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Identifying barriers for the implementation and the operation of biogas power generation projects in Southeast Asia: An analysis of clean Development Mechanism projects in Thailand

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Abstract

Tapioca starch and palm oil industries are considered as ones of the fast-growing agro-industries in Thailand. Both industries release a significant amount of wastewater with high organic content as a result of their production processes. Traditionally, open pond systems have been used to treat wastewater and consequently achieve compliance with environmental standards. Over the last few years however, more sustainable, expensive and modern alternatives have begun to be used to treat wastewater (mainly anaerobic reactors). The start of clean development mechanism (CDM) projects in Thailand has also contributed significantly to this expansion.[1]

One significant advantage of the anaerobic reactors, over the open ponds, is the possibility of capturing, in a controlled environment, the greenhouse gases (GHGs) generated, principally biogas with a high concentration of methane. The biogas can be used to generate heat and/or produce electricity, substituting fossil fuels as an energy source. The number of biogas utilization projects in Thailand and the Southeast Asia region has been increasing substantially in recent years. While a biogas plant can bring economic benefits with respect to energy self-sufficiency and cost-saving over time, the design and operation of a biogas plant requires high investments and is still perceived as a risky business due to a number of barriers. In addition, actual data from biogas plants indicate that the performance of a biogas plant with respect to the amount of biogas is not as attractive as it was initially expected among the project developers. Even though many literatures show the performance of biogas plants in certain experimental conditions, surprisingly, few literatures have explained or have shown data about the low performance of the biogas plants compared to the expected projected performance or design.

The purpose of this study is to identify these barriers in biogas technology implementation and operation in Thailand, and to determine how these barriers lower the performance of the biogas business. The study was conducted based on the analysis of 48 selected CDM projects in Thailand and further analysis through consultation with relevant professionals in CDM and the biogas business in Thailand. The results of this study provide important lessons for future biogas utilization and greenhouse gas emission reductions in the Southeast Asian region.

[1] The Clean Development Mechanism (CDM), defined in Article 12 of the Kyoto Protocol, allows a country with an emission-reduction or emission-limitation commitment under the Protocol (Annex B party) to implement an emission-reduction project in developing countries. Such projects can earn saleable certified emission reduction (CER) credits, each equivalent to one ton of CO_2, which can be counted towards meeting Kyoto targets.

Keywords

Barriers in project implementation and operation, tapioca starch industry, palm oil industry, biogas in Thailand, Clean Development Mechanism.

Introduction

Thailand is the world's leading exporter of rice, and it exports other agricultural products like shrimps, coconuts, sugarcane, palm oil and tapioca (Library of Congress, 2007). In addition to rice and sugarcane, the tapioca and palm oil industries have played a major role in boosting the Thai agricultural economy. Thailand is the world's second largest producer and the largest exporter of tapioca starch (FAOSTAT, 2007). It also has a rapidly growing palm oil industrial sector. Rapidly developing technology and applied Research and Development (R&D) to improve the quality and quantity of crop, combined with a broad range of crop usage has helped the country to maintain its key position in the tapioca starch and palm oil sectors (Thai Tapioca Starch Association [TTSA], 2009).

Starch and palm oil industries are not new to Thailand and have existed in the country for a long time. In fact, many of the firms are family-owned businesses that have existed for generations. However, the practice of capturing and utilizing biogas is new to Thailand, where business as usual has previously involved the utilization of open lagoon systems (Rajbhandari & Annachhatre, 2004). There are 86 starch and tapioca industries in Thailand from which 60 have biogas systems, which shows a high technology penetration, at nearly 70%. On the other hand, out of the 49 palm oil industries only 22 have biogas systems (Prasitpianchai, 2009). In relation to industry regional distribution, the Northeast part of Thailand is the forerunning region in tapioca industries and constitutes near 70% of the total tapioca production of the country (Sriroth et al., 2000). On the other hand, the palm oil industry is mainly concentrated in the Southern part of Thailand (Chavalparit et al., 2006).

There are several factors that have motivated plant owners to implement a biogas system within their starch or palm oil plants. Rapid technological development, meeting self-energy demands, low dependence on imported fuels, revenues from selling electricity to grid (Umweltbundesamt,

2007) and CDM/VER [2] revenues are a few of them (Adhikari et al., 2008). Since 2002, there has been an increase in the biogas application among agro-industries like tapioca starch, palm oil, initially due to VER projects. Moreover, in 2006, the government decided to give an extra incentive for biogas producers by buying energy from small companies generating biogas (up to 10 MW) at a special rate and paying an "adder" for feed-in electricity from all sizes of biomass and biogas installations (Kossmann, 2008). Also in the ame year, the Thai DNA started to issue Letters of Acceptance (LoAs), stimulating CDM projects development.

The investment in Thai biogas is expected to be around US$ 100 million within the next 10 years, although US$300 million would be required to fully develop the sector (Du Pont, 2005). In the context of CDM, biogas has a decisive comparative advantage over other renewable technologies. The reductions in emission of methane can provide a larger volume of Certified Emission Reductions (CERs) when compared to sole reduction of GHGs from fossil energy substitution (Umweltbundesamt, 2007). As shown in Table 1, a close observation of a number of registered CDM projects confirms that the expected internal rate of return (IRR), including the additional revenue stream from CERs, is attractive when compared to benchmark values in the market:

Table 1: CDM registered projects and expected investment rate of return

CDM Project	Plant Type	Project IRR including CERs	Project IRR without CERs	Market Benchmarking Value
Bangna Starch Project	Starch (Tapioca)	17.37%	5.24%	6.56%
Siam Quality Starch Project in Chaiyaphum	Starch (Tapioca)	27.03%	8.68%	15.00%
Green Glory Project in Surtthani	Palm Oil	19.41%	-1.83%	8.52%
Chumporn applied biogas technology	Palm Oil	17.00%	6.1%	14.95%
Thachana Palm Oil Company	Palm Oil	19.60%	10.0%	15.00%

Considering additional revenues from CDM, biogas projects would be in a position to achieve very good returns on investment as compared to applicable IRR benchmarks. However, interviews carried out with project managers and consultants from an international carbon trading company, working on Thai CDM projects, reveals a different reality. Internal data from the trading company

[2] VER stands for Voluntary Emissions Reductions or Verified Emissions Reductions, referring to the carbon credits outside the Kyoto Protocol compliance regime. The voluntary market has developed as a simplified process based on the CDM project cycle, but with less rigorous standards, lower costly, and applicable to a broad variety of projects (TFS Green, 2010)

shows that 86% of the projects do not reach the expected COD_{in} load, 58% of projects do not produce the desired amount of biogas, and 42% of the projects do not reach the desired COD removal efficiency rate[3,4,5], which has a negative impact on the profitability of projects – not allowing them to reach the theoretical potential.

Research objectives and methodology

This study is aimed at understanding why the biogas business, despite being perceived as attractive by various stakeholders (e.g. investors, carbon credit companies, technology providers), performs at a level well below than expected.

To do so, the study explores the concept of "barriers" and their effects on the Thai biogas industry. The term barrier in the paper's context refers to the obstacles that restrict the widespread adoption of renewable energy systems and specifically hinder the integration and performance of biogas plants in Thai tapioca starch and palm oil industries (UNDP, 2008). In relation to CDM, these barriers are considered as obstacles to the implementation of a project which cannot be eliminated if the project was not registered as a CDM or VER project (UNFCCC, 2008). This is what is termed 'additionality' in the context of CDM.

This paper starts with a brief technical overview of tapioca starch, palm oil and biogas production processes. Then it continues with a literature survey to understand the classifications of barriers in renewable energy technologies in general. The authors address the results of two different analyses to identify barriers to the implementation of biogas utilization projects in Thailand. The first analysis looks into CDM projects for biogas utilization in Thailand. The second analysis is conducted based on a consultation of relevant professionals in CDM and the biogas business in Thailand. They conducted several interviews and a brain storming session with the project managers and consultants from an international carbon trading company and a biogas technology supplier working in Thailand.[6] The intent of interviewing these specialists was to draw together their experiences and uncover the barriers they think are the cause(s) of hindrance to biogas technology integration, implementation and operational performance. In addition, the authors

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[3] COD is the Chemical Oxygen Demand. It is a measurement of the amount of oxygen in water consumed for chemical oxidation of pollutants and is normally measured in mg/l.

[4] COD_{in} load is given by the COD concentration multiplied by the volume of wastewater that enters the anaerobic reactor.

[5] COD removal efficiency rate is given by the COD removed by the anaerobic system divided by the COD concentration entering the anaerobic system (COD_{in}).

