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Thema:

Project evaluation on economic feasibility of renewable energy projects in Thailand

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Thema der Masterthesis

Projektevaluierung der Wirtschaftlichkeit von Erneuerbaren Energien Projekten in Thailand

Stichworte

Biogas, Bankability, Projektevaluierung Erneuerbare Energien, Multi-Stakeholder Analyse, Eigenschaften Biogasanlagen, Fragebogen Biogasanlagen, Energiemarkt Thailand

Kurzzusammenfassung

In der vorliegenden Arbeit wird ein Bewertungs-Verfahren zur ganzheitlichen Betrachtung von Biogaslagen im thailändischen Erneuerbaren Energien Markt entwickelt. Dabei werden technische, operationale, sozio-ökonomische und ökonomische Faktoren hinsichtlich ihres Einflusses auf die Wirtschaftlichkeit von Biogas- Anlagen betrachtet. Die erste Bewertung des vorliegenden Datenmaterials zeigt, dass der auf multiplen Kriterien beruhende Ansatz bei der Interpretation wirtschaftlicher Kennzahlen zu neuen Erkenntnissen führen kann. Inhaltlich wurden aus den gewonnenen Erkenntnissen Thesen zum Biogasmarkt in Thailand gebildet. Grundsätzlich lässt sich feststellen, dass Optimierungspotenziale insbesondere bei der Nutzung der Energie, bei der Technologie, beim Anlagenbetrieb, bei Sicherheitsfragen sowie bei den angewendeten Geschäftsmodellen bestehen. In Bezug auf kleinere Anlagen lässt sich sagen, dass ihre Wirtschaftlichkeit stark von der staatlichen Förderpolitik abhängig ist.

Anja Haupt

Title of the paper

Project evaluation on economic feasibility of renewable energy projects in Thailand

Keywords

Biogas, bankability, project evaluation renewable energies, multi-stakeholder analysis, biogas plant performance, questionnaire biogas plants, energy market Thailand

Abstract

In this study a method for the assessment of the overall performance of biogas plants within the context of the renewable energy market in Thailand has been developed. The influence of technical, operational, socio-economic and economic factors on the financial viability of biogas plants is hereby assessed. A first evaluation of the data obtained indicates that an assessment based on multiple criteria can bring new insights when interpreting financial figures. A number of assertions were able to be formulated that are open to verification in further studies. The potential for the optimisation for biogas plants can generally be ascertained by looking at the final use of the energy, the technology used, the plant's operation, for questions of plant safety and for the applied business models. For the small-scale plants investigated, it was found that the financial feasibility heavily depends on governmental incentives.

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Units of measurement

g	gramme
h	hour
kg	kilogramme
ktoe	thousand tons of oil equivalent
kW	kilowatt
kWh	kilowatthours
l	liter
m	meter
m^2	square meter
m^3	cubic meter
mg	milligramme
MJ	megajoule
MTOE	million tons of oil equivalent
MW	megawatt
PJ	petajoule
t	ton
TWh	terrawatthours
W	watt

Abbreviatons

ABR Anaerobic Baffle Reactor
ACL Anaerobic Covered Lagoon
AD Anaerobic DIgestion
AEDP Alternative Energy Development Plan
AFF Anaerobic Fixed Film
BAU Biogas Advisory Unit
B/C Benefit to Cost Ratio
C Carbon
CD Channel Digester
CDM Clean Development Mechanism
CH_4 methane
CHP Combined Heat and Power Plant
CO_2 Carbon Dioxide
COD Chemical Oxygen Demand
CSP Concentrated Solar Power
CSTR Completely Stirred Tank Reactor
CMU-CD Chiang Mai University Channel Digester
DM Dry Matter
DSS Decision Support System
ECPFC Energy Conservation Promotion Fund Committee
EGAT Electricity Generating Authority of Thailand
ENCON Energy Conservation Promotion Fund
EPC Energy Policy Committee
EPPO Energy Planning and Policy Office
ERDI Energy Research and Development Institute
ESCO Energy Service Companies Venture Capital Fund
GDP Gross Domestical Product
giz Gesellschaft für internationale Zusammenarbeit
H_2S Hydrogen Sulphide
IPP Independent Power Producer
IRR Internal Rate of Return
K Potassium
MCDA Multi Criteria Decision Analysis
MC-UASB Medium Farm Channel-Up flow Anaerobic Sludge Blanket
MEA Metropolitan Electricity Authority
MTOE Million Tons of Oil Equivalent
MoE Ministry of Energy of Thailand
MSW Municipal Solid Waste
N Nitrogen
NEPC National Energy Policy Council
NEPO National Energy Policy Office
NPV Net Present Value
O_2 Oxygen
oDM organic Dry Matter

O&M	Operation and Maintenance
P	Phosphorus
PDP	Power Development Plan
PEA	Provincial Electricity Authority
PV	Photovoltaic
PPA	Power Purchase Agreement
R&D	Research and Development
REDP	Renewable Energy Development Plan
ROIC	Return of Investment of Capital
RPS	Renewable Portfolio Standards
S	Sulfur
SPB	Simple Payback Period
SPP	Small Power Producer
THB	Thai Baht
TLCC	Total Life Cycle Cost
TSS	Total Suspended Solids
UASB	Up flow Anaerobic Sludge Blanket
Vol-%	Volume percent
VSPP	Very Small Power Producer

0. Introduction

This Master's thesis is result of a project being undertaken by the giz in Thailand to conduct an evaluation of Thai renewable energy plant. It forms part of the "Project Development Program Southeast Asia" (PEP Southeast Asia) that was launched recently. PEP is an initiative of the German Ministry of Economics and itself part of the overall "Renewables Made in Germany" programme. The objective of the program is to support the export of German technology abroad, thereby enhancing the worldwide development of renewable energy markets.

The giz office in Thailand is continuously monitoring development in the local renewable energy markets. An up-to-date evaluation of projects using the defined technologies can help, firstly as a means of obtaining performance information about the existing facilities using that technology, and secondly by exploring the success or failure of the associated political strategies and economic trends. Further, the results can be used within the PEP programme to inform German companies about market needs.

The technologies originally selected for this study were photovoltaic power and biogas. However, owing to time constraints during the field research phase, only one of the technologies – biogas – was able to be investigated in depth.

The giz's aim was an investigation about the bankability of different plant and an analysis of the variations in the IRR (internal rate of return) and economic performance of these plants. The title of this thesis is based on these original considerations. To meet this goal a methodology has been developed in the current study into how the performance of biogas plant can be defined and evaluated. This methodology is based on the assumption that an analysis of financial figures alone is not sufficient to evaluate economic plant performance, and that the limits for the functioning of a technology are also set by the political and societal context. To produce a comprehensive assessment, other aspects such as technical, economic, environmental and socio-economic factors should also be taken into account. Furthermore, when trying to find a definition for the term "bankability" we have integrated the perspectives of different project stakeholders about what constitutes economic or "bankable" plant performance into our evaluation, and have defined a set of criteria on this basis. Using these criteria, a questionnaire for plant operators and owners has been designed. Subsequently, the questionnaire has been tested during a field research visit to Thailand in July 2012.

Because of various difficulties which arose during the field research phase, the emphasis of this paper is rather on the development of the methodology rather than on the actual plant results themselves. The data collected in Thailand has been used to formulate assertions about the technology and to evaluate the methodology that was developed. The paper has therefore been subtitled: "The development of a methodology for a multi-dimensional assessment of the performance of biogas plants".

We would also like to note that the present study is mainly based on that raw data that we could obtain during the field research, as there appears to be little recent literature published in English about the Thai renewable energy market.

1. Renewable Energies in Thailand

1.1 Overview to the energy situation

Over the last 20 years, Thailand has undergone a dynamic phase of economic development. Thailand is successfully transforming itself from an agrarian society towards an industrial economy. Agriculture, formerly the most important branch of the economy, has been transformed from its previous, existence-based structure into a commercial sector. The per-capita value created by non-agricultural industry has grown continuously and has now overtaken that of agriculture. A study undertaken by the Food and Agricultural Organization of the United Nations comments: "The contribution of the agricultural sector to GDP and to exports has decreased significantly since the mid-1980s."[1] This trend has continued in recent years. In 2011, the manufacturing sector contributed already 39 % to the GDP total of 346 billion US Dollars; - in comparison - agriculture only 9 %.[2]

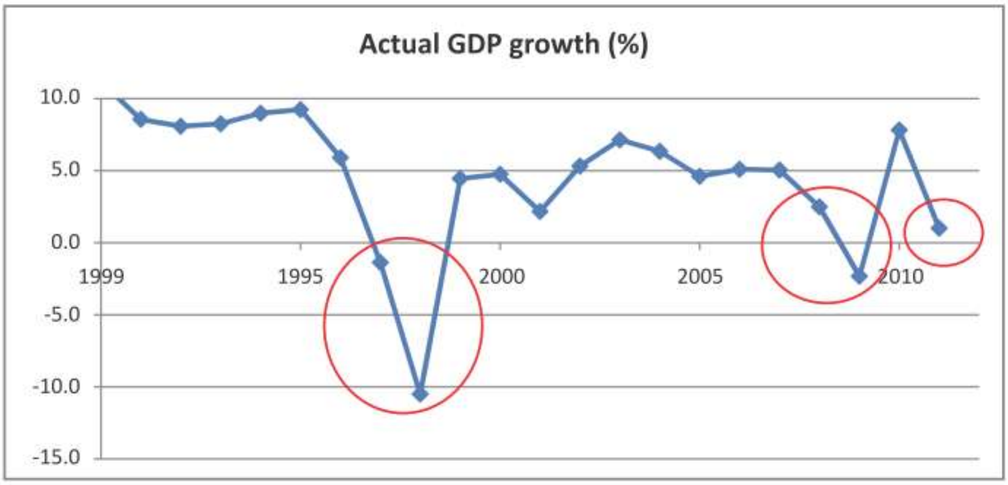
Before the Asian crisis of 1997-1998, Thailand was one of the world's fastest growing economies with an average growth rate of 8-9%. As a result of these rates of economic growth, poverty has been reduced from its former peak of 21% in 1997 to 8% in 2009. Today, poverty is mainly a rural phenomenon: 88% of Thailand's poor live in rural areas.[3]

Nevertheless, as economic data shows, Thailand's economical growth has undergone frequent highs and lows in recent years. This was due to two major factors. Firstly unstable situations within the country (either as a result of political disturbances or owing to meteorological disasters) and secondly due to the country's high dependency on the world economy owing to its high volume of exports. The Thai export sector is the key business driver for the GDP, accounting

[1] A. Gobena, K.Kulowesi, et.al.: Case studies on bioenergy policy and law: options for sustainability", 2009, p.291
[2] c.f. "Trading Economics",n.d. and "Thailand at a Glance", n.d.
[3] c.f. World Banc: "Navigating turbulence, sustaining growth", 2011

for more than 50%.[4] Following a period of stable growth of 4-5% per annum in the period 2002 – 2007 (during the recovery from the Asian crisis of the 90's), the global financial crisis of 2008-2009 has once again resulted in double-digit falls for most of Thailand's economic sectors. The economy contracted 2.3% in 2009. However, in 2010 it expanded again, even at its fastest pace since 1995. This expansion was briefly interrupted by the flood disaster of 2011, but has again been followed by a fast recovery in 2012.[5] The following graph displays the GDP's development over the last decade:

Figure 1: Thai GDP growth in the period 1999 - 2011

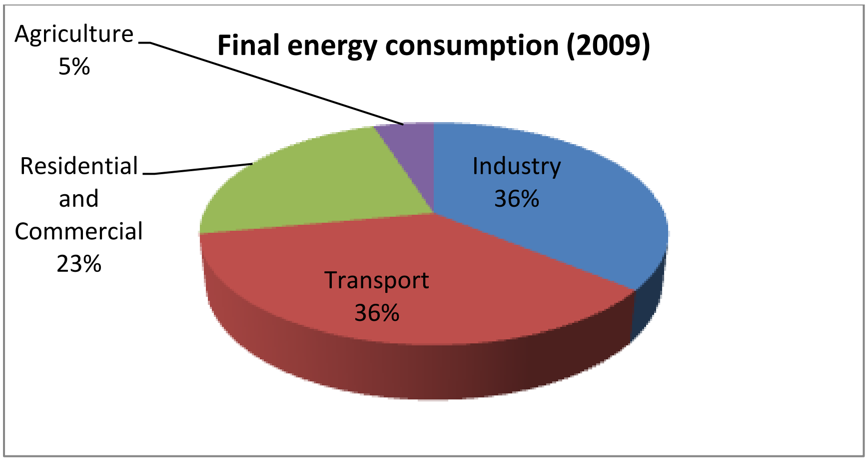


Source: Greacon: Proposed Power Development Plan 2012, 2012, p. 11

The country's economic growth has had a deep impact on its national energy consumption. In 2011 the final energy consumption had already risen to 60,869 ktoe, compared to 51,646 ktoe in 2006, or 39,283 ktoe in the year 2000.[6] The industrial and transports sectors account for the biggest share of energy consumption, followed by residential and commercial applications, and finally the agricultural sector:

[4] c.f. World Bank: „Exports of goods and services", 2012
[5] c.f. "Index mundi", 2012
[6] c.f. Energy Policy and Planning Office: "Energy Statistics: Historical Statistics 1986-2011 (26-Year Series), 2012

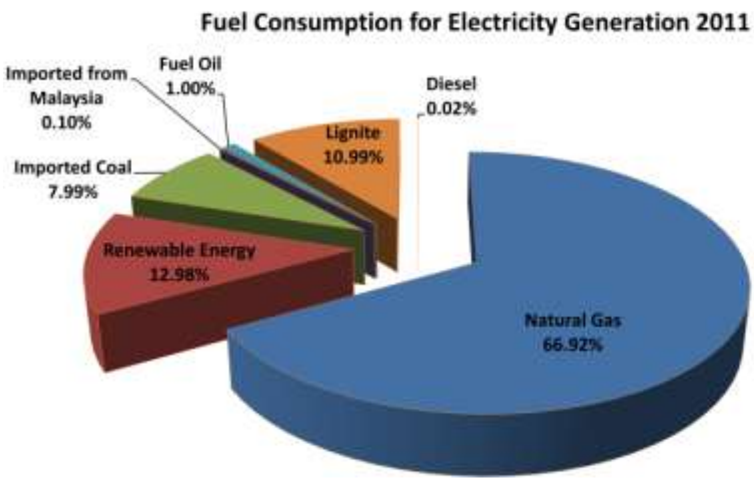
Figure 2: Shares of the different sectors on final energy consumption in Thailand, 2009



Data source: World Bank Group, "Thailand: Clean Energy for Green Low-Carbon Growth", 2011, p. 9; own graphic

Energy generation in Thailand is mainly based on natural gas. As also Nakawiro has pointed out, natural gas has over the decades emerged as the main fuel for electricity generation. This has been due to its environmental appeal, relatively low capital requirements, shorter payback period and the higher efficiency of gas-based power plant technology.[7] The following chart shows, that almost three-quarters of Thailand's electricity is generated from natural gas (70%). Coal (21%), hydro power (6%) and a small amount of oil-based generation (0.1%) round off the energy mix.

