3 Environmental assessment
The GHG emissions were determined as the production of CO$_2$, CH$_4$, and N$_2$O. The emission factors used in this study were obtained from the data published by the 2006 IPCC Guideline for National Greenhouse Gas Inventories and the Thailand Greenhouse Gas Management Organization [8,9]. In order to express the contribution of CH$_4$ emission in terms of global warming potential (GWP) as the CO$_2$eq, an equivalency factor of 21 was applied [8]. The CH$_4$ and N$_2$O production potential was assessed based on the concentrations of degradable organic matter in the substrate input. Further emissions released from the biogas combustion to produce heat and electricity, as well as emissions from resource usage, were regarded as the inputs to the process. Air emission, such as CO$_2$, CH$_4$, and NO$_x$ from the fuel combustion was calculated from eq. (4);

\[
\text{Air emission} = \sum (Q_i \times EF_i)
\]

where $Q_i$ is the quantity of fuel type $i$ (MJ/FU), FU is the functional unit, and $EF_i$ is the emission factor of fuel type $i$ (kg pollutant/MJ).

3. Results and discussion
The main investor’s concern was the investment cost so suitable BCTs selected under this criterion were an ACL, MCL, and ABR (table 1). The ABR produced the highest biogas and methane with the highest OLR and COD removal efficiency, whereas the ACL produced the lowest biogas and methane with the lowest OLR and COD removal efficiency. The ABR technology provided a better performance because of its reactor configuration. Wastewater flows under and over the baffles as it passes inside the reactor. This flow pattern reduces bacterial washout and enables the ABR to retain an active biological mass without the use of any fixed media [3,10]. The ACL consists of a wastewater storage lagoon with a cover. The cover traps the gas produced from the decomposition of the organic materials in the wastewater. It is the most popular BCT in Thailand because it does not have a very high investment cost and is relatively easy to operate and maintain [5]. However, for the cassava starch industry, the MCL is the most popular system because MCL, which was developed from a conventional anaerobic lagoon to overcome the sedimentation problem of sludge in the ACL, supports the fluctuation/variance of solid waste in each production season and has low investment and operating costs [2].

The investment cost varied with the biogas technology, size of the reactor, and the OLR to the system (kg COD/m$^3$ of reactor/d). For the electricity utilization option, the MCL was the most economically attractive option, yielding the highest NPV of 14.24 million USD per 10 y operation with an IRR of 46.11% and PBP of 2.12 y. For the thermal energy utilization option, ACL was the most economically attractive technology, yielding the highest NPV of 11.34 million USD per 10 y operation with an IRR of 94.23% and PBP of 1.06 y (table 1). In contrast, the ABR required the highest investment and operation costs in all scenarios at 9.66 and 1.77 million USD under the electricity utilization option, respectively, and 7.58 and 1.44 million USD under the thermal energy utilization option, respectively. These results were similar to those reported previously in a study on the environmental and economic assessment of cassava pulp utilization alternatives [11].

| Table 1. Economic assessment of the selected BCTs of the two different biogas utilization scenarios |
|---------------------------------------------------|-------------------|-----------------|-------------------|
| Key indicator | Unit | Electricity utilization option | Thermal energy utilization option |
|----------------|------|-----------------|-----------------|
| Discount rate | %    | ACL  | MCL  | ABR  | ACL  | MCL  | ABR  |
| Investment cost (1st year) | million USD | 4.60 | 7.50 | 9.66 | 2.36 | 5.39 | 7.58 |
| NPV | million USD | 14.01 | 14.24 | 3.51 | 11.34 | 10.30 | 2.51 |
| IRR | % | 65.72 | 46.11 | 34.43 | 94.23 | 46.35 | 30.82 |
| PBP | Year | 1.51 | 2.12 | 2.75 | 1.06 | 2.11 | 3.02 |
A renewable energy project generally has a positive GWP impact due to the replacement of fossil fuel-based energy provision and avoidance of organic substrate disposal. The reduction in the GWP or GHG emission via biogas production under the electricity utilization option, compared to electricity generation from the national grid for the ACL, MCL, and ABR were 16,266.51, 19,752.19, and 20,914.08 t CO₂eq/y, respectively. The reduction in the GWP or GHG emission via biogas production under the thermal energy utilization option compared to the thermal energy generation from fuel oil were 221.77, 269.29, and 285.13 t CO₂eq/y for ACL, MCL, and ABR, respectively, (figure 1).

Figure 1. Environmental assessment of the case study (cassava pulp treatment) for the electricity and thermal energy utilization options.

In general, the cassava starch factories produce biogas from wastewater to completely replace fuel oil for starch drying with excess biogas available to generate electricity covering 19–57% of electricity consumption [1]. Therefore, a cassava starch factory with biogas generation from both the wastewater and cassava pulp can supply sufficient thermal energy and electricity for energy consumption within the factory while the surplus electricity can be sold to the national grid [5]. The open lagoon after the biogas system contributed to the third-largest GHG emissions in the cassava starch factory. The organic matter removal efficiency of the biogas system depends on the BCTs so the selection of BCTs has a direct impact on the GHG emissions [1]. This study showed that the ABR, among the three options, offered the largest reduction in GHG emissions due to its highest capturing and utilizing capacity of CH₄ in the biogas.

4. Conclusion
The three most suitable BCTs based on the investment cost, which was considered in this study as the most important factor influencing biogas technology selection, were ACL, MCL, and ABR. The results from the analyses showed that the biogas utilization option was the major contributor to the NPV for the biogas system investment. The most economically attractive scenario was the production of biogas from MCL for the electricity utilization option. This scenario had the highest NPV per 10-year operational period with a high IRR and a low PBP due to the low cost of machinery and equipment used in the biogas system and generated a high revenue from selling the surplus energy. Electricity generation from biogas offered the maximum environmental benefit and the GHG emission of the biogas alternative for electricity utilization option was the lowest. Therefore, replacing fuel oil with biogas in the cassava starch industry is not only financially beneficial but also good for the environment.
5. References

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