[6] For confidentiality reasons the name of the companies are omitted.

attempted to find academic literature discussing each barrier, which are identified through consultation with experts in Thailand. Finally, the barriers found through the second analysis were deployed into causes and sub-causes with a view to identifying the real issues (root causes) behind poor biogas performance. These barriers are deployed in a cause-effect diagram (fishbone structure) in Annex II.

The following section describes the overview of starch and palm oil production, followed by the benefits of implementation of a biogas system with the production process.

Tapioca starch production process overview

Initially fresh cassava roots are weighed to determine the starch percentage. Sand is then removed, followed by a rinsing and peel separation process. In order to do this, the roots are placed first in a sand removal drum and then into a rinsing gutter (Food Market Exchange, 2009). The cassava roots are subsequently chopped into small pieces in a chopper, and then transferred into a rasper where water is added creating a slurry to facilitate the procedure. At this point, the slurry is a mixture of starch, impurities, fiber and water. The slurry is then moved to centrifuges for extraction of the starch from the fibrous residues. The extraction is carried out by centrifuges in series (normally three or four). For a superior extraction, the slurry passes through coarse extractors consisting of perforated baskets and then fine extractors with a filter cloth (Chavalparit & Ongwandee, 2009). During this stage water and a sulfur solution are added to the centrifuges, in order to facilitate the bleaching and dilution. The slurry is now separated into fibrous residues (pulp) and starch milk. The pulp goes to a pulp extractor to recover the remaining starch and subsequently the extracted pulp is moved to a screw press for dewatering. Normally this dry fibrous residue is sold as animal feedstock. The starch milk is pumped into a separator (two stages) for the removal of impurities. The cleaned milk is pumped into horizontal centrifuges, in order to remove the water before drying (Chavalparit & Ongwandee, 2009). The result of this stage is a starch cake, which is taken to a hot air dryer column. This hot air is produced by oil burners. The dried starch (moisture concentration around 12%) passes through a sifter and the resulting fine powder is packed into sacks for sale.

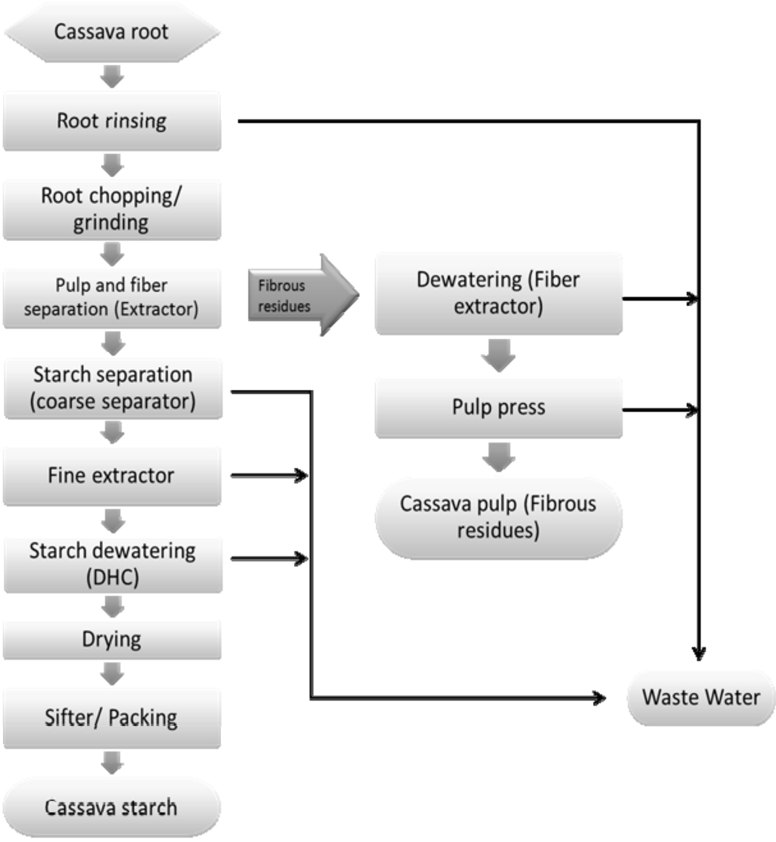

Figure 1: Tapioca starch production process. (Source: adapted from Food Market Exchange, 2009 and Chavalparit & Ongwandee, 2009.

Palm Oil production process overview

The fresh fruit bunches (FFBs) are harvested and arrive from the fields as loose fruit or bunches. To begin the bunches go to be sterilized or cooked. The sterilization process uses pressurized steam while cooking utilizes hot water. The main benefits of this phase are: to prevent the formation of fatty acids, to make the removal of the fruit from bunches easier and make bunches simpler to handle during the subsequently stages (Poku, 2002). The next stage is the bunch stripping, in which the sterilized bunches are separated from the bunch stalks through the use of a rotary drum thresher. The fruits are then transported into digesters, where the palm oil will be released from the fruit through the rupture of the oil-bearing cells. At this point, the digested material is ready for pressing or extraction of palm oil. There are two main methods for extracting oil from the digested material; a “wet” method that uses hot water to wash away the oil and a “dry” method that utilizes only mechanical presses. The separated crude palm oil is collected and taken to the clarification session. The residual pressed cake is taken to a separation system for drying and sorting of the fibers and the kernel nuts. In small-scale factories the kernel nut separation from the fibers is done by hand while in large-scale factories an air cyclone is used. The large-scale factories use the fibers as fuel for the steam boilers. The kernel nuts are then cracked and separated from the shells before being dried in silos for packing.

The oil sent for clarification/purification is a mixture of palm oil, cell debris, fibrous material, water, and "non-oily solids". During the clarification process the oil passes through different sub-phases: screening to separate fibrous particles, sand removal utilizing a sand cyclone, and a settle tank to separate the oil from water (Chavalparit, 2006). The resulting crude oil goes to the purification stage, in which a centrifuge separates water and fine suspended solids. After purification, the palm oil still contains water and this is removed by a vacuum evaporation system. Finally, the dried oil is kept in tanks before being packed for sale to an oil refinery.

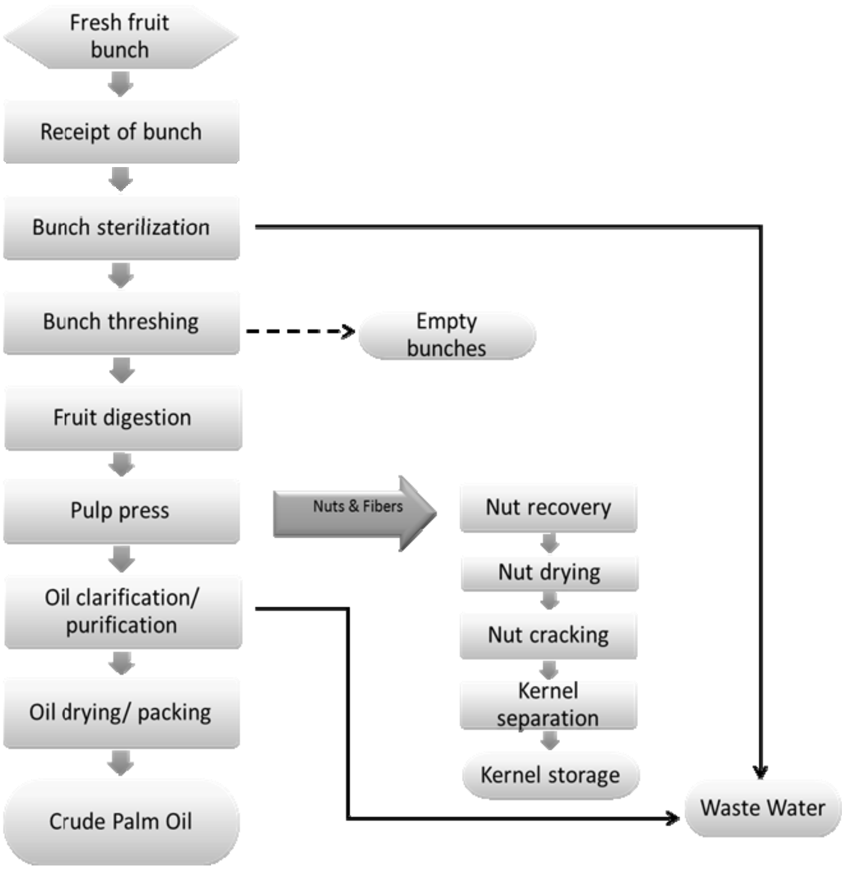

Figure 2: Palm oil production process. (Source: adapted from Poku, 2002 and Chavalparit, 2006.