Figure 3: Power generation in Thailand by fuel type, 2011



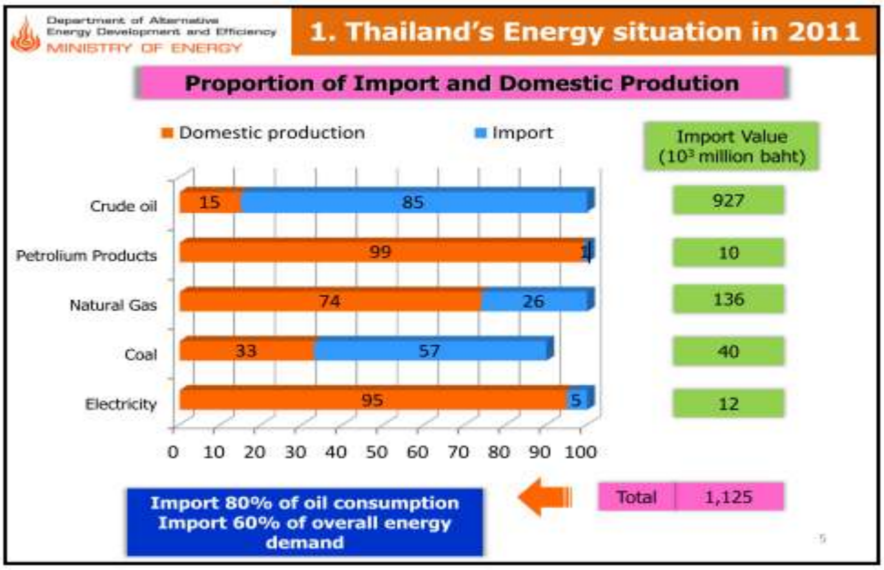
Source: EPPO "Energy Statistics of Thailand", 20011

At present Thailand can still cover a large share of its gas needs through its own reserves, but the rapidly growing energy demand described above is already showing its effect. Recent data from the EPPO is forecasting that the reserves of gas (and also crude oil) are shrinking rapidly. On the

[7] c.f. Nakawiro et al.: "Gas dependence and fuel import reliance in future electricity capacity expansion in Thailand", 2007

basis of the current production (December 2011), the gas fields will dry up within the next 28 years.[8] Thailand will not only have to import more gas in the years to come. Due to its growing energy demand, when analysing the share of domestic production and imports of *all* fossil fuel resources, Thailand has already become a net importer of fossil fuels. While the country's total energy production is 61.71 MTOE (2009)[9], net energy imports lie at 47.37 MTOE (2009)[10]. The following graph displays the individual energy resources and the proportion of them coming from domestic production and imports:

Figure 4: Proportion of import and domestic production of individual energy resources in Thailand 2011



Source: Sutabutr: "Overview of biomass power project in Thailand", 2012

International observers are already assessing Thailand's growing demand and increasing dependency on energy imports as posing a threat for its energy security, and forecasting that the Thai power sector may not have sufficient capacity to cover its electricity needs in the future.[11] This could also pose a significant threat to Thailand's export-oriented industrial basis. According a report published by Welzenbacher, an important factor for its economic success are the moderate energy prices, partly also based on subsidies. With a growing dependency on energy imports Thailand might have to increase prices and therefore challenge the international competitiveness of its economic sector.[12]

[8] c.f. Energy Policy and Planning Office: "Table 1.3-1 Energy Reserves" *(attached to annex)*
[9] c.f. International Energy Agency "Selected 2009 Indicators Thailand", 2011
[10] c.f. , ibid. International Energy Agency,2011
[11] c.f. Ölz et al.: "Deploying Renewablse in Southeast Asia", 2010, p. 27
[12] c.f. Welzenbacher: "Goldener Tiger am Scheideweg?, 2012, p.48

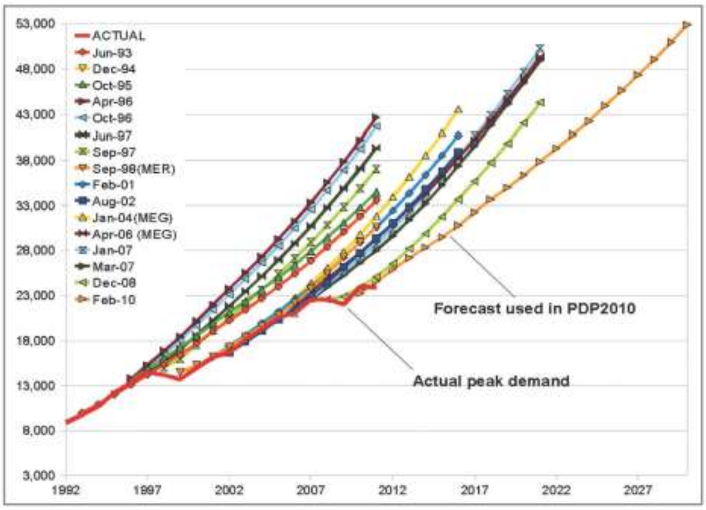
Following recent discussions, it is currently unclear which strategy the country will undertake to secure its future energy supplies.

The Thai Energy Ministry and the Electricity Generating Authority of Thailand (EGAT[13]) aim to consolidate the energy mix using other conventional energy sources such as large-scale coal-fired and nuclear power plants. However, they are being confronted by growing public resistance to any expansion plans for coal-fired electricity and, since Fukoshima, to nuclear power plant too.[14] In the last Power Development Plan report (PDP) [15] from 2012, which has been prepared by EGAT, the Ministry of Energy, has confirmed that owing to public resistance, the start of the construction of the two proposed nuclear reactors will be postponed for 3 years. It is now planned to commence construction in 2023.[16] Coal- fired power plants face the same difficulties for similar reasons. Nakawiro states: "The main reserve of lignite is geographically located at a single site in the north, which currently accommodates the biggest coal fired power projects in the country. Any expansion of coal fired power plants nearby is unlikely due to public opposition to environmental emission."[17]

Other parties claim that Thailand's energy supply security could be assured without nuclear or additional coal-fired power plants by focusing instead on energy efficiency and demand side management measures. Greacen, a former advisor to the Thai government, has shown by analysing past official forecasts for electricity demand, that in the past 20 years there has always been a "clear systemic tendency to over-estimate actual demand for electricity"[18] . The following graph illustrates actual peak demand in Thailand (solid red line) compared to every forecast used in the development of government power policy over the past 20 years:

[13] State enterprise that owns and manages about 50% of Thailand's electricity generation capacity, as well as the nation's transmission network. Compare also chapter 1.2.
[14] Ibid, c.f. Greacon: "Proposed Power Development Plan (PDP)2 2012", 2012, p. 23
[15] c.f. Electricity Generating Authority of Thailand: Summary of Thailand Power Development Plan 2010 – 2030, 2010, Rev. 3
[16] ibid., c.f. Electricity Generating Authority of Thailand, 2010, Rev. 3, p. 7
[17] ibid Nakawiro et al, 2007, p. 3
[18] ibid Greacen "Proposed Power Development Plan (PDP)2 2012", 2012, p. 11

Figure 5: Actual power peak demand (red line) compared to the forecasts in the Power Development Plan



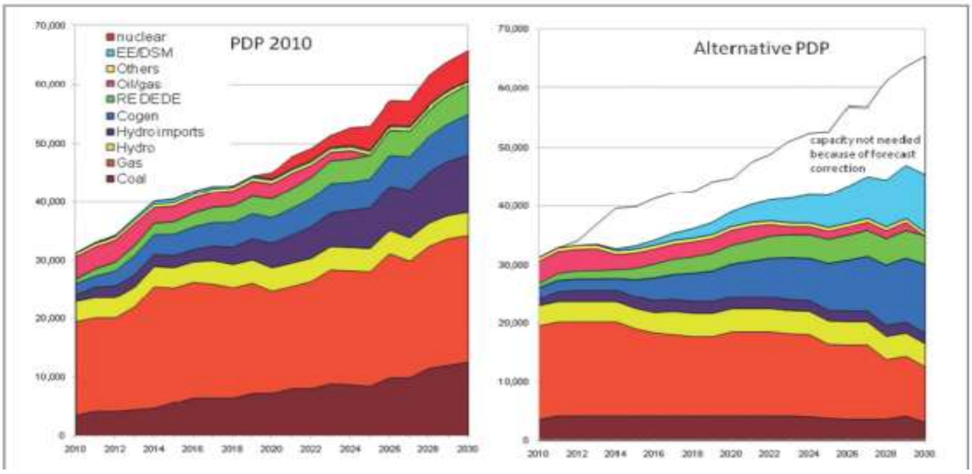
Source: Greacen: "Proposed Power Development Plan (PDP) 2012", 2012, p. 11

According Greacen, the reasons for the failure to produce accurate forecasts can be found in the methodology used to forecast demand. This has been based on medium- and long-term GDP growth forecasts, models of consumption for certain classes of end-consumer where sufficient data has been available and an underlying assumption of exponential growth. However, according Greacon: "GDP growth rates adopted by forecasters have proven to be overly optimistic. Whereas planners predict a base-case of 5% annual GDP growth from 2007 to 2011, actual GDP growth has averaged only 2.8%."[19]

In his report he therefore proposes a different resource mix to that proposed in PDP 2012; this is shown in figure 6. Notable differences include a reduction in the capacity needed so as to match corrections to the forecast, the ommission of nuclear power, a progressive reduction in the number of natural gas power plants as they are retired, and reduced growth in coal-based generation. Following Greacen's recommendations, Thailand could cover its energy demand solely by increasing the share of power from renewable energy resources and cogeneration, and by undertaking energy efficiency measures.

[19] ibid. Greacen, 2012, p. 11

Figure 6: Energy supply resources foreseen by the official PDP 2012 (left) and proposed by the study from Greacen (right)



Source: Greacon: "Proposed Power Development Plan (PDP) 2012", 2012, p. 28

In summary, the above discussion demonstrates how, due to the country's economic development and the consequence of this on the energy market, the Thai energy situation has changed rapidly over recent years. The further development of renewable energy technologies is not only driven by technical considerations, but has to be viewed within this context of political decision making.

1.2 Development of renewable energies

The development of renewable energies in Thailand has been fostered by three main drivers: the (still incomplete) liberalization of the Thai energy market since the early 90's, the set-up of renewable energy development targets in 2008 and the set-up of incentive schemes to promote the private sector participation on the generation of electricity by renewable resources.

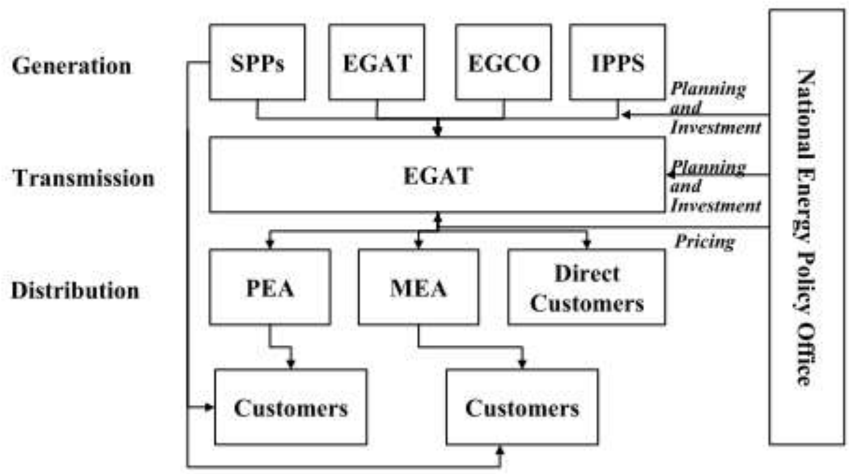
Liberalisation and development of renewables

Thailand's electricity sector has experienced wide reaching changes over the last two decades. These can be linked to the efforts of the Thai government to initiate necessary investment by private capital in order to meet the growing energy demand. As in many other countries too, the focus was laid on the restructuring of the former state energy monopoly. Mainly the following trends have been institutionalised:

- Partly privatization and creation of competition on the generation side
- Promotion of customer generation
- Unbundling of generation, transmission and distribution

Today, Thailand's semi-unbundled structure is called the "Enhanced Single Buyer" model. The state-owned Electricity Generating Authority of Thailand (EGAT) plays a predominant role as it accounts for almost 50% of the power generation market. The other market shares are hold by private players, called Independent Power Producer (IPP) and Small Power Producer (SPP). EGAT still has a monopoly of electricity transmission, and is therefore the single buyer of electricity. The Metropolitan Electricity Authority (MEA) buys bulk power from EGAT and is responsible for its distribution in metropolitan areas, whereas the Provincial Electricity Authority (PEA) is responsible for that in provincial areas.

Figure 7: Thai electricity supply industry



Source: World Energy Council: "Pricing energy in developing countries", 2001

The liberalization of the Thai energy market started in 1992, through the "Energy Conservation Promotion Act"[20]. This was enacted by the newly formed National Energy Policy Council (NEPC), a government body for energy matters. Council members include ministers from all related sectors (defence, energy, finance, foreign affairs, agriculture, transport, commerce, science and industry). The NEPC acts through three executing government agencies - the Energy Conservation Promotion Fund Committee (ECPFC), the Energy Policy Committee (EPC) and the National Energy Policy Office (NEPO)[21]. The determining agency for private sector participation in energy generation was NEPO. NEPO was responsible for pushing the introduction of Independent Power Producers (IPP) in 1992, granting these the right to invest in, own and operate large scale power plant in addition to EGAT. The law recognised IPPs, allowing them to sell electricity under Power Purchase Agreements (PPA) or directly to users located nearby, without touching EGAT's monopoly for electricity transmission. By 1997 EGAT had signed seven

[20] Nomenclature is not clear. In some documents the act is translated as "National Energy Policy Council Act".
[21] NEPO later on was renamed to EPPO (Energy Policy and Planning Office).

contracts with IPP's for a total of 6,000 MW of power[22], all of them were gas generated power stations. With the introduction of the SPP program (Small Power Producer), also in 1992, the NEPO also integrated for the first time electricity generated by non-conventional energy resources into the power mix, and opened therefore a market for renewable energy technologies. SPPs, just as the IPPs, could sell the electricity to EGAT, initially to a maximum allowed capacity of 60 MW, but this was later increased to 90 MW. The purchasing price was determined by EGAT on the basis of the costs it thereby avoided. By April 2002 EGAT had signed 60 Power Purchase Agreements for SPPs. However the procedure during the first years was not without controversy: "The SPP programme created significant interest on the part of small co-generation and renewable producers, but many ultimately complained of unfair treatment by EGAT and PEA. There were complaints that SPP licenses were granted predominantly to large industrial power customers, but were denied to many potential power producers (hospitals, shopping malls universities…)."[23]

However, the restructuring of the Thai energy sector had set-up the basis for the development of alternative energy technologies.

Owing to unattractive tariffs and costly interconnection requirements, the actual usage of renewable energy resources remained limited to bagasse, rice husk and woodchips until 2001. In 2001, the government reacted to this situation by introducing the VSPP (Very Small Power Producer) program, whose aim was to increase the volume of electricity generated from renewable energy resources. This proved to be a success, as the installed capacity for VSPPs, which had been limited to 1 MW under the original plan, was raised in 2006 to 10 MW.[24] The strength of the VSPP program was, that it offered less complicated power purchase arrangements for net metering and, for the first time, an additional "Adder" programme[25]. This produces an increase of approximately 5% over the normal tariff.

Nevertheless in comparison to the overall energy consumption the gains of the program were rather small. It took four more years, until 2006, for a remarkable expansion of the renewable sector. According Amranand, former energy minister of Thailand, this was due to political infighting in the first four years after the foundation of the Ministry of Energy in 2002. These were concerning the future direction of the liberalization process. Following the part-

[22] c.f. Greacen, " Thailand's Electricity Reforms: Privatization of Benefits and Socialization of Costs and Risks", 2004, p. 522
[23] ibid. Greacen, 2004, p.523
[24] c.f. Greacen: "Power Sector in Thailand: from problematic planning and governance to feed-in tariffs", 2011 Palang Thai, presentation held in Vientienne, Laos, March 2011
[25] Adder = term for compensation for renewable energy electricity in Thailand

privatization of the generation sector, plans were made to introduce a power pool, in which electricity would be bought and sold on a spot market with market clearing price bidding. In October 2002 the Cabinet approved plans to unbundle the generation, transmission and distribution of electricity so as to create competition in the power sector. EGAT, PEA and MEA were to be split into separate companies and the bulk of their assets sold off to private investors. But these plans were dropped after a change in government and resistance from EGAT. In March 2006 the Supreme Administrative Court even cancelled two royal decrees that privatized EGAT. The growth of the renewable energy sector was held up too: "Despite the broad government policy to promote renewable energy, the new policy of introducing Renewable Portfolio Standards (RPS) never got off the ground as the MoE spent the next 4 years drafting RPS guidelines which were never completed, while the SPP program came to a near complete standstill."[26]

The set-up of renewable energy development targets

With rising oil prices, global warming and a new government, investments in co-generation projects were able to start again in 2006, for the first time since 1998. The implementation of the Energy Industry Act in 2007, focusing on the promotion of renewable energies, brought in a new policy to foster the alternative energy sector. This is still in force today. In 2009 the Cabinet approved the fifteen year Renewable Energy Development Plan 2008 – 2022 (REDP), which sets development goals for renewable energies. Its original aim was to increase the share of renewable energies to 20.3% of total final energy consumption by 2022. The renewable energy generation target was set at 6% of total power generation. In June 2012 the National Energy Policy Committee (NEPC) approved the final revision of the REDP, increasing the target for renewable energy consumption to 25% by 2022. With the exception of small hydro power and MSW, the targets for all other renewable energy sources have been increased, most significantly by about 400% for solar energy generation (from its original 500 MW to 2000 MW) and for biogas generation from 120 to 600 MW - a 500% increase. The following table gives an overview on the currently installed capacity for power generation and the targets before and after the final revision.

[26] Amranand: "Alternative Energy, cogeneration and distributed generation: Crucial strategy for sustainability of Thailand's energy sector", 2008

Table 1: Current capacity of alternative energy power generation, and targets before and after the final revision of the Alternative Energy Development Plan

	Current capacity in MW	Target 2012-2021 before revision in 6/2012, in MW	Target 2012-2012 after revision in 6/2012, in MW
Solar power	150	500	2000
Wind power	7	800	1200
Biomass	1751	3700	4900
Biogas	138	120	600
MSW	13	160	160
Small hydro	86	324	324

Sources: EGAT: "Summary of Thailand Power Development Plan", 2010; Ketjoy: "The solar power market development", 2012

Incentives for Renewable Energies

A range of incentives has now been set up by the Ministry of Energy and Ministry of Industry to promote renewable energy development. The MoE has supported renewable energy projects through the Adder incentive since 2007. This is an additional energy purchasing surcharge, levied on the top of the normal price, which is provided for periods between 7 and 10 years. The following table gives an overview to Adder rates and the timescales allowed for the different renewable energy technologies.

Table 2: Adder rates

Technology	Adder rate 2010 in THB/kWh	Special Adder for Diesel replacement in THB/kWh	Special Adder for three southernmost provinces in THB/kWh	Support duration (years)
Biomass and Biogas				
<= 1MW	0.5	1.0	1.0	7.0
> 1 MW	0.3	1.0	1.0	7.0
Waste				
Landfill or digestion process	2.5	1.0	1.0	7.0
Thermal process	3.5	1.0	1.0	7.0
Wind				
<= 50 kW	4.5	1.5	1.5	10.0
> 50 kW	3.5	1.5	1.5	10.0
Micro hydro				
50 - <=200 kW	0.8	1.0	1.0	7.0
< 50 kW	1.5	1.0	1.0	7.0
Solar	6.5	1.5	1.5	10.0

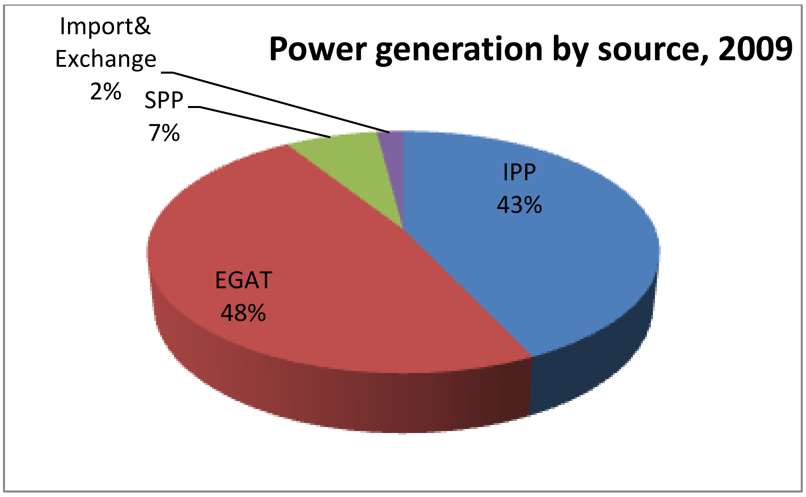
Source: Tanpipat: "Thailand PV Status Report 2011", 2012, p.11

The Energy Conservation Promotion Fund (ENCON Fund), established under the Energy Conservation Act in 1992 and administered by the NEPC, is another of the MoE's incentive schemes that aims to provide financial support for renewable energies. The ENCON Fund is a revolving fund consisting of 7,000 million THB from the Ministry and 7,000 million THB provided by commercial banks, at interested rates fixed at or below 4% for a loan period of 7 years. The idea is to encourage the creation of larger lending programs by banks at affordable rates by means of the revolving fund. Further, private investment is being encouraged through the Energy Service Companies Venture Capital Fund (ESCO Fund). Through this fund a total of 1,000 million THB is being made available to projects, though not to exceed 50 million THB per project. Projects are assisted through loans at a 4% interest rate, venture capital, support for equipment leasing and technical support. The Ministry of Energy also provides grants for design, consultancy and as partial investments in biogas, municipal waste and solar water heating projects.

Also, the Board of Investment – a board under the Ministry of Industry which assists in the formulation and implementation of investment promotion policies - has implemented a range of investor's incentives. These include an exemption for import duty on machinery, an 8-year corporate income tax exemption, and an additional 50% reduction in corporate income tax for a 5-year period (across years 9 – 13 of the project).

About 50% of total power is now generated by IPPs and SPPs. In 2010 EGAT bought 2,731 GWh from SPPs and 10,035 GWh from IPPs. The following chart displays the individual market shares of EGAT, SPPs and IPPs in current Thai power production. (VSPPs are not pictured, as their share is less than 1%.)

Figure 8: Power generation in Thailand by source, 2009



Data source: EPPO "Energy Statistics of Thailand", 2009, own graphic

1.3 Bioenergy

Bioenergy is the most important renewable energy source in Thailand today. It is estimated that about 60 million tons of biomass resource - such as agricultural waste, wood, animal dung, garbage and sewage - are produced each year[27]. A calculation by Prasetsan and Saijakulnukit[28] estimated the total energy potential of biomass to be 475.4 PJ in 1997[29]. Since then estimates of the biomass potential have varied widely in different studies[30]. Because of the advanced development of the Thai bioenergy sector, it is seen as one of the most important areas to be further exploited in the search to find a balance between food security and an ecological and economic use of feedstock for bioenergy production.

As an agro-industrial country, Thailand possesses a wide range of biomass resources. Major sources are sugar cane, rice, oil palm, wood waste and other agro-industrial wastes. Thai sugar cane production averages approximately 57 million tons annually.[31] Sugar cane is harvested once a year. The stem of the cane is separated from the rest of the plant during harvesting and later used for the extraction of sugar cane juice. The foliage of the plant, such as the leaf and shoots, are used as animal food, for manure or are left on the fields. When used as biomass, they provide a calorific value of approximately 16 MJ/kg[32],[33]. But also the bagasse, a waste material of sugar cane processing, can be converted into energy. Its calorific value is approximately 17 MJ/kg[34]. Each hectare of a sugar cane field provides 19 tons of biomass (bagasse plus plant foliage)[35].

Rice is one of the most important agricultural products in Southeast Asia. In Thailand the average annual value of paddy production is about 25 million tons.[36] It can be harvested 2 to 3 times per year. Only the grain is used for food production. While the rice straw is often left on the fields, the husks are likely to be used as fertiliser or for the production of cement. Both rice husks and rice straw have a calorific value of 16 MJ/kg[37]. One disadvantage of this is the increased effort of

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[27] c.f. Thepent: "Agricultural engineering and technology for food security and sustainable agriculture in Thailand", 2009

[28] c.f. Prasetsan, Saijakulnukit: "Biomass and biogas energy in Thailand: potential, opportunity and barriers", 2006

[29] The calculation includes agricultural residues, new plantation, animal waste, MSW, industrial waste water, black liquor and palm oil effluent.

[30] c.f. Barz: "Agricultural Residues as Promising Biofuels for Biomass Power Generation in Thailand", 2011

[31] c.f. Papong et al.: "Overview of Biomass Utilization in Thailand", n.d.

[32] Hard coal has a calorific value of 29 MJ/kg.

[33] c.f. Kober: Barrieren für die Nutzung erneuerbarer Energien zur Elektrizitätserzeugung in Schwellen- und Entwicklungsländern am Beispiel der Biomassenutzung in Südostasien, 2005, p.12

[34] ibid., c.f. Kober, 2005, p. 12

[35] ibid., c.f. Papong et al., n.d.

[36] Ibid, c.f. Papong et al. n.d.

[37] ibid., c.f. Kober, 2005, p.12

collecting the rice straw from the fields, resulting in additional transportation costs and effort for crushing the straw. Currently, about 17 million tons of bagasse and rice husks are utilized as fuel for industrial heating and power.[38]

Oil palm production in Thailand has an annual value of approximately 3.6 million tons per year.[39] Residues from palm oil extraction offer another important resource for energy generation through biomass. Fibres, hulls and pulp have all a high calorific value of 20 MJ/kg[40]. Against this must be offset the effort required to crush the hulls and the competing uses for the fibres in the textile industry.

The following table, taken by Papong, presents a possible way of classifying these residues, giving some examples for each :

Table 3: Classification of the most common biomass resources in Thailand

Agricultural crops	Agricultural residues	Wood and wood residues	Waste streams
Sugar cane	Rice straw from rice fields	Fast growing trees	Rice husk from rice mills
Cassava	Cassava rhizome from tapioca fields	Waste from wood mills	Molasses and bagasse from sugar refineries
Corn	Corn cobs from corn fields	Waste from pulp and paper mills	Residues from palm oil extraction
			Municipal solid waste

Source: Papong et al., n.d.

Biomass energy in Thailand is consumed in the residential and commercial sectors (approximately 56%) and in the manufacturing sector (about 44%), to produce heat, steam and electricity[41]. In the manufacturing sector the four biggest consumers of biomass energy are the food and beverage, non-metallic, chemical, and wood and furniture sectors. In particular the food and beverage industry uses the residues from processed raw materials for its own energy generation. Examples here are sugar mills, which use bagasse as fuel for production of thermal energy for the distillation process, or the steam produced during bagasse combustion to generate electricity in steam turbines. Rice mills use the rice husks as a fuel for drying the paddy or for further processing such as parboiling. In oil palm mills the fibre and shells are used as fuel for producing thermal energy used during the sterilization of the bunches of fresh fruit.[42]

[38] c.f. Thepent: "Agricultural Engineering and Technology for Food Security and Sustainable Agriculture in Thailand", 2009
[39] ibid , c.f. Papong et al., n.d.
[40] ibid., c.f. Kober, 2005, p.12
[41] ibid., c.f. Papong et al, n.d.
[42] Ibid, c.f. Papong et al., n.d.

The main biomass technologies used are gasification, combustion, pyrolysis and anaerobic digestion[43]. The biomass conversion technologies in use are one major constraint on biomass power generation. According to Thepent: “Most of the existing technologies employed in Thai industries are traditional technologies which have been used for a long time without any technological barrier. (…) State-of-the-art technologies which are considered more efficient and environmentally friendly than the traditional technologies are currently available in the market, with minimal development barriers, although its uptake is still limited to a few industries.”[44] Thailand’s manufacturers would need support in the development of high-efficiency biomass systems. To date, high-efficiency, high-pressure boilers, turbines and other power components are mainly still imported from Europe and Japan. Other constraints on biomass utilization are: collection of resources (e.g. plant residues after the harvest); biomass characteristics; availability of land for planting; crop patterns; transportation and storage.