Benefits of biogas system

The processes involved in production of the finished products generate a huge amount of wastewater with a high organic content, which can be recovered as biogas through biogas digesters and converted into other forms of energy, such as heat and electricity. These digesters contain a variety of active methanogenic bacteria that can produce biogas by anaerobic digestion of the organic substrates (Rajbhandari & Annachhatre, 2004). For each ton of roots processed, the tapioca process produces 19.1±9.32 m^3 of wastewater with a high organic load (Chavalparit & Ongwandee, 2009). This quantity of wastewater has the potential to produce up to 40 m^3 of biogas (with 55% of methane), which is equivalent to around 20-30 liters of oil. On the other hand, the average quantity of wastewater generated from a palm oil mill is in the range of 0.64 m^3/ton of FFB (Chavalparit et al., 2006). Through the wastewater treatment of this effluent and subsequent capturing of biogas, the palm oil mills can also produce a considerable amount of heat and electricity. Just by the efficient utilization of biogas and using high efficiency gas engines and boilers, both the starch and palm oil plants have the potential to meet their energy demands (TTSA, 2008).

There is a huge biomass potential in Thailand, as the tapioca and palm oil industries are two of the largest food processing industrial sectors in the country. Implementation of biogas technology can be a long-term solution for waste management and production of heat and/or electricity from renewable energy sources, as indicated by GTZ (Prasitpianchai, 2009).[7] The advantages of biogas involve a huge variety of benefits ranging from pollution control, solving waste disposal problems and meeting energy demands to environmental and sustainable benefits. Considering the current global concern and climate change issues, biogas systems are an ethical choice in some cases, while CDM incentives are another major benefit of implementing biogas systems. The combination of CDM and biogas technology produces economic benefits for the project owner while reducing GHG emissions (Advance Energy Plus, 2008).

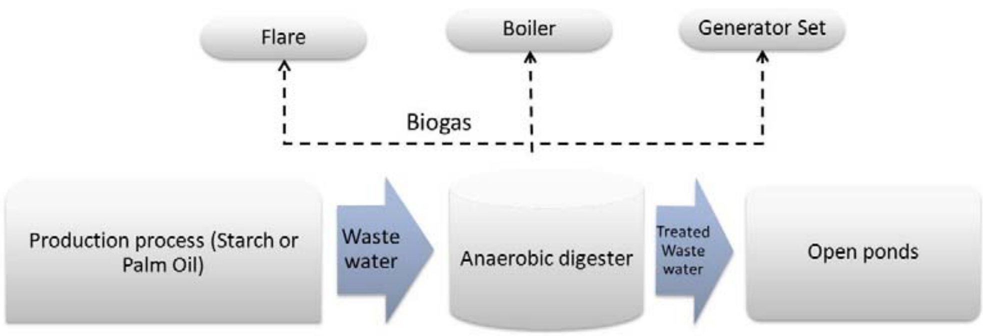

Figure 3: Overview of biogas generation and utilization

[7]Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), German Agency for Technical Cooperation, Thailand.

The steps involved in the processing of tapioca starch and palm oil are standardized among palm oil producers. However, the selection of biogas technology and machinery for wastewater treatment varies considerably. Upflow Anaerobic Sludge Blanket (UASB), Continuously Stirred Tank Reactor (CSTR), Covered In-Ground Anaerobic Reactor (CIGAR), Anaerobic Baffled Reactor (ABR), Anaerobic Fixed Film Reactor (AFFR), covered lagoon and a combination of an anaerobic digester with other technology are the few technologies predominantly utilized in Thailand.[8] According to the results of study UASB is the most common technology followed by CIGAR and CSTR, while AFFR is the least common.

The following section exhibits several classifications of barriers that are commonly discussed among scholars who conducted a barrier analysis on the implementation of renewable energy projects. The authors paid attention to these classifications of barriers to formulate their framework to examine barriers against biogas utilization projects in Thailand.

General categorization of barriers

Painuly and Fenhann (2002) present a method to classify barriers. They divide barriers into awareness/information, capacity, economic, environmental, financial, institutional, market, policy, social and technical barriers. Table 2 illustrates examples of each barrier:

Table 2: Barrier types (Source: Painuly & Fenhann, 2002)

Barrier Type	Examples
Awareness/ Information	Lack of awareness / access to information on Renewable Energy Technologies (RETs)
Capacity	Lack of skilled manpower and training facilities

[8]In a UASB system, an anaerobic process forms a blanket of granular sludge, which suspends in the tank. Wastewater flows upwards through the blanket and is processed by the anaerobic microorganisms to produce biogas. In CSTR the mixture of anaerobic bacteria and wastewater in a reactor is stirred continuously to capture methane. In CIGAR technology, the liquid waste is retained in constructed lined lagoons covered with a plastic membrane. Gas produced by digestion of the waste is trapped under the flexible covers and is recovered. The ABR consists of an initial settler compartment and a second section of a series of baffled reactors. The baffles are used to direct the flow of wastewater through a series of sludge blanket reactors. In AFFR a consortia of bacteria attach and grow as a slime layer or bio-film. The wastewater passes through the media-filled reactor and the attached and suspended anaerobic biomass converts both soluble and particulate organic matter in the wastewater to biogas. Noticeably, the very basic mechanism of the bioprocess and treatment is more or less same in all the technologies, only variations in the construction or design results in the changes in the names of the technology.

Economic	Unfavorable costs, taxes, lack of subsidies and energy prices
Environmental	Visual pollution, lack of valuation of social and environmental benefits
Financial	Inadequate financing arrangements (local, national, international) for RET projects
Institutional	Institutional capacity limitations (R&D, demonstration and implementation)
Market	Size of markets, limited access to international markets for modern RETs, limited involvement of the private sectors
Policy	Unfavorable energy sectors policies and unwieldy regulatory mechanisms
Social	Lack of social acceptance and local participation
Technical	Lack of access to technology, inadequate maintenance facilities, bad quality of the product

Mayaki (2007), on the other hand, presents a list of barriers from a risk management perspective. Mayaki identified all possible risks as well as counter-measures to eliminate or diminish the forecasted consequences of each risk.[9] Table 3 exhibits 13 categories of risks (or barriers) as follows:

Table 3: Risks and barriers (Source: Mayaki, 2007)

Risk (Barrier) Type	Explanation
Country risk	Risks that international banks will reach their lending limits to a certain country, not providing money for new investments
Political risk	Risk of change in government; failure of issuing critical permits; government insufficiency to enforce legal provisions
Business risk	Uncertainty of the future net cash flow
Technology risk	Risk of underperformance of novel technologies
Financial risk	Risks that fluctuations on interest rates or currency will ruin the project's cash flows
Credit risk	Risk that the borrower cannot honor the payments of the principal and interest. It is usually based on two factor: industry and company characteristics
Market risk	Risk that the investment in a certain project will decline due to changes in the economy or any relevant event affecting the market reality
Financial instrument risk	Diverse types of financial instruments have different risk levels. Unsecured debt has a higher risk than a secured debt
Operating risk	Risk that the borrower will not allocate appropriate human and technical resources to effectively run the project, resulting on a poor operational performance
Construction and sponsor risk	Risk of non-completion, late completion or over budget completion of the project
Economic risk	Analysis of the project's assumptions in order to determine if the revenue projections are enough to cover the loans and operating costs
Environmental risk	Risk of environmental liabilities caused by insufficient environmental studies; risk of future changes in environmental legislation

[9] Risk, in the original context of Mayaki (2007), can be understood as the chance of losing some or all of the original investment assigned to a project, but in this study, risk can also refer to barriers.

Legal risk	Risk that lawsuits, adverse judgments or not enforceable contracts can affect the lenders' project security.

Similar to Painuly and Fenhann's classification, barriers are generally categorized into the following five barriers in the study of barriers among CDM project activities:

1. Business culture barriers;
2. Investment/financial barriers;
3. Prevailing practice barriers;
4. Technical barriers; and
5. Social barriers.

The authors of this paper use this classification of five barriers to analyze barriers among CDM biogas projects in Thailand. On the other hand, they also use the following list of four barriers for classifying barriers observed through practical experiences of experts in Thailand. This is because the authors wish to identify not only the barriers at the planning phase of the projects but also the barriers in the operational phase. The barriers after project implementation are not identified or discussed in the CDM project design documents (PDDs) since they are always written before the project implementation.[10]

1. Management-related barriers: barriers related to management in general, planning and strategic decisions;
2. Operation-related barriers: barriers related to operation of the plant and operator related issues;
3. Technology related barriers: barriers related to technology providers, process characteristics and anaerobic system technologies;
4. Cost-related barriers: barriers related to cost and investment issues that in due course impact on the performance of the biogas plants.