Biogas

Thailand has a broad variety of feedstock to generate biogas. Their huge potential has been demonstrated by, for example, a study by the Joint Graduate School of Energy and Environment. In this, they conducted an evaluation of the biogas feedstock, the results of which are displayed in the following table:

Table 4: Available biogas feedstock in Thailand

Feedstock	Available amount per year
Cow manure	9.2 million tons
Pig manure	1.3 million tons
Agro industrial waste water from cassava starch	34.4 million m^3
Agro industrial waste water from crude palm oil	2.5 million m^3
Agro industrial waste water from ethanol	5.9 million m^3
Agro industrial waste water from canned tuna	18.8 million m^3
Agro industrial waste water from canned pineapple	4.8 million m^3
Agro industrial waste water from sugar	7.9 million m^3
Agro industrial waste water from slaughterhouses	2.1 million m^3
Cassava pulp	3.9 million tons
Municipal solid waste	15.3 million tons

Source: Chaiprasert: “ Biogas production from agricultural wastes in Thailand, 2011, p. 63-65

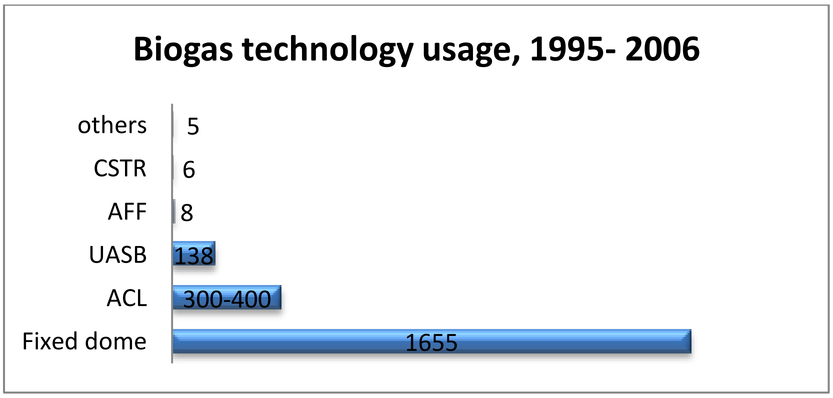
Different biogas technologies are involved according the feedstock used[45]. For animal manure the technologies mainly used are: Fixed Dome, Anaerobic Sludge Blanket (UASB) and Anaerobic Covered Lagoon (ACL). The technologies used for processing waste water from the agro

[43] Ibid, c.f. Papong et al., n.d.
[44] ibid. Thepent, 2009
[45] Ibid, c.f. Chaiprasert, 2011

industries are: UASB, Anaerobic Fixed Film (AFF), Completely Stirred Tank Reactor (CSTR), Anaerobic Baffle Reactor (ABR), ACL and Anaerobic Hybrid Reactors. CSTR reactors are usually used for the digestion of municipal solid waste.

Siteur classifies the development of the biogas usage in the country in three major phases.[46] The first phase for biogas generation reaches as far back as the 1950's, when the technology was introduced by the main agricultural university, Kasetsart University, to generate biogas from livestock. Initiated by the Ministry of Health, during the 1960's, house-hold size demonstration plants were installed aiming at the hygienic disposal of animal manure. Other promotion programmes had been started after the oil crisis in the 1970's and 1980's with the involvement of the National Energy Administration (NEA) and the Department of Agricultural Extension (DAE). As a result, in 1988 5500 small-scale plants with a digester size between 4 to 6 m^3 were installed. Nevertheless, these initiatives are controversial, according Siteur 60% of these plants never operated. In 1988 a common programme between GTZ, DAE and Chiang Mai University was launched, called the Thai-German Biogas Programme, constructing biogas system of various sizes until 1996. In 1995 also NEPO stepped in and launched the National Biogas Dissemination Programme for medium- and large scale livestock farms. Between 1995 and 2006, 2,300 plants were installed, most of them small scale (1,655). Fixed Dome, ACL and UASB were the most widely used technologies:

Figure 9: Biogas technology usage, 1995- 2006



Figures from: Chaiprasert: "Biogas generation and utilization in Thailand", 2007, BITEC, own graphic

The programmes by GTZ and NEPO are considered as the kickoff for the further development of the biogas sector in the agricultural industry, marking the second phase: "The livestock programs were helpful in developing the technical capacity among agriculture, academic and government sectors and in setting the stage for later development in industry."[47] The industry began to take

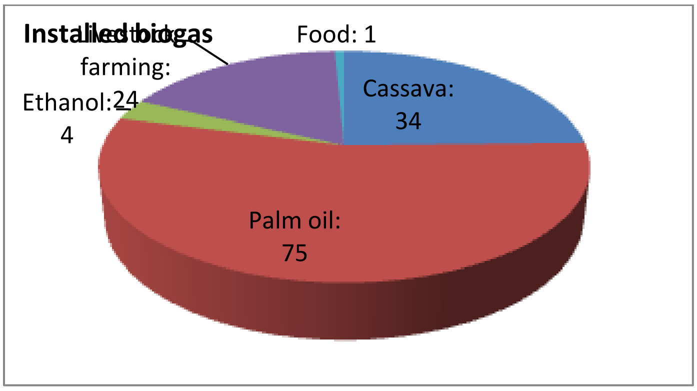
[46] c.f. Siteur: "Rapid development of industrial biogas in Thailand", 2012
[47] ibid. Siteur, 2012

up biogas technologies around the year 2000, particularly the tapioca starch mills. High energy costs for their production processes and large amounts of organic waste waster made them a suitable target for the introduction of biogas technology. This development was supported by EPPO with subsidies for investment costs. On the beginning, the factories were still hesitant, until the installation of Khorat Waste To Energy project (KWTE).

This first fully commercially financed industrial biogas plant was considered a success and marked a turning point for the whole sector, initiating the third phase which started in 2004. This phase is characterized by a rapid development of industrial biogas applications. For starch production, in only 7 years 50 starch mills (out of total 77 medium-to-large-scale plants) installed a biogas plant. This sector was followed by palm oil mills. According Siteur, by 2012 most of the 60 medium to large scale palm oil mills had a biogas plant installed.

The installed capacity today is 137.98 MW[48]. As described above, major raw material sources are waste water from the agro industries and agro-processing factories that use cassava food waste, palm oil waste and animal slurries. According a presentation from the Department of Alternative Energy Development and Efficiency, more than half of the currently installed capacity uses palm oil waste as feedstock, followed by plants which use cassava as feedstock:

Figure 10: Installed biogas power plant capacity in MW, 2010



Figures from: Sinsukprasert: "Thailand Biomass and Waste to Energy", 2012, own graphic

The target for the installed capacity by 2021 fixed in the Alternative Energy Development Plan (AEDP) has just been increased from 120 MW to 600 MW. The figure cited above from Sinsukprasert shows that the original target has been reached already in 2012. But according an information from Siteur, since the end of 2011 no more new VSPP applications are accepted and the government is developing an alternative mechanism.[49] We have also seen, that many medium to large scale agro-industrial productions, particularly in the cassava and palm oil sector,

[48] c.f. Sinsukprasert: "Thailand Biomass and Waste to Energy Overview", 2012
[49] ibid., c.f. Siteur, 2012

have already a biogas plant installed. Therefore we suppose, that the future development to reach the 600 MW target will be in the exploitation of new feedstock and biogas plant development at small scale agro-industrial production sites. Regarding the feedstock, there can already be observed new trends. For example, the generation of biogas by the rubber industry with concentrated latex as feedstock has been introduced. In addition, a number of new plants have been built which are able to digest food waste. Between 2008 and 2012, in total 220 bio-digesters for food waste were built, producing 1,320,000 m³ of biogas per day[50]. Furthermore, energy crops, solid waste and compressed biomethane gas will be important areas of focus.[51]. Research and development for small-scale applications is promoted e.g. by the Biogas Center of Chiang Mai University. The university's Biogas Center carries out research into biogas digester design, focusing on the development of simpler and more efficient digesters that are affordable also for smaller agricultural farms. Since 2008, the Chiang Mai University Channel Digester is the most frequently used biogas technology for animal waste streams[52].

Summary

Thailand is currently struggling to stabilize its energy situation, which is characterized by high dependence on neighbouring countries for energy, inconsistent growth of energy demand and a partly liberalised energy market. The country faces now a double-edged challenge: On the one hand, the country has to ensure a *sustained* growth of energy generating capacities at an affordable price. "The challenge for the Thai economy in the coming decades will be how to cope with highly volatile commodity/energy prices and a sustained rising trend that will push up the cost of raw materials and a cost of living for all Thais."[53] On the other hand, Thailand also has to ensure the *sustainable* growth of its installed capacity, one that must take into account a green energy supply associated with a transparent and fair policy: "A lack of public trust that the benefits of [economic] development will be equally shared and that the costs of environmental degradation will be fairly borne is a key development dilemma that needs to be addressed in order for the country to move on a sustainable growth path."[54] Renewable energies could play an important role in overcoming this challenge. Renewable energy resources, particularly bioenergy, have already been exploited to some extent over the last decades and their further promotion is also on the political agenda for the next years. Nevertheless, incoherencies in the political strategy show that a precise determination of the role they will have to play is not yet finalized.

[50] ibid., c.f. Sawasdeenarunat, 2012
[51] ibid., c.f. Sawasdeenarunat, 2012
[52] c.f. Sawasdeenarunat: „Overview of biogas power projects in Thailand", 2012
[53] ibid. Suwanaporn, 2012
[54] World Bank Group: "Thailand: Clean Energy for Green Low-Carbon Growth", 2011, p. 9

2. Specification of the objective

The previous chapter has illustrated how the Thai biogas market has already exhibited strong growth. A large number of biogas plants have already been built, and there still remains an untapped potential. The aim of the GIZ is to gain an understanding as to whether biogas plants in Thailand are operated effectively from an economic viewpoint – i.e. whether they are "bankable". For this, the IRR of biogas plants was to be investigated.

IRR is an important parameter in indicating the performance of biogas plants, particularly for the investor or plant owner. However, consideration must be given as to whether the analysis of the IRR or the economic performance alone represents a sufficient criterion for the evaluation of a plant's economic success. According to Djatkov: "Although economic performance may be satisfactory, there is a chance to improve other aspects that directly or indirectly influence the economic performance and achieve even greater profit.(…) All these lead to the conclusion that it is necessary to assess overall efficiency of biogas plants."[55]

Furthermore, it must be remembered that there are several stakeholders involved in a plant apart from the bank or investor. For the others, different parameters besides IRR may provide a better indication of efficiency or bankability. For this study it has not been specified which stakeholder's perspective of economic viability should be evaluated and, depending on the stakeholder's perspective used, the term effectiveness might have to be extended to include social or environmental impact too. Therefore we will have to find a definition for the term "bankability" that goes beyond typical financial indicators and takes into account different stakeholders' perspectives and interests.

We can now define the objective of this paper as follows:
a) Finding a suitable definition for the term "bankability".
b) Developing an assessment scheme with a catalogue of criteria for the evaluation of biogas plant.
c) Developing an instrument for data collection and data acquisition.
d) Undertaking data acquisition.
e) Evaluating and identifying the hurdles that the Thai biogas sector must overcome for its further growth.

[55] Djatkov et al.: "New method for assessing the performance of agricultural biogas plants", 2012

3. Assessment of a biogas plant from a focus on financial viability: preliminary considerations

3.1 Multi-stakeholder perspectives on "bankability"

From an investor's perspective the term "bankability" refers simply to cash flows and financial parameters calculated from cash flows – to quote the Business Dictionary: "A project or proposal that has sufficient collateral, future cash flow, and high probability of success, to be acceptable to institutional lenders for financing."[56] However, recent approaches break up the narrow understanding of bankability by integrating other stakeholders' perspectives on business success: "Bankability can be seen as a multidimensional construct based on legal, technical and economic project requirements. Moreover, bankability has different meanings and business impacts for various stakeholders."[57] By working with this broadened definition of bankability in the following analysis we can investigate which other stakeholders should be taken into consideration and which parameters besides typical financial figures based on cash-flows can be used to describe the performance of biogas plants.

The stakeholders taken into consideration for our analysis include manufacturers, investors, service providers (e.g. companies who provide operation and maintenance service), project developers, residents in the neighbourhood of a plant or energy consumers. We found a variety of criteria for bankability for the first four mentioned stakeholders in the report "The Myth of Bankability" by the University of St.Gallen. In the following paragraphs we will assess the most relevant criteria for each stakeholder (however this is by no means a complete analysis).

Bankability for manufacturers of technical components means that both a company's products as well as the company itself have to be acceptable to banks and project developers. This means they have to substantiate the long-term reliability of their products or technologies. To turn the argument on its head, it means that durable and stable functioning of a manufacturer's technology will increase trust in them and hence their acceptability. Further, certification of products and the extent of the guarantee provisions can increase a product's acceptability and thereby contribute to a project's bankability.

Incentives for investors to finance a biogas project can be found in both the micro-and macro-economic environment of a plant. Regarding the macro-economic environment, "critical issues

[56] "Business dictionary", n.d.
[57] Hampl et al.: "Bankability – From Myth to Management", 2011, p.11

are uncertainties related to the reliability of specific renewable energy policy frameworks."[58] Therefore the stability of the market stimulation as set by the policy framework, such as tax incentives or Adder rates, forms an important criterion for a project's bankability. "Above all, the local legal environment needs to be as reliable as possible."[59] According the study, other parameters which are paramount for investors are the experience and financial strength of project partners, stable cash-flows and confidence in the experience and performance of the technology.

It is in the interest of service providers that a biogas plant provides assured energy yields and economic return. Therefore the reliability of the technology, correct dimensioning of the plant and sufficient expertise to ensure its effective operation are relevant criteria. The characteristics of the location can also contribute to the bankability from a service provider's perspective.

Project developers have to face a dual challenge: "to develop projects that are accepted by both lenders and investors equally, and further contribute to their own track record."[60] The issues for project developers mentioned in the study are project size, financial soundness, integration along the industry value chain, partnerships with component manufacturers, relationships with banks, liabilities and guarantees for technical components and guarantees for the performance ratio.