[10] PDD is the document containing all technical and organizational information of the CDM project activity. It is used by the investors, stakeholders and designated operational entities (DOE) to evaluate the project's potential.

Results of analysis

Analysis of barriers among CDM biogas projects

To understand the most relevant barriers experienced by the project developers in the Thai tapioca starch and palm oil industries, the authors examined 48 specific CDM biogas projects in Thailand.[11] They conducted a detailed analysis by examining the project design document (PDD) of each project.[12]

Table 4 summarizes the results of the study.

Table 4: Barriers identified among CDM projects

Barrier Category	Barriers cited on the studied PDD's	Project – Number (#) according to Annex I
Business culture	Insufficient knowledge / confidence in new technology	3, 9, 12, 13, 17, 19, 38, 39, 40, 41, 42, 43, 47
	No strong driver to become energy self-sufficient	39, 42, 43
	Limited information for project developers	1, 8
	Lack of attention on biogas business by owners (not core business)	3, 20, 40
Investment/ Financial	New anaerobic digester (AD) systems require large investments	1, 3, 18, 20, 21, 22, 23, 24, 25, 29, 33, 34, 36, 37, 40, 44, 48
	AD systems operation and performance risks	1, 4, 6, 7, 8, 9, 10, 17, 19, 20, 40, 41, 42, 43, 48
	Uncertain commercial returns	1, 4, 5, 36, 37, 38, 48
	Difficulties to obtain loans and find local investors	4, 9, 8, 17, 38, 42, 43, 48
	High operation and maintenance (O&M) costs	3, 4, 5, 9, 29, 33, 34, 36, 37, 38, 44, 47, 48
	Unawareness of CDM amongst financial institutions in Thailand,	1, 39
	Renewable energy perceived as unfamiliar and risky investment	3, 20, 39, 40, 41, 42, 43
	Involved commercial risks	1, 3, 8, 9, 17, 19, 41, 42, 43, 44
	Volatility of Thai Baht /uncertain economic developments	3, 4, 8, 26, 39, 41, 42, 43
	Electricity sold not enough to cover project's expense	29, 34

[11] Annex I contains a complete list of projects.

[12] Public access data is available at the website of United Nations Framework Convention on Climate Change. http://cdm.unfccc.int/Projects/index.html.

Prevailing practice	No driver to change from open lagoons (well known, cheaper and prevailing technology) to AD systems	1, 3, 4, 5, 6, 7, 10, 11, 13, 14, 15, 16, 18, 20, 21, 22, 23, 24, 25, 26, 29, 34, 36, 37, 38, 39, 41, 42, 43, 44, 45, 48
Social	No knowledge about anaerobic digesters and their benefits and risks	3, 4, 8, 9, 17, 39, 40, 41, 42
Technical	Low or no awareness about AD systems and new technologies.	1, 4, 5, 8, 9, 17,19, 26, 30, 31, 39, 42, 43, 47
	Lack of skilled and trained staff	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 21, 22, 23, 24, 25, 26, 29, 30, 31, 34, 38, 39, 40, 41, 42, 43, 44, 45, 48
	Lack of equipments and local technology providers/ suppliers (imported technology)	1, 3, 4, 5, 8, 9, 13, 17, 19, 26, 30, 31, 38, 39, 40, 41, 42, 43, 44, 45, 48
	Sensitivity of the AD systems (strict and delicate operating parameters)	3, 11, 12, 13, 14, 15, 16, 21, 22, 23, 24, 25, 29, 34, 40, 41, 44, 45, 48
	Few other similar plants using similar technology (technology not widespread in the country)	1, 14, 18, 20, 29, 34, 39, 40, 42, 43, 44, 45, 48
	Lack of standards on bioenergy systems and equipments	13
	Palm oil mill effluent (POME) has different characteristics compared to other industries effluents	1, 41

The results of the analysis indicates that the most common cited barriers among the CDM projects were: 1) Lack of skilled and trained staff; 2) No driver to change from open lagoons (well known, cheaper and prevailing technology) to AD systems; 3) Lack of equipment and local technology providers/suppliers (imported technology); and 4) Sensitivity of the AD systems (strict and delicate operating parameters). Three out of four most cited barriers refer to technical problems, showing the concern of the project developers about the correct operation of the biogas systems. Although treated as different barriers, it is possible to link these barriers. Since a poor technology transfer for a new technology and lack of local technical support, aggregated with a low qualification and training of operational personnel, can have a direct impact on the performance of the sensitive AD systems.

The following section addresses the second part of the analysis. It presents the barriers identified from the practical experience of the project managers and consultants from an international carbon trading company and one biogas technology supplier in Thailand.

Barriers from practical experience

The focus of the second analysis is not only the barriers found during the planning phase of the projects, but also the barriers that could be identified after the start-up of the projects, such as in the operational phase. As indicated above, these barriers were not identified in the first analysis since the CDM PDDs are always written before project implementation and do not incorporate barriers from the operational phase.

The barrier identification was developed through several interviews and brainstorming sessions with the experts from Thailand. The result of the brainstorming session can be observed in the cause-effect diagram (fishbone structure) in Annex II. After the recognition of all possible barriers, a second stage for prioritization (voting) of the identified causes was also carried out with the interviewees.

In order to support the empirical findings from the interviewees with published evidences, a detailed literature research was carried out to corroborate with the practical assessment.

Table 5 presents the results of the analysis. It lists the main barriers identified through the consultation process among the experts. It also lists the literatures that discuss each barrier stated by the experts:

Table 5: Barriers identified through practical experience as well as literature review

Barrier Category	Barrier[13]	Literature
Management-Related	(1.1) No consideration for project lifetime benefits, aiming at only short term investment returns	Chavalparit (2006); Schneider et al. (2008)
	(1.2) Lack of attention on biogas business by the management, since it is only a marginal activity within the plant	Chavalparit (2006); UNDP (2007)
	(1.3) Low education degree of management	Chirathivat & Chantrasawang (2000)
	(2.1) No search for professional design of biogas facilities	Paepatung et al. (2007)
	(3.1) Lack of integrated planning	Department of Industrial Works and GTZ (1997)

[13] The number in front of each barrier corresponds to the designated number in the diagram of Annex II.

	(3.2) Constant changes of production patterns	Department of Industrial Works and GTZ (1997); Ward et al. (2008)
	(3.3) Production process has higher priority than wastewater quality	Department of Industrial Works and GTZ (1997)
	(4.1.1) "Family business" model (not so professional and structured)	Visvanathan & Kumar (1999); Chirathivat & Chantrasawang (2000);
	(4.1.2) Open lagoon system already comply with regulations	Rajbhandari & Annachhatre (2004); Najafpour et al. (2006)
	(4.1.3) Business culture/ environment (traditional, not so sophisticated agro-industry field)	Sriroth et al. (2000); Chavalparit et al. (2006)
	(4.2) Lack of business long term strategy and business plan	Industrial Development Division/ Department of Industrial Promotion (1995)
Cost-Related	(5.1) Imported technology	Parr et al. (2000); Prasertsan & Sajjakulnukit (2006)
	(5.2) Need of large infra-structure investment	Mara (2003)
	(6.1) Lack of options for comparing with other starch and palm oil companies	Prasertsan & Sajjakulnukit (2006); Paepatung et al. (2007)
	(6.2) Energy density of wastewater much lower as compared to other fossil fuels, requiring specific attention	Chavalparit & Ongwandee (2009)
	(6.3) Optimistic figures provided by technology suppliers	Prasertsan & Sajjakulnukit (2006)
	(6.4) Lack of knowledge about anaerobic digester systems (management level)	Umweltbundesamt (2007); Energy Policy and Planning Office (EPPO,2007)
Operation-Related	(8.2) "Economic incentive" to reduce performance (operator-kickbacks by fuel supplier)	No specific literature found.
	(8.3) Lack of financial incentives to improve/ maintain performance	Visvanathan & Kumar (1999)
	(10.1.1) No understanding of the complex biological / operational process (Operator)	Choorit & Wisarnwan (2007); Uddin et al. (2008)
	(10.1.2) Lack of proper training on operation	Umweltbundesamt (2007); Uddin et al. (2008)
	(10.1.3) Lack of standardized courses	Umweltbundesamt (2007)