Residents or energy consumers need to secure energy supplies at an affordable price. Residents also have an interest that the technology used is safe , which is especially the case for biogas plants as they can be potentially hazardous (risk of explosion at the plant). Another benefit that a biogas plant can bring is odour reduction from feedstock such as manure.

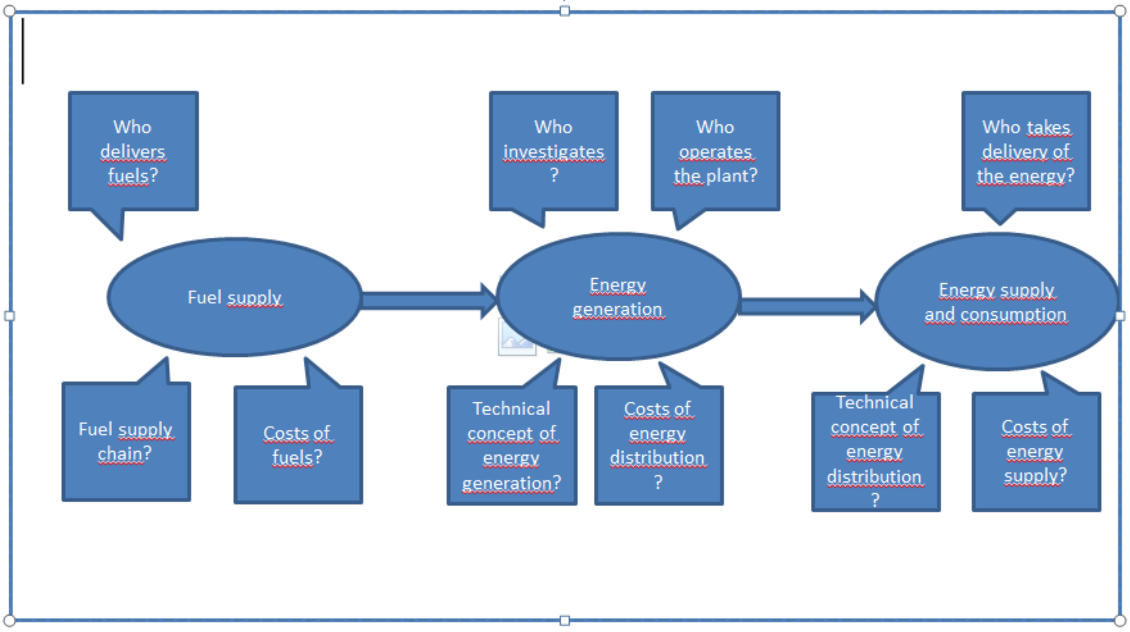
3.2 Multi-dimensional perspective: Consideration of the entire system

Given that different stakeholders come into play at different points of a biogas-plant value chain, we have to examine the overall system in which a plant is planned, constructed and operated. The German technical agency for sustainable raw materials (Fachagentur für Nachwachsende Rohstoffe) reports: "Especially for biogas plants it is important to look at the whole system, from the crop/waste used as fuel (including any necessary processing and its transport to the plant), through the power generation plant itself, to the power distribution to the consumer".[61] All elements in this chain should be examined to the same level of detail. Often the focus only takes

[58] ibid. Hampl et al., 2011, p. 12
[59] ibid. Hampl et al., 2011, p. 12
[60] ibid. Hampl et al., 2011, p. 14
[61] Fachagentur Nachwachsende Rohstoffe e.V.: Leitfaden Bioenergie: Planung, Betrieb und Wirtschaftlichkeit, 2007, p. 272

in the technical details, which can lead to drastic errors in project design. The following diagram, borrowed from Fichtner gives an overview to all essential process steps, from the procurement of raw materials through to power consumption that must be included in an evaluation.

Figure 11: Consideration of the overall system for bioenergy projects



Source: Fachagentur für Nachwachsende Rohstoffe e.V.: Leitfaden Bioenergie: Planung Betrieb und Wirtschaftlichkeit, 2007, p.273

3.3 Literature review and our approach

In many cases, evaluations are made from just one particular perspective (e.g. the view of the biogas plant owners, financing institutions or the economic analysis of a country's energy sector) and only take one element in the value chain above into consideration. Djatkov comments: "Assessment of overall performance of biogas plants has been seldom reported."[62] During a literature review we have found some initial examples of a multi-stakeholder approach. In the study on new methods for assessing the performance of agricultural biogas plants, Djatkov et al. have developed a methodology for assessing, comparing and improving the performance of selected biogas plants in Germany.[63] Their assessment on the performance of biogas plants examines the plant from four aspects: biogas production, biogas utilization, environmental impact and socio-economic efficiency. For each aspect they have determined two performance criteria. The evaluation is based on fuzzy set theory and fuzzy mathematics.

[62] ibid. Djatkov et al., 2012, p. 105
[63] ibid., c.f. Djatkov et al., 2012, p. 105

Andreas Möller has developed a quality standard for planning, operating and maintaining biogas plants in his dissertation.[64] Möller criticises the shortcomings of many biogas plants during planning, construction and operation; he attributes the cause to management defaults. Therefore he has developed a quality management system that can be used as a standard not only for plant operators and owners but also for other stakeholders. "This certification should give the involved stakeholders - from the financial and insurance sectors, the end-consumers of electricity, water and gas to the technical authorities and investors - a reliable indicator of good management and good practice in the organisation."[65] In his study he has developed various checklists which can be applied by the different stakeholders in the different stages of the life cycle.

A similar approach was developed by the Austrian Ministry of Technology as part of its initiative "Energy systems for the future"[66]. They developed an evaluation system for assessing the performance of biogas plants according to a variety of criteria. "The aim of this 'Biogas seal of approval' should be, on the one hand to give electricity consumers, district authorities or investors positive indications about the quality of the overall process, and on the other hand to show the plant operators to be particularly trustworthy providers of green power."[67] For the assessment they listed around 400 parameters which can be used to characterise biogas plant, including technical-functional, economic, socio-economic and ecological aspects. The criteria are assessed using a mathematical algorithm (data envelopment analysis).

The Intelligent Energy Europe initiative "biores" developed a Decision Support System methodology based on Multi-Criteria Decision Analysis (MCDA) to compare different investment options for small-scale biogas applications on six European islands.[68] An MCDA system aims to support decision makers who are faced with having to make a large number of conflicting evaluations, by ranking a number of strategies (actions or alternatives) through a number of criteria (attributes or aspects). The MCDA methodology developed by the biores initiative evaluates biogas systems by means of social, economic, environmental and non-technical indices. "MCDA tools are particularly valuable in situations where criteria are especially hard to measure and quantify due to limited, dissimilar or disperse information, different levels of expertise and interests. This is particularly the case when systematic derivation of informed decisions might require a large number of participants – as is often the case in decisions on

[64] cf. Möller: Entwicklung eines Qualitätsstandards für Planung und Betrieb von Biomethananlagen zur Verbesserung der Prozessabläufe, Funktionssicherheit, Effektivität und Wirtschaftlichkeit, 2008, p.6
[65] ibid., c.f. Möller, 2008, p. 6
[66] c.f. Braun: Aufbau eines Bewertungssystems für Biogasanlagen – „Gütesiegel Biogas", 2007, p.7
[67] ibid, c.f. Braun, 2007, p. 7
[68] c.f. Venetis et al.: Decision Support Methodology including requirements and specifications of the DSS, 2009

bioenergy systems."[69] Further, Braun expects the DSS tool to assist broad participation of stakeholders while maximizing the communication of information by integrating the knowledge of local people. He concludes that therefore MCDA will support decision-makers to realize what is feasible (e.g. maximize employment or environmental benefits) at what associated costs.

Our approach

For the present evaluation of biogas plants, a suitable methodology was developed based on above cited approaches. Therefore we have identified four main **categories** that are crucial for the success of renewable energy projects from different stakeholders' perspectives (operational functionality / technical functionality / socio-economic functionality / financial performance). Then a set of **criteria** was established to define the four categories, based on these approaches. However, in contrast to those studies, one requirement of the present evaluation is that it must be undertaken by a single person. Therefore, for example, an assessment of the 400 or more criteria needed to produce a complete assessment was not possible. To identify a limited number of key criterias that characterize biogas plants, so allowing a comprehensive evaluation of them, typical guidelines used by different stakeholders in the process of planning, designing or evaluating biogas plants were analysed first. These included feasibility studies, guidance for project managers of bioenergy projects, studies on risk assessment, economic analyses and CDM reports. The parameters identified in the referenced studies were either quantified according to one of the four main categories or, if this was not possible, then qualified.

3.4 Measures for financial assessment

IRR has been chosen as the main criteria for assessing financial viability. Nevertheless, to assess the financial performance of projects in general and biogas projects in particular, different measures can be applied. Before we develop the necessary criteria for our evaluation, in the following paragraphs we want to first present an overview of commonly used methods so as to verify whether IRR is indeed the most appropriate parameter for the purpose of this study.

Net Present Value (NPV)

The NPV is the most commonly used investment criterion. It is calculated as the difference between all discounted cash inflows and cash outflows associated with a project. "A positive NPV denotes the fact that an investment generates sufficient returns to finance the employed capital plus interest on the capital (at the defined interest rate) plus an additional surplus (increase in

[69] ibid., Braun,2007, p.10

wealth) at the amount of the NPV. NPV = 0 still means that the project can re-finance the capital employed plus interest.”[70]

Equation 1: Calculation of NPV

$$\text{NPV} = \left(\text{ci}_0 - \text{co}_0\right) + \frac{(ci_1 - co_{1)}}{(1+i)} + \frac{(ci_2 - co_{2)}}{(1+i)^2} + \cdots + \frac{(ci_t - co_t)}{(1+)^t} = \sum_{t=1}^{T} \frac{(ci_1 - co_{t)}}{(1+)^t}$$

Where: ci_t = cash inflows in period t

co_t = cash outflows in period t

i = interest rate

T = number of analysis periods

Total Life-Cycle Cost (TLCC)

TLCC is a simplified form of NPV. It takes into account the present value of all cash outflows, but ignores cash inflows. TLCC evaluates differences in cost between project alternatives over the entire life cycle of these alternatives. For each period, cash outflows are assessed and then discounted to their present value. It cannot be used to assess the absolute attractiveness of any project or investment, but it can be used to assess the relative attractiveness of several alternatives, all of which would generate the same cash inflows.

Equation 2: Calculation of TLCC

$$TLCC = \sum_{t=0}^{T} \frac{Ct}{(1+d)^n}$$

Where: Ct = cost in period t

T = number of analysis periods

n = annual discount rate

Internal Rate of Return (IRR)

The IRR usually serves as a criterion for investment decisions by defining the highest acceptable rate of interest at which a project can still serve capital and interest repayments without any additional surplus remaining for the investor. The IRR is linked directly to the NPV (Net Present Value), denoting the maximum interest rate the project can withstand to deliver an NPV (Net Present Value) of 0. By defining a “hurdle-rate” (a percentage of the return that the investor asks for) the IRR can be used for the assessment of a project’s absolute attractiveness. To assess

[70] Renewables Academy: Investment appraisal and management accounting for renewable energy projects, 2012, p. 25

relative attractiveness of various projects, the IRR of different alternatives can be compared, choosing those with the highest IRR.

Equation 3: Calculation of IRR

$$0 = NPV = \sum_{t=1}^{T} \frac{(ci_{1-}co_{t)}}{(1+)^{t}}$$

Where: ci_t = cash inflows in period t

co_t = cash outflows in period t

T = number of analysis periods

Simple Payback Period (SPB)

SPB corresponds to the period of time needed to recoup an initial investment. Up to the end of this period cash outflows will still be negative; thereafter they will become positive. SPB is useful for measuring the project risk. A longer SPB indicates a higher risk.

Equation 4: Calculation of SPB

$$(\mathrm{ci_0} - \mathrm{co_0})_1 + (\mathrm{ci_0} - \mathrm{co_0})_2 + \ldots + (\mathrm{ci_0} - \mathrm{co_0})_t = \sum_{t} (\mathrm{ci_0} - \mathrm{co_0})_t \geq co_0$$

Where: ci_0 = cash inflows in period 0

co_0 = cash outflows in period 0

t = number of analysis periods

Benefit to Cost Ratio (B/C)

The B/C ratio describes the relationship between the cumulative discounted positive cash inflows and negative cash outflows, so ascertaining whether and to what degree the benefits of a project exceed the costs. B/C ratios above 1 depict attractive investment options in absolute terms.

Equation 5: Calculation of B/C

$$B/C = \frac{PV\ (all\ benefits)}{PV\ (all\ costs)}$$

Where: PV (all benefits) = present value of all positive cash flow equivalents

PV (all costs) = present value of all negative cash flow equivalents

NPV and IRR are the most appropriate economic metrics for the purposes of this study. NPV analyses the relative viability of a project, allowing an estimate of whether one project is likely to be more profitable than another, and is preferable for comparing the viability of different options. Furthermore, NPV is also a useful measure for assessing the absolute attractiveness of a project. Every project with a NPV > 0 is absolutely attractive. It generates additional wealth for the investor and thus denotes an improvement over their current state. The IRR is closely linked with NPV; it can be used to estimate the viability of individual projects, comparing them against the market benchmark IRR. However, the IRR does not take into account different investment sizes. "An alternative might offer a higher internal rate of return, but at a much smaller initial investment. The absolute gain in wealth to the investor might still be higher with a different – bigger – alternative which offer a (slightly) lower IRR."[71] Therefore, for the purpose of comparing different alternatives, IRRs should be applied only in combination with NPVs.

SPB is an easy way to compare alternative projects. However it has the constraint that it does not take into account the time value of money, as it does not discount the cash flows. Furthermore, it ignores returns after payback. A project with a shorter SPB can still have a lower NPV when considering the entire project life. Nevertheless this method is helpful for a "first-cut" analysis of a project, indicating when a project will pay back its initial investment costs.

B/C ratio is often used to evaluate investments from a social perspective[72]. It is therefore most suitable for evaluating projects in which social costs are dominant, or projects that involve public interest. "They range from direct government investments in public works to private investments by utilities in which the impacts on the ratepayers, investors, and the environment all may have to be considered to determine if the action is appropriate."[73] Even though in renewable energy projects social costs can be an important element, as we will see later this is not the case for the plants assessed. Furthermore also B/C analyses don't consider the values of different investment sizes. Therefore they are not appropriate for this paper.

TLCC can be used for ranking alternatives, but only if they provide the same returns and benefits. As the probability that the study will examine projects with the same costs or benefits is very low, this method is not suitable for our study.

[71] ibid. Renewables Academy, 2012, p. 27
[72] c.f.: Short et al.: A manual for the economic evaluation of energy efficiency and renewable energy technologies, 1995, p. 58 ff.
[73] ibid. Short, 1995, p. 58

4. Development of a procedure for the assessment of biogas plants: categories, performance criteria, variables

4.1 Determination of categories

By “categories” we mean a limited number of general characteristics through which a variety of biogas plants can be compared. By means of these categories conclusions can then be made about the bankability of the plants, weighting them individually according the stakeholder’s perspective.

Following on from our previous considerations, the categories used for the assessment of biogas plants should meet two requirements: To conform to the initial objectives of the GIZ, the categories must reflect the financial viability or bankability of the renewable energy plants. However, taking in the wider definition of bankability as being a multidimensional construct based on legal, technical and economic project requirements, having different meanings for the various stakeholders, the categories must allow the assessment of other factors which might not have an economic character but at the same time can influence the economics of a plant.

The “Fachagentur für Nachwachsende Rohstoffe e.V.” cites 4 factors in its handbook “Biogasgewinnung und –nutzung” which are crucial to the economic viability of a biogas plant. These are[74]:

- Investment costs
- Gas yield
- Gas quality
- CHP (or the energy converter used)

For investment costs, a general rule is that bigger plants result in lower costs. The feedstock used also has a significant impact: “The lowest investment costs are achieved with simple liquid manure plant. In the most cost effective case, a fermenter with a pre-tank, including simple piping and pumps together with a small cogeneration plant is adequate. Should renewable raw materials be used, then additional peripheral equipment will be needed.“ [75] One of the most important factors influencing the gas yield is the feedstock and its quality. It is important to know at least the dry matter and organic dry matter content of the substrate so as to be able to calculate the expected gas yield properly. The concentrations of methane and hydrogen sulphide are crucial to the biogas quality. While the methane concentration determines the energetic

[74] c.f. Fachagentur Nachwachsende Rohstoffe e.V.: Handreichung: Biogasgewinnung und –nutzung, 2009, p. 189

[75] ibid. Fachagentur für Nachwachsende Rohstoffe, 2009, p. 190

value of the biogas, hydrogen sulphide may damage the plant. The efficiency of the energy conversion process will finally determine the amount of usable energy that can be generated. Here, we would like to bring out one point not mentioned in the handbook - that is the organizational structure and process management actions. As we will see later on, failures in the planning process or legal defaults can have very costly effects.

Taking these factors into consideration, we can now determine the **categories** to assess and describe the overall biogas plant performance. We have designated four categories[76]:

1) Operational functionality

The above mentioned gas yield and gas quality strongly depend on operational and process parameters during the biogas production process. The gas yield should correspond to the dimensioning of the plant and should not vary over time. The gas quality refers to its composition and therefore to its energy value. For both, the stability of the process in the fermenter is crucial. Therefore under the operational functionality category we bring together all those factors which contribute to the process stability, including the biological or chemical aspects of the feedstock and of the digestion process.

2) Technical functionality

The technology used is significant for achieving the expected performance parameters. The handbook therefore exemplifies the energy converter. In our understanding, technical functionality refers not only to the energy converter, but also to the fermenter technology and potentially to any other technical processes such as pre- and post-treatment. Problems in the functioning of the technology can result in increased cost and decreased revenue. Compared to the first category, the technical functionality category summarises those factors which contribute to the process stability from the point of view of the implemented technology and also include the planning and dimensioning process for the implemented technology.

3) Socio-economic functionality

Dictionaries define the term socio-economic as: “A branch of economics that focuses on the relationship between social behaviour and economics.”[77] The actual meaning of socio is: “mutual relations as a precondition for cohabitation”[78]. Following these denotations of the terms, for our purposes socio-economic functionality describes the relations and actions between the stakeholders, with the aim to act economically advantageous. Therefore socio-economic

[76] Djatkow (2012) uses similar categories in his approach. He also describes 4 categories: biogas production, biogas utilization, environmental impact and socio-economic efficiency. However, in the abstract of his paper we had available for the current study, no derivation of his categories was described.

[77] “Investopedia”, n.d.

[78] Prokovskii: Ecodynamics, 2012

functionality is determined by organizational structures, management actions and legal issues, since these will have a strong influence on the biogas plant performance in addition to the parameters cited above from the handbook.

4) Financial performance

The financial performance, described by the cash flows and resulting key numbers, depends on both “plant-inherent” processes and also on external factors. Investment costs as cited in the handbook are one component of the cash flows, but we consider operational costs and incomes to be equally important.

4.2 Performance criteria

In the next step we have defined **performance criteria** to describe each category. These criteria are numeric, so as to facilitate a final comparison between the assessed plants. For the first three categories we have defined two performance criteria respectively; for the financial performance category, three performance criteria. The procedure of selecting the two (or three) criteria is similar to that described by Djatkov, and allows us to have a manageable but also meaningful number of characteristic factors (in total 9) for the final comparison. Also similarly to Djatkov, we have designated the performance criteria according to pertinent performance figures of biogas plants. Some of our performance criteria are based on Djatkov[79], others we have determined according to the requirements of this study, and take into consideration the different stakeholders and the complete system. The performance criteria are described in detail below together with their associated variables.

4.3 Variables

Our third step defines relevant **variables** that influence the performance criteria. "A variable describes a characteristic or property of individuals, groups, organizations, or other entity."[80] In addition, a variable has specific 'characteristic values', which can be either continuous or discrete. The former exhibit a multitude of characteristic values, such as the energy output of a system in watt-hours. The latter exhibit only a restricted number of categories. An example here would be the presence or absence feedstock supply contracts. The variables are necessary either to calculate the performance criteria or to evaluate the calculated performance criteria and to draw further conclusions regarding their values. Without this last mentioned step, we would be able to

[79] In detail these are: the biogas quality factor, the efficiency criterion and manpower input. The first two mentioned criterias we found independently from his study, the criterion of manpower input we took from his study because of its suitability to describe the corresponding category.

[80] Diekmann: Empirische Sozialforschung, 2006, p. 100

measure the performance of the plants, but could not carry out a meaningful evaluation of the figures.

In the following chapter each category with the individual performance criteria and their variables will be described in detail.

4.4 Description of categories, performance criteria and variables

(1) Operational functionality

The most essential factors to describe the operational functionality are the quantity and quality of the biogas. Therefore we have determined the following two performance criteria: the specific biogas volume (1.1) and the biogas quality factor (1.2).[81]

The specific biogas volume refers to the quantity and describes the relationship between the fermenter size (theoretical biogas output) and the biogas output achieved in practice; this is calculated as:

Equation 6: Calculation of the specific biogas volume (1.1)

$$BV = \frac{Y_p}{Y_c}$$

Where: BV = Specific biogas volume

Yc = Theoretical biogas yield according fermenter size (m^3/day)

Yp = Actual biogas output (m^3/day)

The biogas quality factor describes the content of methane. As the methane concentration depends on the feedstock used, it can be defined by the ratio between the theoretically possible methane content of a feedstock and the practically achieved content. It is calculated as:

Equation 7: Calculation oft the biogas quality factor (1.2)

$$BQF = \frac{MC_p}{MC_c}$$

Where: BQF = Biogas quality factor

MCc = Theoretical methane concentration according to feedstock [%]

MCp = Actual methane concentration [%]

[81] Some of the terms we use to determine the performance categories might be used in other context with slightly different meanings. However, we will define the denotation of each term in connection to our assessment scheme.

The variables which influence biogas yield and biogas quality are the feedstock (1a), processes in the fermenter (1b) and operating parameters (1c).

(1a) Feedstock

The quantity and composition of the substrates have a crucial influence on the quality and quantity of the biogas produced. The energy sources for the production of biogas are fats, proteins and carbohydrates, however specific methane yield decreases in this order. Based on the mass, a higher methane yield can therefore be achieved with fats than with carbohydrates. Therefore the feedstock must be specified. The correct feedstock composition can be assessed by testing its ingredients and solid matter content. Further, to be able to forecast particular biogas yields, the ratio of dry matter and organic dry matter and their consumed volume is important for dimensioning the digester and the storage facilities. If the feedstock is contaminated, then suitable technology for pre-treatment has to be available. There are further factors connected with the feedstock such as availability, price etc., which are outlined in the other categories because they don't refer to bio-chemical factors.

(1b) Fermenter processes

The fermenter is the heart of the biogas plant, therefore the fermenter biology and processes in the fermenter have to be closely monitored to guarantee the quality and volume of generated biogas. Even small changes in the microbiology can cause interruptions to the whole digestion process, resulting in lost revenue. Should the energy yields achieved give rise to doubts, the parameters in this section are meant to aid analysis of those causes originating in the process management of the fermenter. The following lines give an overview to the parameters that determine the stability of the digestion process:

Process parameters:

Temperature

Temperature plays an important role in anaerobic digestion. The bacteria for anaerobic digestion cannot survive in psychrophilic conditions (< 25° C). Most biogas plants are operated under mesophilic conditions (32-42°), which guarantee stable processes and a relatively high gas yield. Thermophilic conditions (50-57°) are particularly suitable for substrates which need hygienisation.[82] Whatever temperature conditions are chosen, it is crucial that the average temperature is kept stable without too wide fluctuations.

[82] ibid.,c.f. Fachagentur für Nachwachsende Rohstoffe e.V, 2009, p. 26

pH value

Whereas the hydrolysing and acid producing bacteria of the first two phases of the fermentation process prefer a pH value between 4.5 and 6.3, the acetic acid and methane producing bacteria of the second phase require a pH in the neutral range – between 6.8 and 8.0. If the two phases take place in a single fermenter, the guide value for the second phase should be used, with a pH value between 6.8 and 7.5. If the pH deviates too widely, then this will impact both the gas yield as well as the gas constitution.[83]

C/N Ratio

The C/N ratio of the substrate used is important for maintaining a stable process. If the carbon concentration is too high, then full conversion will not be possible and the methane potential present will not be fully utilized. In contrast, if the nitrogen concentration is too high, then ammonia may build up, which will hinder the growth of the bacteria. The C/N ratio should lie approximately at the ratio 10:30; the C/N/P/S ratio at 600:15:5:1.[84]

Inhibitors

Too high a concentration of inhibitors will interfere with or slow down the process. Inhibitors are either introduced through the input substrate in the fermenter, or are formed during the fermentation process. Even a too high addition rate of substrate can inhibit the fermentation process. During the fermentation process ammonia can form, which in even low concentrations can have an inhibiting effect on the microorganisms. Hydrogen sulphide, even at low concentrations, can also inhibit the fermentation process, along with other negative effects such as corrosion of the components or acidification of the engine oil. The inhibitory effect of hydrogen sulphide occurs at a concentration of 50 mg/l H_2S; of ammonia from 0.15 g/l.[85]

Gas composition

Biogas is made up of several components, of which the methane content is the most important parameter. The methane content can vary between 50 and 75% by volume. The second largest component is carbon dioxide (25-45% by volume)[86]. Too high a CO_2 content "dilutes" the gas and can lead to higher costs for the gas storage. It can also be an indicator of the pH value being too low. Therefore, the CO_2 concentration should be as low as possible.

[83] ibid., c.f. Fachagentur für Nachwachsende Rohstoffe e.V., 2009, p. 27
[84] ibid., c.f. Fachagentur für Nachwachsende Rohstoffe e.V., 2009, p. 27
[85] c.f. Kaiser et al.: Sicherung der Prozessstabilität in landwirtschaftlichen Biogasanlagen, 2007, p. 10
[86] c.f. Roitsch et al.: Charakterisierung und Optimierung von NawaRo-Biogasanlagen, 2009, p. 27

(1c) Operating parameters

Volumetric loading

The volumetric load is the amount of organic dry matter that is fed into the fermenter per day and per cubic meter of net fermenter volume. If volumetric load is too high, the bacteria performance decreases and there is reduced gas production. The volumetric load should be between 2-3 kg oDM/m³ d.[87]

Hydraulic retention time

The hydraulic retention time is related to the volumetric load and is similarly an important parameter for the sizing of the fermenter. It indicates the duration that a fed substrate remains in the fermenter before being discharged. The longer the retention time, the greater the yield of gas per kilogram of dry organic solids. If the feed rate of the substrate is increased, the retention time will be reduced.

The following table summarizes the variables to be assessed for the operational functionality category:

Table 5: Variables for category of operational functionality

Variable	Description	Unit
Type of feedstock		Description
Used load per day	Specification of mass	t/day or m³/day
Feedstock characterization	Concentration of dry matter and organic dry matter	%
	Concentration of nutrient matter (N,P,K)	% DM
Gas yield	Total gas production	m³/year
Content of methane	Percentage of methane in biogas	Vol-%
Fermenter size		m³
Operating time of biogas plant		days/year
CH_4 content	Determines energy value	Vol.-%
CO_2 content	Lowers energy value	Vol.-%
Temperature	Psychrohpilic, mesophilic or thermophilic conditions	°C
pH value	Should range between 6.5 – 7.3	
C/N relation	Should be about 10:30	
H_2S	Should be < 50 mg/l	mg/l
NH_3	Should be < 0,15 mg/l	mg/l
Volumetric loading	2-3 kg oDM/m³ d	kg oDM/m³ d
Hydraulic retention time	Depends on fermenter size and volumetric loading	days

[87] ibid., c.f. Kaiser et al., 2007, p. 9

(2) Technical functionality

For the category of technical functionality, we consider the availability and efficiency of the technology used to be the most important criteria. These are described by the formulae (2.1) and (2.2) below.

The availability (2.1) describes the extent to which the biogas plant is available for operation, and herewith the reliability of the complete system. It is calculated by subtracting the hours in which the plant is out of operation owing to damage or repair per year from the total hours in a year:

Equation 8: Calculation of availability (2.1)

$$A = 8760 - H_d$$

Where: A = Availability [h]

H_d = Hours per year plant is out of operation due to damage or repair [h]

The efficiency criterion (2.2) is defined by the relationship between the efficiency of the energy converter specified by the manufacturer and the nominal performance of the plant in operation. It is calculated as:

Equation 9: Calculation of electrical efficiency (2.2)

$$E_{el} = \frac{E_p}{E_n}$$

Where: E_{el} = Electrical efficiency

E_p = Electrical efficiency of energy conversion reached in practice [%]

E_n = Nominal electrical efficiency [%]

Equation 10: Calculation of thermal efficiency (2.2)

$$E_{th} = \frac{E_{tp}}{E_{tn}}$$

Where: E_{th} = Thermal efficiency

E_{tp} = Thermal efficiency of energy converter reached in practice [%]

E_{tn} = Nominal thermal efficiency [%]

The variables used to further describe the efficiency and availability are: The characteristics of the technology (2a) and overall plant design (2b).