	(10.1.4) Qualified workers / operators go to other industries and provinces	Sriroth et al. (2000); Chavalparit et al. (2006); Prasertsan & Sajjakulnukit (2006)
	(10.1.5.1) Language barriers (O&M manual not available in local language)	Parr et al. (2000); Prasertsan & Sajjakulnukit (2006)
	(10.1.5.2) Poor quality O&M manuals, depending on experience of technology provider	Umweltbundesamt (2007)
	(12.1) Young history of biogas industry in Thailand	Chavalparit (2006); Prasertsan & Sajjakulnukit (2006); Umweltbundesamt (2007); EPPO (2007)
Technology - Related	(14.1.1) Lack of local professionals and technology / service providers in the area	Parr et al. (2000); Prasertsan & Sajjakulnukit (2006); Uddin et al. (2008)
	(15.1.1) Bacteria are not too tolerant to variations of temperature and wastewater quality	Choorit & Wisarnwan (2007)
	(16.1)No long term financial incentives and contractual arrangements between the supplier and owner	Schneider et al. (2008)

The following sections explain each identified barrier more in detail:

Management-related barriers

(1) Plant owners' lack of knowledge about AD systems (investment decisions and management decisions), caused by:

(1.1) No consideration for project lifetime benefits, aiming at only short term investment returns

Explanation: Most of the time, the focus of companies is to maximize the profit over a short period. Frequently the managers have little to no information about biogas or anaerobic digester systems and the subsequent technical implications and costs. Consequently when the knowledge about biogas benefits is limited, the managers prefer to invest in production rather than new technology (Chavalparit, 2006). Moreover, even when aware of new technology, inappropriate technical or cheaper solutions are selected (Schneider et al., 2008).

(1.2) Lack of attention on biogas business by the management, since it is only a marginal activity within the plant

Explanation: Biogas production for energy is often considered as not as important as the core (palm oil or starch production) business (UNDP, 2007). Managerial efforts and planning are concentrated on maximizing production of the finished product rather than in biogas production, which is often considered the secondary business (Chavalparit, 2006).

(1.3) Low education degree of management

Explanation: As per the findings from interviews, in the Thai starch and palm oil industries around 70% of the factories are small or medium sized. They are usually owned and operated, and have been for generations, by families. Often the owners do not have any former education or are incapable of hiring skilled managers, due to the location of the plants and salary opportunities. Within the small and medium companies in Thailand, more than one third (36.1%) of the owners have only an elementary education (Chirathivat & Chantrasawang, 2000).

(2) Improper choice of technology supplier and service provider, caused by:

(2.1) No search for professional design of biogas facilities

Explanation: As mentioned at item (1.1), often the managers do not seek professional support when researching biogas technology due to financial reasons. On the other hand, often the managers do not know where to search for the information they need, since there are no standard guidelines or publicly available information about biogas performance and technologies. There is no support from the government and there are very few initiatives in R&D in regions where biogas is prominent (Paepatung et al., 2007).

(2.2) Plant owners' lack of knowledge about anaerobic digester systems: Already explained in item (1) of this section.

(3) Misaligned incentives between feedstock supplier and operator, caused by:

(3.1) Lack of integrated planning

Explanation: For an enhanced production of biogas, it is fundamental that the quality of wastewater should be monitored. The production process needs be to be controlled, since the wastewater quality (produced as a by-product) is important for the biogas production (Department of Industrial Works and GTZ, 1997). When biogas systems are in place a more elaborate production and forecasting plan needs to be prepared, for example forecasting the quality of raw material and seasonal fluctuations.

(3.2) Constant changes on production patterns

Explanation: In an unstable process, additives in uncontrolled proportions, differing qualities of raw materials (such as tapioca roots with different percentage of starch and other substances) and an excess of fatty acids, can affect the wastewater characteristics (Ward et al.,2008). In order to have a constant and planned biogas production, the entire process needs to be stabilized and constantly monitored (Department of Industrial Works and GTZ, 1997).

(3.3) Production process has higher priority than wastewater quality

Explanation: As mentioned in item (1.2), the core business of the plants studied is the production of palm oil or starch. By-products play a secondary roll and often remain unmanaged. Many plants ignore the type, quality and value of the wastewater produced, consequently affecting the biogas production at a later stage (Department of Industrial Works and GTZ, 1997).

(4) Overestimation of input data for plant design (Plant Owner), caused by:

(4.1) Lack of measurement of actual process parameters to purchase proper technology, caused by:

(4.1.1) "Family business" model (not so professional and structured)

Explanation: As mentioned in item (1.3), around 70% of the Thai starch and palm oil industries are run by families and have been owned and managed for generations as a family business. In these industries, half of the management positions are occupied by family members or relatives to the entrepreneurs (Chirathivat & Chantrasawang, 2000). The management structure is usually simple and the tasks limited to confined activities (Visvanathan & Kumar, 1999).

(4.1.2) Open lagoon system already comply with regulations

Explanation: To comply with environmental regulations over the past decade, many plants have been using open lagoon systems for the treatment of wastewater, both in palm oil (Najafpour et al., 2006) and the starch industries (Rajbhandari & Annachhatre, 2004). Open lagoons are simple to construct, are simple to operate and maintain, and are robust. The broad use of open lagoons reflects their acceptance on the market.

(4.1.3) Business culture/ environment (traditional, not so sophisticated agro-industry field)

Explanation: The starch and palm oil businesses are suited to the traditional agro-industry field in Thailand. About 70% of the total tapioca production in the country is located in the northeast part of the country (Sriroth et al., 2000). For palm oil industries, most of them are concentrated in the southern parts of Thailand (Chavalparit et al., 2006). These industries do not have a history of, an interest in, or financial capability to invest in R&D, since their market is not dynamic compared to other sectors (IT or automotive, for example).

(4.2) Lack of business long term strategy and business plan

Explanation: As mention in items (4.1.1) and (4.1.3), the starch and palm oil industries are traditional agro-industries, normally run by families in an informal manner and structure. In addition, many companies have an incorrect perception of the reality of the market (Industrial Development Division/ Department of Industrial Promotion, 1995). In these circumstances, a long term strategy or the development of a business plan is not realistic, nor is it a common practice for these industries.

Cost-related barriers

(5) High Investment costs, caused by:

(5.1) Imported technology

Explanation: Most technologies for wastewater systems and biogas came from developed countries (Parr et al., 2000). Proper transfer and adaptation to tropical climates requires investment (Prasertsan & Sajjakulnukit, 2006) and will result in costs being incurred (importation taxes, logistics, training, etc.).

(5.2) Need of large infra-structure investment

Explanation: As per the findings from interviews, the major component of the investment in a biogas project is dedicated to its infra-structure and the reactor. A UASB reactor for example, needs to be constructed with reinforced concrete (Mara, 2003), which causes the capital investment to be higher than a traditional fossil fuel investment.

(6) Unawareness of operational and maintenance costs, caused by:

(6.1) Lack of options for comparing with other starch and palm oil companies

Explanation: In the biogas market in Thailand there is no centralized information and orientation regarding biogas technologies and the equipments that are available (Paepatung et al., 2007). It is also very difficult to find data related to projects' performance and information about projects that have already been implemented (Prasertsan & Sajjakulnukit, 2006).

(6.2) Energy density of wastewater much lower as compared to other fossil fuels, requiring specific attention

Explanation: The tapioca production process generates 10 to 28 m^3 of wastewater for each ton of root processed with a high organic load (Chavalparit & Ongwandee, 2009). This quantity of wastewater has the potential to generate around 40-50 m^3 of biogas, which is equivalent to approximately 25 l of fossil fuel oil. Consequently, for a biogas project, instead of a small diesel oil tank and a generator, a much larger storage area and auxiliary equipment is required and subsequently monitored.

(6.3) Optimistic figures provided by technology suppliers

Explanation: For a precise design of equipment and processes, technology suppliers must have reliable data about the plants and information about previous similar projects. However, such information is frequently not available and some parameters are difficult to predict

(Prasertsan & Sajjakulnukit, 2006). As a result, there is an improper evaluation regarding the real needs of the customers and in order to sell their products the suppliers present optimistic values in their proposals.

(6.4) Lack of knowledge about anaerobic digester systems (management level)

Explanation: In Thailand there is a lack of awareness about renewable technologies (Umweltbundesamt, 2007) including awareness on biogas technology (Energy Policy and Planning Office [EPPO], 2007). There is also a lack of public support in terms of information, and little information regarding biogas is transferred. In addition to this, since the degree of education of the managers is low (item 1.3), the technology of anaerobic digesters and biogas production appears to the managers as being very complex issues.

(7) Lower financial returns than expected, caused by:

(7.1) Higher investment and O&M costs than initially expected, caused by:

(7.1.1) No concern about project lifetime benefits, aiming only short term investment return: Already explained in item (1.1).

Operation-related barriers

(8) Operator not motivated to perform

(8.1) Lack of attention on biogas business by the management, since it is only a marginal activity within the plant: Already explained in item (1.2).

(8.2) "Economic incentive" to reduce performance (operator-kickbacks by fuel supplier)

Explanation: As per findings from the interviews, there are cases in which the operators responsible for the wastewater quality control, or for the biogas production process, are persuaded to reduce their performance by the fuel suppliers (bribe) in order to utilize more fossil fuels than biogas for energy production.

(8.3) Lack of financial incentives to improve/ maintain performance

Explanation: As mentioned in items (4.1.1) and (4.1.3), the tapioca and palm oil industries are traditional agro-industries, often managed by families with a basic application of management principles under a simple organizational structure. In addition, biogas production is not considered as important as the core business (item 1.2). Thus, on many occasions the operators are not motivated to perform due to a lack of a company performance reward policy or due to a different remuneration compared to his coworkers in the core production business.

(9) Lack of proper maintenance, caused by:

(9.1) Operators not skilled and trained: to be detailed in item (10.1).

(9.2) No concern about project lifetime benefits, aiming only short term investment return: Already explained in item (1.1).

(10) Human error in operation, caused by:

(10.1) Operators not skilled and trained, caused by:

(10.1.1) No understanding of the complex biological /operational process (Operator)

Explanation: Anaerobic digesters are very complex and sensitivity systems that depend on many parameters, such as pH, design of reactor, hydraulic retention time, and temperature control, among others (Choorit & Wisarnwan, 2007). The understanding of biogas technologies is considered much more complex than fossil-based technologies (Uddin et al., 2008). Consequently, for an operator in a rural area, with low education and a low level of understanding of the biological processes, it is very difficult without proper training or correct orientation to pursue the use of this technology.

(10.1.2) Lack of proper training on operation

Explanation: As mention in the item (10.1.1), the anaerobic digesters are complex and sensitive systems. Often, even the managers do not understand how it works (item 6.4). So, due to a low understanding of the new processes, managers rely heavily on the technology provider. In order to remain focused on the core production process, or to save costs, often the managers do not provide adequate or appropriate training for the operators on the new wastewater/ biogas processes and systems.

(10.1.3) Lack of standardized courses

Explanation: In Thailand, there is a lack of centralized information about biogas technologies and standards for biogas systems and equipment design (Umweltbundesamt, 2007). As a consequence, except for training courses provided *in-company* by technology providers, there are no standardized courses for the operators of biogas plants.

(10.1.4) Qualified workers/operators go to other industries and provinces

Explanation: The biogas industry in Thailand is still perceived as being in its infancy and it is difficult to attract appropriately qualified and knowledgeable staff (Prasertsan & Sajjakulnukit, 2006). In addition, the location of the plants contributes to the issue of not attracting staff; around 70% of the total tapioca production of the country (Sriroth et al., 2000) is located in the northeast parts of Thailand and the palm oil industry is mainly concentrated in the southern parts of Thailand (Chavalparit et al., 2006).

(10.1.5) Lack of standard operational procedure, caused by:

(10.1.5.1) Language barriers (O&M manuals not available in local language)

Explanation: As mention in item (5.1) most of the technologies utilized in biogas production are imported. Therefore it is natural that the O&M manuals are in the mother tongue of the manufacturer and in English. As per findings from the interviews, often the manuals are not translated into Thai language; neither are there workers in the client company that are able to speak English. This situation creates a serious language barrier that is often identified after the hand-over of the project to the owners.

(10.1.5.2) Poor quality O&M manuals, depending on experience of technology provider

Explanation: In Thailand, there are a lack of standards for bioenergy systems and equipment design (Umweltbundesamt, 2007). Since there is no centralized information and orientation regarding biogas technologies, the users need to rely on the manuals elaborated by the technology provider. Depending on how experienced the provider is and how adapted the technology is to Thai conditions and environment, the quality of the O&M manuals may vary.

(11) Insufficient skills to control critical process parameters, caused by:

(11.1) Operators not skilled and trained: Already explained in item (10.1).

(12) Lack of experience in operation, caused by:

(12.1) Young history of biogas industry in Thailand

Explanation: The biogas industry in Thailand is still perceived as young (Prasertsan & Sajjakulnukit, 2006) and there are few successful cases (Umweltbundesamt, 2007). For example, according to Chavalparit (2006), at the time of the study into the palm oil industry, there were only 7% of plants using anaerobic digestion tanks. For the starch industry, the Ministry of Energy of Thailand started supporting pilot biogas plants from the year 2003 onwards (EPPO, 2007). As a result, there are few specialized local professionals in the biogas field.

Technology-related barriers

(13) Too ambitious performance specifications by technology provider, caused by:

(13.1) No proper evaluation of plant profile to suggest appropriate anaerobic digester technology (supplier), caused by:

(13.1.1) Lack of measurement of actual process parameters to purchase proper technology: Already explained in item (4.1).

(14) Technology transfer done poorly, caused by:

(14.1) Technological support from abroad (takes time and costly), caused by:

(14.1.1) Lack of local professionals and technology/service providers in the area

Explanation: Most technologies for wastewater (Parr et al., 2000) and biogas systems (Prasertsan & Sajjakulnukit, 2006) came from developed countries. Since the biogas technology is still new in Thailand (item 12.1) there is a lack of local capacity building and availability of human resources with appropriate knowledge (Uddin et al., 2008). Therefore, the adaptation to local climate and conditions is often not conducted properly and there are few, or no, local companies that can provide proper technical assistance.

(15) Complexity and sensitivity of the anaerobic digester systems, caused by:

(15.1) Biological process with sensitive organisms, caused by:

(15.1.1) Bacteria are not too tolerant to variations of temperature and wastewater quality

Explanation: Anaerobic digesters are very complex and sensitive systems. Variations in critical parameters such as reactor configurations, concentrations of total volatile fatty acid (TVFA), pH, organic loading rates, inhibitor concentrations, hydraulic retention time (HRT), temperature, and substrate composition can lead to a process failure. These parameters require constant monitoring and investigation such that they can be maintained at, or near to, optimum conditions (Choorit & Wisarnwan, 2007).

(16) Performance guarantee expires after hand over (supplier), caused by:

(16.1) No long term financial incentives and contractual arrangements between the supplier and owner

Explanation: In many projects the technology suppliers are hired only to implement the wastewater and biogas systems and leave as soon as operation begins (hand-over). The users are sometimes not aware of warranty issues, leading to unreasonable expectations. These short-term, acquisition only deals are unlikely to contribute to an appropriate technology transfer as opposed to long term, repetitive deals, with more intense personal interactions (Schneider et al., 2008).

The analysis revealed 29 root barriers for the poor biogas performance. As Table 5 indicates, in most cases, there is literature that identified and discussed each barrier. It was also observed, however, that many barriers were connected to each other and it was often difficult to clearly identify what are the causes and/or consequences of certain barriers.

In order to ascertain the barriers that are most relevant and affect the performance of the biogas industry, the authors conducted a second round of interviews. In this phase, they compiled all root causes identified after the brainstorming session and put these together in a spread-sheet format. They asked the participants to vote, according to their consideration, the relevance of the cause, as per the following proportion rule:

- 20% of the causes are very important;
- 30% of the causes are of middle importance;
- 50% of the causes are of low important.

The compilation of the data indicates that the six (6) most important barriers voted were as follows (arranged in decreasing order of importance): [14]

- Item 1.2 – Lack of attention on biogas business by the management, since it is only a marginal activity within the plant;
- Item 10.1.1 – No understanding of the complex biological process (Operator);
- Item 10.1.2 – Lack of proper training on operation;
- Item 6.4 – Lack of knowledge about anaerobic digester systems (management level);
- Item 4.2 – Lack of business long term strategy and business plan
- Item 6.3 – Optimistic figures provided by technology suppliers

It is recognized, using this prioritization method, that most of the barriers are related to managers' competence in successfully integrating the biogas technology with the existing business. Managers need to understand the particularities of the new business unit and develop a strategic plan, forecasting the biogas benefits and possible obstacles. This result may suggest that the barriers related to operational problems could be avoided or diminished by proper allocation of resources in the development of education, skills and training for the staff operating the biogas business.

[14] Adopting Pareto's Principle, 80% of the impact of the problem resulted from 20% of the causes. In this analysis, 6 barriers represent ~20% of the causes. The Pareto Principle was observed by Dr. Joseph Juran in the 1930's and it is one important tool in Total Quality Management (Reh, 2009).

Conclusion

The purpose of this study was to identify barriers in biogas technology implementation and operation in Thailand. As indicated in the introductory section of this paper, while a biogas plant can bring economic benefits, with respect to energy self-sufficiency and cost-saving over time, the design and operation of a biogas plant requires high investments and is still perceived as a risky business due to a number of barriers. It was noted at the beginning that there is little literature that explains the low performance of biogas plants when compared to the expected projected performance or design.