(2a) Characteristics of the technology

This section of the assessment looks at the components used and how they have been assembled. An initial, key factor assessed in this section is whether the plant is a turn-key facility or made up from equipment from different suppliers. "A turn-key facility usually poses a lower financial risk than a facility composed of equipment from different suppliers. This is due to the fact that should problems occur during the construction phase, having a single component provider or constructor will make it easier to deal with claims. On the other hand, a facility composed of items from different suppliers may reduce costs and increase internal labour by the plant operator, but requires also more knowledge about the biogas production process."[88] Therefore, this section aims to give an overview to the technical components used, their characteristics and the configuration as a whole. In addition the reliability of the components from different manufacturers should be assessed. In this context, the equipment guarantees and specifications play an important role. Inadequate guarantees can increase costs if components break prematurely and have to be replaced at additional cost. Additionally, the safety of the technology is currently of special interest in Thailand, owing to the number of accidents that have occurred in recent years.

(2b) Overall plant design

This section assesses the feedstock storage facilities, pre-treatment technologies, the number of fermenters, storage facilities for the digestate, cleaning technologies and also the materials used to construct the facilities and components. It addresses the underlying question of whether the whole plant configuration is suitable for the volume and consistency of the feedstock and digestate and if the planning and dimensioning had been carried out correctly in its entirety, therefore the suitability to feedstock and work-flow requirements. Feedstocks for anaerobic digestion are often available only during a certain period of the year. If inadequate storage has been secured for feedstock, the plant will not be able to operate for its calculated annual operational time or capacity, resulting in reduced power generation. Pre-treatment technology has to be available that is suited to the consistency of the feedstock used. Also post-treatment technology and storage constructions have to be available for the biogas and the digestate; these should correspond to the degree of contamination and volume of biogas and digestate.

[88] Ferber et al.: Criteria to assess biogas investments: Guidelines for financing institutes and investors, 2011, p. 9

A summary of the variables to be assessed in the category of technical functionality is given in the following table:

Table 6: Variables for categoy of technical functionality

Variable	Description	Unit
Feedstock storage facilities	Type, manufacturer	Description
	Material	Description
	Size	m^3
Pre-treatment technology	Type , manufacturer, guarantees	Description
Substrate injection	Type, manufacturer, guarantees	Description
Fermenter	Geometry, number and construction	Description
	Capacity (volume)	m^3
	Material	Description
	Manufacturer, guarantees	Description
Stirring technology	Type, manufacturer, guarantees	Description
Purification technology for biogas	Type, manufacturer, guarantees	Description
	Capacity	m^3
Efficiency of purification technology	Methane concentration before and after purification	% CH_4
Gas storage facility	Number, material	Description
	Capacity	m^3
Energy converter	Type, manufacturer, guarantees, number	Description
	Capacity	kW
Electrical or thermal efficiency	Efficiency, as indicated by manufacturer	%
Annual electricity and thermal production		kWh /year
Annual operating time of energy converter		h/year
Annual out of operation time due to damage		h/year
Annual out of operation time due to maintenance		h/year
Monitoring technology	Parameters monitored, type, manufacturer, guarantees	Description
Safety technology	Type, manufacturer, guarantees	Description

(3) Socio-economic functionality

Whilst the assessment of the technical functioning serves to describe the plant performance just from a technical point of view, the socio-economic functionality focuses instead on the human and organizational factors and, additionally, on conditions influenced by the location and the closer environment. The performance criteria for the socio-economic functionality are the manpower input (3.1) and the specific electricity costs (3.2).

The manpower input (3.1) is the relation of effort spend regarding operation and maintenance of the plant to the nominal electrical capacity, measuring the efficiency of manpower. It is calculated as the annually sum of manpower hours for operation and maintenance (h/year) divided by the nominal electrical capacity:

Equation 11: Calculation of manpower input (3.1)[89]

$$MI = \frac{MI_O + MI_M}{P_n}$$

Where: MI = Manpower input

MI_O = Manpower input for operation [h/year]

MI_M = Manpower input for maintenance [h/year]

P_n = Nominal electrical capacity [kW]

The specific electricity cost relates all the annual expenditures to the electricity produced, assuming that e.g. disadvantageous contracts with suppliers, insurances for fertilizer distribution and others will increase the annual costs:

Equation 12: Calculation of specific electricity cost (3.2)

$$Ce = \frac{C_a}{E_a}$$

Where: Ce = Specific electricity costs [Baht/kWh]

C_a = Annual costs [Baht]

E_a = Electricity produced per year [kWh]

The variables that further describe the socio-economic functionality are the expertise of the staff (which determines the relationships within the company) (3.1), a description of the external company relationships by assessing the project structure, the existing contracts, insurance and the construction process (3.2), and a description of the location and the geographical area (3.3).

[89] This criteria is taken from Djatkov (2012). He calls it "labour input".

(3a) Expertise of staff

The competence of the project developer, the plant operator, the operations staff and other service providers to properly carry out their individual process steps plays a significant role in the success of a biogas project. Biogas production requires knowledge about many different sectors: agriculture, biology and chemistry, plant technology, legal and economic issues. Faults during production can lead to underperformance, short-term interruption or even complete standstill of the equipment and result in revenue losses. So in this section, the number of years and the level of experience of the staff involved within the company will be used as a metric.

(3b) External relations: Construction process, project structure, contracts, insurances

This section assesses information regarding the quality standards used during the planning and construction process. Delays in completion or increased costs of completion, poor quality standards or underperformance with respect to the operational parameters all result in increased costs.

By verifying what kind of assessments have been undertaken before and after construction allows us to draw conclusions about how diligently the planning had been undertaken. A comparison of the planned and achieved dates for building allows us to assess any delays in construction.

Usually there are a number of different parties involved in constructing and running a biogas plant and the relationships between them are regulated in contracts. Contracts with every individual project partner define their tasks and responsibilities and lower the risk of project failure. The process of contracting with other stakeholders can be difficult to change, having a negative impact on the economic feasibility. It will be difficult to verify these contracts in detail during an assessment, nevertheless we consider it important to form a complete picture of a project through an understanding of the roles of each stakeholder and by ascertaining whether the relationship is regulated by a contract or not. If it is planned to sell the electricity and feed it into the grid, a power purchase agreement is crucial to securing the revenue stream. Usually the agreement has to be provided as part of any loan negotiations with the banks, prior to the project's initiation. For the purpose of this questionnaire the intention has been to assess if the contractual negotiations for the PPA (power purchase agreement) are likely to cause any problems or delays.

Even if the biogas plant is optimally designed and operated, unforeseeable accidents or problems can always occur. If technical, operational or contracting risks are not sufficiently covered by insurance, costs can increase or the whole project could even fail. Therefore an assessment must be made whether the most important insurance aspects are covered, such as insurance for physical damage, equipment failure and damage by fire or during construction.

(3c) Characterization of the location and geographical area

This section aims to ascertain in detail whether the location is suitable in terms of its existing infrastructure and the distances involved for transporting feedstock, water supplies, the grid connection, heat, electricity and fertilizer residues. Another issue is the transportation cost of the feedstock; the average distance the feedstock must be transported needs to be properly assessed. Using a simple rule of thumb, this should not be further than 10 km from the biogas plant, so as to keep transportation costs low. The availability of suitable feedstock is of major importance for the efficient operation of the plant. The presence of sufficient agricultural land nearby available to use the digested biomass will provide additional revenues by allowing the sale of the digested biomass as fertilizer. Poor logistics will lead to higher operational costs. Difficulties in connecting to the grid will lead to higher capital costs. In addition, the vicinity of any neighbours has to be taken into consideration. If they are too near, conflicts might arise regarding odour or other issues.

The following table resumes the variables to be assessed for the socio-economic functionality category:

Table 7: Variables for category of socio-economic functionality

Variable	Description	Unit
Construction time	Comparison of planned and achieved construction time	Dates
Commissioning	How commissioning was undertaken and its documentation	yes/no
Diligence studies (feasibility study, due diligence, legal diligence, technical diligence, financial diligence)	Availability of what kind of diligence studies	yes/no
Contracts (grid connection contract, power supply contract, digestate supply contract, feedstock delivery contract)	Availability of what kind of diligence studies of contracts	yes/no
Organizational structure	Owner, operator, financing institution, feedstock supplier	Description of duties
Insurance (physical damage, equipment failure, fire damage, accidents, general liability, construction work)	Availability of what kind of insurances	yes/no
Geographic location	Characteristics of the surroundings	Province, town
	Size of geographical area	ha
	Distance to grid connection, energy consumers, water source, feedstock supplier, digestate delivery, residential area	m, km
	Connection to public roads	yes/no
Experience of staff	Qualification	Description
	Experience in working with biogas plants	Years
Manpower for operating the plant	Total of hours per year spend for operation	h/year
Manpower for maintaining the plant	Total of hours per year spend for maintaining the plant	h/year
Annual costs		Baht/year
Electricity produced per year		kWh/year

(4) Financial performance

The financial performance criteria are the Net Present Value (NPV, 4.1), the Internal Rate of Return (IRR, 4.2) and the Simple Pay-Back Period (SPB, 4.3). For their calculation see section 3.4.

The variables needed to assess the financial performance of renewable energy plants through the NPV, IRR or SPB are: investment costs (4a), annual costs (4b) and all revenues (4c), which together determine the cash flow, as well as the financial structure (4d).

(4a) Investment costs

The investment costs include those for:

- Planning and design
- Land acquisition
- Procurement of mechanical equipment
- Plant buildings
- Construction, civil works
- Further costs such as insurance, permissions, taxes, duties, transport
- Other costs

(4b) Annual costs

Annual costs include:

- Capital costs
- Operation and maintenance
- Replacement of mechanical equipment
- Feedstock
- Auxiliary cost of materials (water, fuel, electricity) needed to operate the plant
- Administration
- Further costs such as taxes, interest…

(4c) Revenues

The benefits, or income streams for biogas plants in financial terms, are:

- The revenues from the sale of electricity, heat or fertilizer
- Where the power or heat generated is used privately: the savings of substitution of the conventional electricity, heat or fertilizer sources

(4d) Financial structure

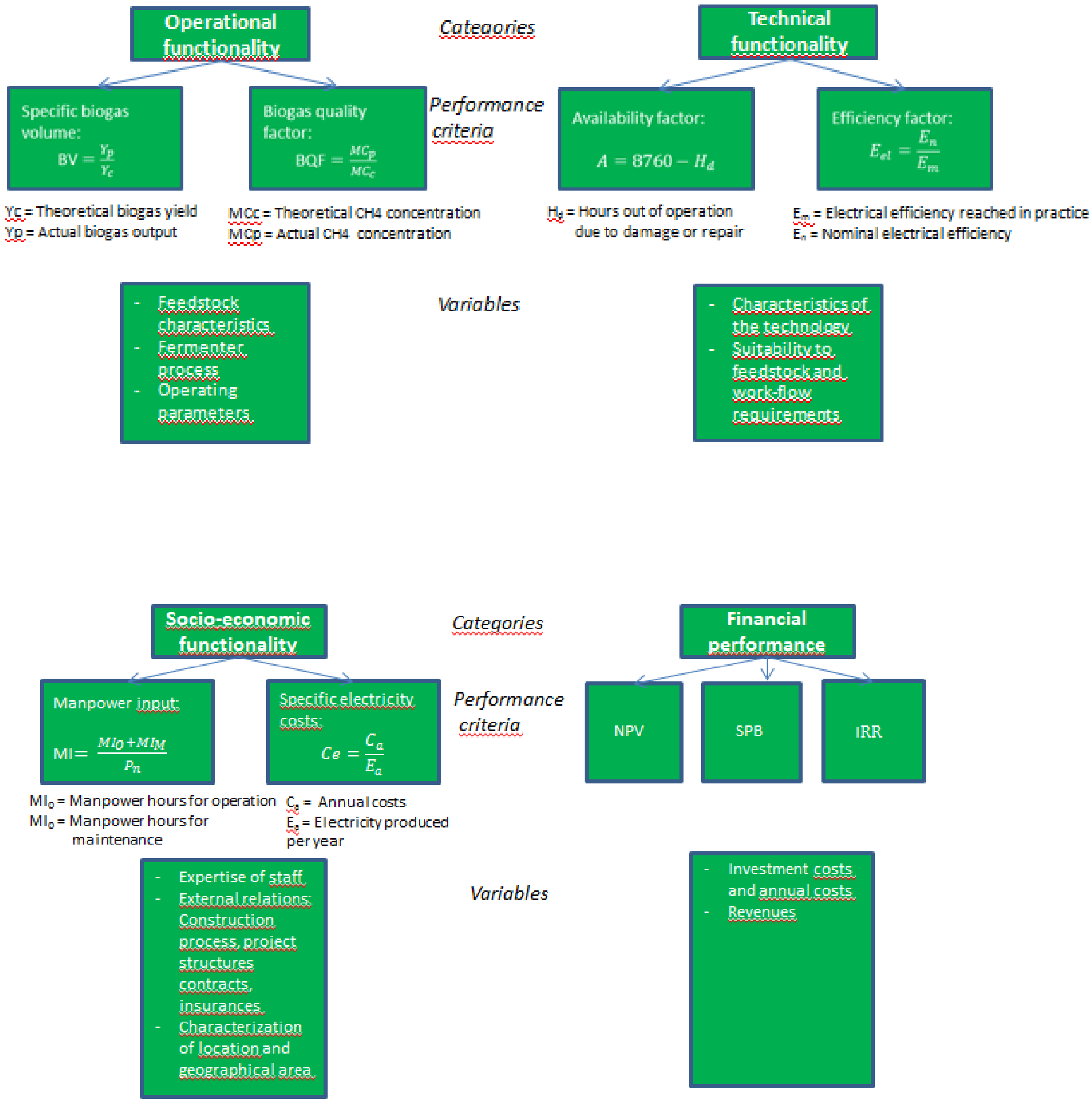
We have assumed that the financial structure (4d) will also have a strong influence on the project's financial performance. The financial structure or legal form depends on the source of the capital and the extent of personal liability of the project stakeholders.