The authors conducted two analyses to identify barriers in implementation of biogas utilization projects in Thailand. The first analysis looked into CDM projects for biogas utilization in Thailand. The most frequently cited barriers included; 1) lack of skilled and trained staff; 2) no drivers to change from open lagoons (well known, cheaper and prevailing technology) to AD systems; 3) lack of equipment and local technology providers/ suppliers (imported technology); and 4) sensitivity of the AD systems (strict and delicate operating parameters).

The second analysis was conducted based on a consultation of relevant professionals in CDM and the biogas business in Thailand. The analysis of the barriers from practical experience provided a complementary understanding of the barriers, by looking into not only the barriers at the planning phase of the projects but also those identified in the operational phase. The barriers classified as most important included 1) lack of attention to biogas business by management; 2) no understanding of the complex biological process by operators; 3) lack of proper training on operation; 4) lack of knowledge about anaerobic digester systems at the management level; 5) lack of long term business strategy and business plan; and 6) optimistic figures provided by technology suppliers. The results of the analysis indicated that most of the barriers were related to managerial issues, and deficiencies of knowledge or information in different levels of the business unit. The barrier related to staff education and training is, however, present in both analyses, giving a strong indication that it is a very relevant in terms of hindering the biogas plants' performance.

This study aims to contribute a better understanding of the barriers that hinder the implementation and performance of biogas business in Thailand, more specifically in the tapioca starch and palm oil industries. Future research is necessary; perhaps by looking into biogas utilization projects in other industries a more successful utilization of biogas potentials, as renewable energy, can be achieved in the future.

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ANNEX I: List of PDD analyzed in this study. All projects are biogas projects for palm oil or starch (tapioca) plants in Thailand.

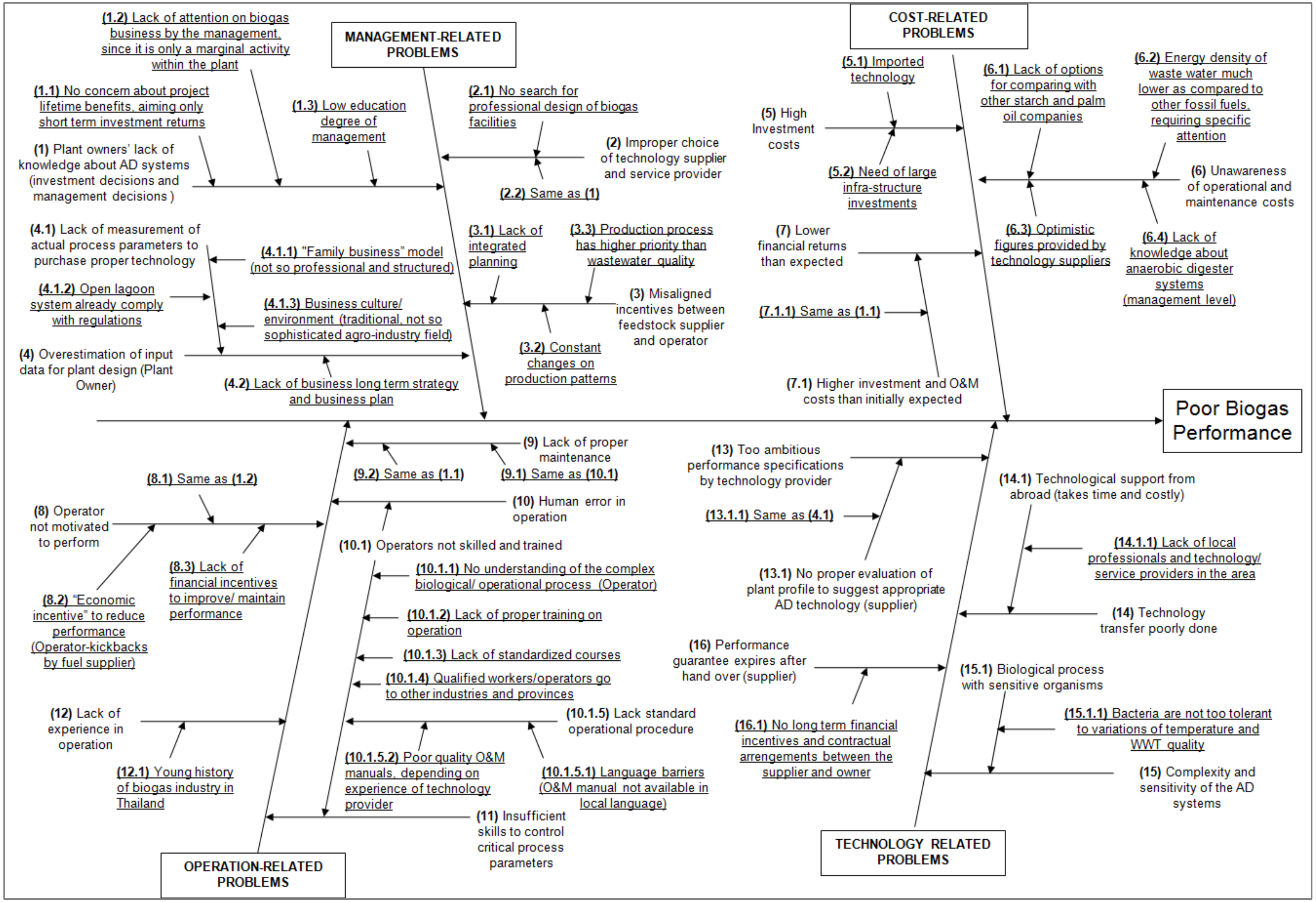
#	Project Title	Status (as of 28-Oct-2009)	Province	Methodology/ Version	Technology	Palm Oil / Starch	Metric tonnes CO2eq/Year	PDD consultant
1	Univanich Siam Biogas to Energy Project	Validation	Krabi	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 11)	CIGAR	Palm Oil	20,895 (10 years crediting period)	EcoSecurities
2	Chok Chai Starch UthaiThani	Validation	UthaiThani	ACM0014 (Ver. 2)	UASB	Starch (Tapioca)	57,997 (10 years crediting period)	Mitsubishi UFJ Securities
3	TBEC Tha Chang Biogas Project	Validation	SuratThani	ACM0014 (Ver. 2)	CIGAR	Palm Oil	54,497 (7 years crediting period)	Carbon Bridge
4	N.P. Biopower project at Charoensuk Starch Co. Ltd.	Validation	KamPhaengPhet	ACM0014 (Ver. 2)	UASB	Starch (Tapioca)	57,023 (10 years crediting period)	Allied Carbon Credit
5	Eiamheng Tapioca Starch Industry Co.,Ltd.	Validation	NakhonRatchasima	ACM0014 (Ver. 3)	UASB	Starch (Tapioca)	165,595 (10 years crediting period)	Mitsubishi UFJ Securities
6	Starch Plant (Sima 1) at NakornRatchasima	Validation	NakhonRatchasima	AMS-III.H (Ver. 10) AMS-I.D. (Ver. 13)	UASB	Starch (Tapioca)	32,252 (10 years crediting period)	Danish Energy Management
7	Northeastern Starch (1987) Co., Ltd. -- LPG Fuel Switching Project	Validation	NakhonRatchasima	AMS-III.H. (Ver. 10) AMS-I.D. (Ver. 13) AMS-I.C. (Ver. 13)	AFFR	Starch (Tapioca)	25,624 (10 years crediting period)	Danish Energy Management
8	Kitroongruang Biogas Energy Project	Registered (23 Oct 09)	Rayong	AMS-I.C. (Ver. 13) AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	CIGAR	Starch (Tapioca)	17,328 (10 years crediting period)	EcoSecurities
9	Kalasin Wastewater Treatment to Energy	Validation	Kalasin	AMS-I.C. (Ver. 9) AMS-I.D. (Ver. 10) AMS-III.H. (Ver. 4)	ABR	Starch (Tapioca)	39,824 (7 years crediting period)	EEA Fund Management
10	AFFR at Chachoengsao.	Validation	Chachoengsao	AMS-III.H. (Ver. 10)	AFFR	Starch (Tapioca)	18,635 (10 years crediting period)	Danish Energy Management
11	Green to Energy Wastewater Treatment Project	Validation	SuratThani	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	AD and Activated Carbon Filtration	Palm Oil	31,403 (7 years crediting period)	Mitsubishi UFJ Securities

#	Project Title	Status (as of 28-Oct-2009)	Province	Methodology/ Version	Technology	Palm Oil / Starch	Metric tonnes CO2eq/Year	PDD consultant
12	Thachana Palm Oil Company Wastewater Treatment Project	Registered (29 Aug 09)	SuratThani	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	CSTR	Palm Oil	23,844 (7 years crediting period)	Mitsubishi UFJ Securities
13	Natural Palm Oil Company Limited	Validation	SuratThani	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 10)	CSTR	Palm Oil	9,809 (10 years crediting period)	Danish Energy Management
14	Eiamburapa Company Ltd. Sakaeo Province	Review Requested	Sa Kaeo	AMS-I.C. (Ver. 13) AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	N/A	Starch (Tapioca)	56,004 (10 years crediting period)	Mitsubishi UFJ Securities
15	Southern Palm in Suratthani	Requesting Registration	SuratThani	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	CSLR	Palm Oil	18,622 (10 years crediting period)	Mitsubishi UFJ Securities
16	Green Glory in Suratthani	Registered (31Aug 09)	SuratThani	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	CSLR	Palm Oil	16,916 (10 years crediting period)	Mitsubishi UFJ Securities
17	P.V.D. International Company Limited	Registered (10 Sep 09)	NakhonRatchasima	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	UASB	Starch (Tapioca)	50,663 (10 years crediting period)	Danish Energy Management
18	Modern Green Power Co. Ltd	Validation	Krabi	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	A+CSTR and A+USAB	Palm Oil	48,406 (10 years crediting period)	PURE Natural Power Co.
19	Roi Et Flour Company Limited	Registered (05 Sep 09)	Roi Et	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	UASB	Starch (Tapioca)	40,276 (10 years crediting period)	Danish Energy Management
20	Univanich TOPI Biogas Project	Registered (24 Aug 09)	Krabi	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	CIGAR	Palm Oil	41,174 (7 years crediting period)	Carbon Bridge
21	Palm Oil Mill at Sikao, Trang	Validation	Trang	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	CSTR	Palm Oil	15,431 (10 years crediting period)	Danish Energy Management
22	Palm Oil Mill at Kanjanadij, SuratThani	Validation	SuratThani	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	CSTR	Palm Oil	18,359 (10 years crediting period)	Danish Energy Management
23	Palm Oil Mill at Sinpun, SuratThani	Validation	SuratThani	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	CSTR	Palm Oil	18,155 (10 years crediting period)	Danish Energy Management
24	Palm Oil Mill at Saikhueng, SuratThani	Validation	SuratThani	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	CSTR	Palm Oil	18,739 (10 years crediting period)	Danish Energy Management
25	Palm Oil Mill at Bangsawan, SuratThani	Validation	SuratThani	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	CSTR	Palm Oil	18,396 (10 years crediting period)	Danish Energy Management
26	T.H. Pellet Wastewater in NakhonRatchasima	Validation	NakhonRatchasima	AMS-I.C. (Ver. 13) AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	Anaerobic Digester	Starch (Tapioca)	43,323 (10 years crediting period)	Mitsubishi UFJ Securities

#	Project Title	Status (as of 28-Oct-2009)	Province	Methodology/ Version	Technology	Palm Oil / Starch	Metric tonnes CO2eq/Year	PDD consultant
27	Bangna Starch wastewater and biogas	Correction Request	Kalasin	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	UASB	Starch (Tapioca)	41,701 (7 years crediting period)	South Pole Carbon Asset Management
28	N.E. Biotech Co. Ltd.	Validation	NakhonRatchasima	AMS-I.C. (Ver. 13) AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	UASB	Starch (Tapioca)	31,173 (7 years crediting period)	South Pole Carbon Asset Management
29	Trang Palm Oil in Trang Province,	Validation	Trang	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	Hybrid Channel Digester	Palm Oil	33,666 (10 years crediting period)	Mitsubishi UFJ Securities
30	Sangpetch Tapioca Flour	Validation	Chaiyaphum	AMS-I.C. (Ver. 13) AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	High Rate Anaerobic Lagoon (HLSystem)	Starch (Tapioca)	55,718 (10 years crediting period)	Mitsubishi UFJ Securities
31	Chaiyaphum Starch Plant	Validation	Chaiyaphum	AMS-I.C. (Ver. 13) AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	High Rate Anaerobic Lagoon (HLSystem)	Starch (Tapioca)	57,177 (10 years crediting period)	Mitsubishi UFJ Securities
32	Biogas project, Cargill Siam Borabu	Registered (05 Sep 09)	MahaSarakhan	AMS-I.C. (Ver. 13) AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	UASB	Starch (Tapioca)	52,881 (7 years crediting period)	Kyoto Energy
33	Srijaroen Palm Oil in Krabi Province	Registered (16 Oct 09)	Krabi	AMS-I.C. (Ver. 13) AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 9)	Modified Covered Lagoon	Palm Oil	20,429(10 years crediting period)	Mitsubishi UFJ Securities
34	Nam Hong Power Wastewater Treatment Project in Krabi Province	Validation	Krabi	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 10)	Anaerobic Digester	Palm Oil	22,488 (10 years crediting period)	Mitsubishi UFJ Securities
35	Pitak Palm	Validation	Trang	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 10)	Anaerobic Sequence Batch Reactor + UASB	Pal Oil	17,328 (7 years crediting period)	South Pole Carbon Asset Management
36	Chantaburi Starch Project	Validation	Chantaburi	AMS-I.C. (Ver. 13) AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 10)	UASB	Starch (Tapioca)	41,034 (7 years crediting period)	South Pole Carbon Asset Management
37	Blue Fire Bio Project	Validation	NakhonRatchasima	AMS-I.C. (Ver. 13) AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 10)	Anaerobic Digester	Starch (Tapioca)	58,726 (10 years crediting period)	South Pole Carbon Asset Management
38	CYY Biopower	Registered (25 Mar 09)	NakhonRatchasima	AM0022 (Ver. 4)	UASB	Starch (Tapioca)	97,468 (10 years crediting period)	South Pole Carbon Asset Management

#	Project Title	Status (as of 28-Oct-2009)	Province	Methodology/ Version	Technology	Palm Oil / Starch	Metric tonnes CO2eq/Year	PDD consultant
39	Korat Waste To Energy	Registered (01 May 03)	NakhonRatchasima	AM0022 (Ver. 4)	ABR	Starch (Tapioca)	310,843 (10 years crediting period)	EcoSecurities
40	Kalasin, Thailand (CWTE project)	Registered (31 Jan 09)	Kalasin	AM0022 (Ver. 4)	ABR	Starch (Tapioca)	87,586 (10 years crediting period)	Environmental Resources Management
41	UnivanichLamthap POME Biogas Project	Registered (01 Feb 09)	Krabi	AM0022 (Ver. 4)	CIGAR	Palm Oil	43,650 (10 years crediting period)	Carbon Bridge
42	Jiratpattana Biogas Energy Project	Registered (16 Mar 09)	Kalasin	AM0022 (Ver. 4)	CIGAR	Starch (Tapioca)	24,726 (10 years crediting period)	EcoSecurities
43	Chao Khun Agro Biogas Energy Project	Registered (09 Mar 09)	Saraburi	AM0022 (Ver. 4)	CIGAR	Starch (Tapioca)	48,167 (10 years crediting period)	EcoSecurities
44	C.P.A.T tapioca Nakhonratchasima	Validation	NakhonRatchasima	ACM0014 (Ver. 3)	UASB	Starch (Tapioca)	105,021 (10 years crediting period)	Mitsubishi UFJ Securities
45	K.S. Bio-Plus Co. Ltd.	Validation	Kalasin	AMS-I.D. (Ver. 13) AMS-III.H. (Ver. 10)	CIGAR	Starch (Tapioca)	65,247 (10 years crediting period)	Advance Energy Plus
46	Siam Quality Starch in Chaiyaphum	Registered (15 Apr 09)	Chaiyaphum	AM0013 (Ver. 4) AMS-I.C. (Ver. 12)	CIGAR	Starch (Tapioca)	98,372 (10 years crediting period)	Mitsubishi UFJ Securities
47	Chumporn applied biogas technology	Registered (09 Feb 09)	Chumphorn	AM0013 (Ver. 4)	A+CSTR	Palm Oil	23,448 (10 years crediting period)	ENVIMA, Perspectives
48	Tapioca Flour Mill	Validation	NakhonRatchasima	AMS-I.C. (Ver. 14) AMS-III.H. (Ver. 12)	CIGAR	Starch (Tapioca)	68,042 (10 years crediting period)	Korat Flour Industry

ANNEX II: Cause and effect diagram derived from a brain storming session with project managers and consultants from an international carbon trading company.



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