Table 8: Variables for categoy of financial performance

Variable	Description	Unit
Investment costs	All expenditures related to building the plant (planning, equipment, construction, land, buildings, transport, insurance …)	Baht
Annual costs	All expenditures that occur annually and are necessary for operation (feedstock, work-force, operation, maintenance, repairs, taxes, interest…)	Baht
Produced electricity	Replacement of conventionally produced electricity	kWh or %
	Electricity fed into the grid or sold to other users	kWh
Produced heat	Replacement of conventionally produced heat	kWh or %
	Heat sold to other users	kWh
Produced fertilizer	Replacement of conventionally produced fertilizers	kg/month and Baht/kg
	Fertilizer sold to other users	kg/month and Baht/kg
Financial structure	Share of equity capital, debt capital or other financial sources	Baht

To summarize this chapter, we have produced a resumé of the evaluation scheme in the following graphic:

Figure 12: Overview on evaluation scheme on all four categories



4.5 Methodology for the evaluation of the performance criteria

The performance criteria relate to an ideal value, which is either an absolute or a relative term. This can not be reached in practice, but the closer the real value comes to the ideal value, the better is the performance of the plant. Furthermore they can be weighted according their relevance to different stakeholders. Nevertheless, we will give only tendencies according the weighting. To define concrete values, more intense research would be required.

Operational functionality

The criterions in these category are of particular relevance to service providers such as the operator and the investor or plant owner. It is the responsibility of the operator to take care on the variables (defined in 4.4), which will influence these criterions, by regulating the bio-chemical processes. As these criterions will determine the biogas yield and herewith also the revenues, they are of equal relevance for the investor.

- The ideal specific biogas volume equals 1.
- The further the actual specific biogas volume is below 1, the worse the performance.

- Ideal biogas quality factor equals 1.
- The further the quality is below 1, the worse the performance.

Technical functionality

Special attention on this category will be given by the manufacturer, besides the service provider or operator and investor. The criterions mainly depend on the quality of technology, developed by the manufacturer. The operator needs to control the output of the technology. And, as for the operational functionality, if the value of these criterions is too low, it will result in an decreased energy output and therefore in lowered financial returns.

- The ideal availability factor equals 8760.
- The further the actual availability is below 8760, the worse is the performance.

- The ideal electrical or thermal efficiency equals 1.
- The further the actual efficiency is below 1, the worse the performance.

Socio-economic functionality

This category will play a major role for project developers, but is also of relevance for the service provider. Furthermore, the variables can also show effect on residents close to the plant. The value of the criterions is largely influenced by the design of the plant, developed by the project developer. Also here, the service provider will have to control the outputs to eventually regulate them.

- The ideal manpower input should be low. No ideal value is given, but it can be compared relatively to other plants investigated.
- Additionally, this criterion should be compared to the availability factor. If both show a bad performance, the increased manpower effort is probably due to frequent damages

of the plant. If the availability factor shows a god performance, operational or maintenance procedures are conducted inefficiently.

- The specific electricity costs should be low.
- Besides being used to compare the specific electricity costs of different plants, this can be used to compare the electricity price with that for conventionally generated electricity.

Financial performance

This category will be mainly in the focus of the investor or plant owner, as it determines his revenues.

- The NPV should be greater than or equal to 0. If the NPV equals 0, the project can re-finance the capital employed plus interest. If the NPV is greater than 0, the project generates an additional surplus.
- In our literature search, we found a hurdle rate of the IRR for Thai biogas plants of 15%[90]. So we have set the minimum IRR to be 15%. The IRR values of different plants can also be used for comparison purposes - that with the highest IRR being the most attractive.
- The SPB should be low. When comparing the SPBs of different plants, the one with the lowest value is preferred. [91]

5. Methodology for the practical field research

5.1 Preliminary considerations regarding empirical research

For the next stage in planning the research design, we must first define what kind of research study we will have to undertake in order to produce the planned results. The social scientist Andreas Diekmann distinguishes between four different investigation typologies in empirical research[92]:

- An explorative investigation is conducted in case of an unknown research field, where no or just a few assumptions can be made. Such investigations often take the form of preliminary studies or pre-tests, which are followed by the main study. Aim of an

[90] Wongsapai: "Baseline and economics – Analysis of biogas and biomass clean development mechanism projects in Thailand, 2011

[91] For restrictions when comparing SPB or IRR of different plants, see chapter 3.4.

[92] ibid, cf. Diekmann, 2006, p. 30 et seq.

explorative investigation is to define assumptions. The research tools applied are qualitative interviews or non-structured observations, as in most cases there is not enough know-how about the topic available yet to design a structured or quantitative questionnaire.

- By means of a descriptive investigation, frequencies, shares, averages and other characteristics of (social) activities, opinions or miscellaneous variables are explored. An investigation of causations or conjunctions is blanked out by this typology of research. The most frequent use of descriptive investigations can be found in official statistics.
- A third typology is the verification of theories and hypotheses. A frequently applied tool here is the undertaking of an experiment.
- For exploring the effectiveness of practical or (social) design measures with a single or several success criteria, an evaluative investigation is used. An important element of this type of investigation is an assessment of the positive or negative side-effects of measures. "A hypothesis will be investigated, whether and to what extent measure X (or a group of measures, a project) affects the social characteristic U, V, W."[93]

This study meets the characteristics of evaluative research. The consequences (economic, environmental or social) of a project (the implementation of RE-plants) will be monitored and a cost-benefit relationship will be used to assess these.

5.2 Planning the Investigation

a) Research design: Cross-sectional design vs. trend design and panel design

The choice of cross-sectional design, trend design and panel design is made on the basis of the period of data collection involved.[94] For the purposes of this study, only a cross-sectional design (i.e. a one-off analysis of N analysis-units) is appropriate. Trend and Panel designs are surveys that are repeated at different times. Here, the time frame for the current study would not be adequate.

b) Selection of collection units

Following the recommendation of Diekmann for evaluative research, the analysis is to be undertaken on a sampled basis. "The term 'sampled' expresses in a narrow sense the examination of a population using a selected subset."[95] Depending on the biogas technologies

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[93] ibid, c.f. Diekmann,2006, p. 34
[94] ibid, c.f. Diekmann,2006, p. 267
[95] Beiner: Statistik für Sozialwissenschaftler, 1975, p. 148

and raw materials used, different total volumes can be defined for biogas plants, from which the sample can be selected. For practical reasons explained below, the accessibility to the total volume figures was, however, very limited. Therefore only a very rough selection, depending on the feedstock, was selected. The aim was to evaluate 7 plants that use agricultural residues and 7 plants that use waste streams. This automatically throws up the question of sample bias. For one thing, certain raw materials cannot be considered, which could, for example, lead to bias when evaluating the IRR. Potentially, plants could be selected by chance that indicate positive or negative trends in the IRR corresponding to better or worse characteristics of the raw materials. In addition, the response quota from uneconomical plant could be lower than that from the economically better systems. This problem cannot be solved within the scope of this study, however should be taken into account in the final evaluation.

5.3 Data collation

Interviews, expert discussions and literature searches have been used as the survey instruments.

a) Interview techniques: Quantitative versus qualitative interviews

When evaluating findings, empirical research distinguishes between quantitative and qualitative methods. "In quantitative research one is trying to describe behaviours in the form of models, correlations and numerical formats as accurately as possible, and to make them predictable."[96] Here, the particular interest is the numerical form of the pre-defined variables. In the evaluation, measurements are compared and correlated with each other. The qualitative approach is more open and has a more exploratory nature. Guided questions are used as the basis of a survey, whereas in the quantitative approach standardized questionnaires are used. This means that the results are more individual, but cannot be used for representative or numerical assertions.

Regarding the current plant evaluation on the one hand, standardized and comparable answers must exist. At the same time, the design of the questions should allow enough flexibility so that issues arising from an individual context are not excluded.

b) Oral vs. written approach

For practical reasons oral interviews were used for this work. It is true that the data to be collected would be very well suited to a questionnaire-based survey. An e-mailed survey would also have been easier in terms of the geographic distances involved. However, the likely

[96] Winter: „Quantitative vs. qualitative Methoden, 2000

response rate to a written format was called into question even before the study. To compound the issue, it also turned out that many Thai plant operators do not have an e-mail address to which the questionnaire could be sent.

c) Open vs. closed questions

For the questionnaire mainly closed questions were devised, although with some open questions. "The difference between the two types of questions is that in the closed question options for the answer are presented, whilst in open questions an answer is required in self-chosen words."[97] According to Stier, open questions have the advantage that the respondent is less likely to answer in a direction steered by the interviewer. At the same time they pose a higher degree of difficulty for the respondent when answering. In addition, the evaluation of open questions requires higher effort. Closed questions, on the other hand, can be analysed more easily. However, it can happen here, that the response options are not adequate for the respondent. In view of this, when using closed questions, it is recommended that a trial run is carried out. In our questionnaire, we have included a final, open question to any section of closed questions allow some space for the interviewees to add their own remarks.

5.4 Structure and content of the questionnaire

The above determined categories for the assessment, performance criteria and the variables for their further description have been integrated into a questionnaire for the practical field research. The following paragraphs explain the structure of the questionnaire.

General overview: Geographical data, motivation, energy usage, project structure

The first section of questions aims to give the interviewer a general understanding of the underlying structure of the project right from the beginning of the interview, and therefore to be able to adapt the later questions according to the answers given in this section. It deals with the plant’s location, supplies of electricity and heat before building the plant and the share of energy subsequently fed by the plant, so as to gain a picture about the motivation for building the biogas plant (4c). It also requests information about all involved parties in the biogas project to gain an understanding of the project structure, responsibilities and duties, as well as the legal form (3b, 3c).

Location and logistics

This section is connected with the first group of questions on geographical details, as it aims to determine in more detail whether the site has been located correctly, i.e. whether the location is

[97] ibid. Stier: Empirische Forschungs,ethoden, 1996, p. 176

suitably sited in terms of its existing infrastructure and the distances involved for feedstock supplies, heat and electricity distribution and water supplies (3c). The possibilities for selling heat or steam will be assessed to gather information about additional cash flows (e.g. through the sale of heat), as they might enhance the revenues (4c). Also in this connection questions will be asked about the presence of sufficient agricultural land nearby that would allow the sale of the digested biomass or its use on the plant proprietor's own land (3c). The distance to neighbouring buildings has to be taken into consideration too - if these are too close, conflicts concerning odour or other issues might arise (3c). The question of land rights is also relevant in this section, since problems here can lead to many problems in a project (3c).

Feedstock

This section asks for a specification of the feedstock (1a). The interviewee should define the type of feedstock and its characteristics, especially the percentage of biodegradable matter. An additional indication of the gas yield and the methane concentration will help the interviewer to verify the quality of the feedstock. In addition, any possible impurities in the feedstock will be assessed to ascertain whether pre-treatment is necessary and a suitable technology available. Other issues concern the price and the transportation costs for the feedstock as well as its availability and the securing of future feedstock supply (3c). (This point is connected with the previous section, however because of the structure of the questionnaire it is better placed in the feedstock paragraph.) Because feedstock supply is currently a difficult issue in Thailand (owing to increases in prices and contractual disagreements between plant owners and feedstock suppliers[98]), the section ends with an open question about problems in the feedstock supply, giving space to allow the assessment of information not covered by the previous questions.

Energy yields

This group of questions aims to give an idea about the amount of energy generated, including both electricity and heat, the efficiency of the energy conversion and any energy losses, as well as the proportion of the output to be consumed privately and that sold on to third parties (1a, 2c, 4c). It is therefore the basis of calculating the income and evaluating plant size and the efficiency of the conversion process from feedstock to methane and then to electricity or heat.

Digestion process

In this suit of questions all the relevant parameters for the processes and microbiology in the fermenter are assessed (1b). To ensure that we do not only collect instantaneous values, but also to ensure we have information about longer-term fluctuations, median, minimal and maximum

[98] Personal talk with thai biogas plant operators during an information journey of a thai delegation to Berlin in June 2012.

values are requested. Another issue covered in this section concerns the monitoring of the plant, which would indicate whether any disturbances in the digestion process could be detected in sufficient time. The procedures for the monitoring of the plant biology will be verified by asking about the biological controls implemented, their frequency and the responsible laboratory (1b). Because of the importance of the digestion process and since disturbances could occur that are not covered by the previous questions (only the most important parameters can be covered if the time available for the interview is not to be exceeded), the section ends with an open question about any problems that could occur during the digestion process.

Planning and construction

In this section, information regarding the process and quality standards during planning, construction and commissioning is assessed (3b). Relevant information is the availability of appropriate approval certificates before the start of the construction process, an official acceptance of construction work when the construction is complete, qualified commissioning to bring the plant into operation, and any guarantees or performance bonds granted by the planner or construction company once the plant has started operation. To obtain information about possible delays to the approval process by the authorities, the duration for obtaining the necessary permits will also be assessed. Furthermore, in the context of questions about the construction process, data about any delays during the construction will be gathered, as this might increase the investment costs (4a).

Technology

The questions of this paragraph will give the interviewer an overview to the components used in the biogas plant (2a). In the framework requested by GIZ for this evaluation, an assessment of the technology is of special interest. So the questions are not only designed to allow an understanding of the components, but also to assess the reliability of the technologies from different manufacturers. Therefore a focus is laid on guarantees and their specification. In this context, any quality assurances granted by the construction company by means of completion guarantees or certifications will be verified. Further, questions are asked concerning any components that have caused problems and ways these have been solved. Another area of concern in this section is to assess if the technical components have been implemented according to feedstock requirements (2b). This concerns the feedstock storage facilities and pre-treatment technologies, the number of fermenters, storage facilities for the digestate, cleaning technologies and also the materials used in the facilities and components.

Insurance, contracts

This section asks about the existence of the most important insurance cover and contracts (3b). Regarding insurance cover, the aim here is to collect information about whether the plant owner had analysed the risks that might occur and has taken any measures to mitigate or avoid any economic losses resulting from them. Regarding contracts, the aim is to assess whether the plant owner has protected themself against any economic losses should their contractual duties and benefits with other stakeholders not have been clearly and bindingly defined.

Utility interconnection

If it is planned to sell the electricity and feed it into the grid, a power purchase agreement is crucial for ensuring the output revenue stream. Usually such an agreement has had to be provided previously as part of any loan negotiations with the financing banks. For the purpose of this questionnaire the intention is to assess if the contract process for the PPA (power purchase agreement) is likely to cause any problems or delays (3c).

Expertise of staff

The first group of questions in this section concerns the qualification of the plant operator. To collect data about his or her expertise it will be asked for the educational qualification, such as their profession, years of experience working with biogas plants and, if required, any specific training (e.g. courses) (3a). Further, it will be assessed whether maintenance is to be carried out by qualified personnel, e.g. a service company (3a).

Expenditures and revenues

Here, questions are included about all costs and incomes (4a-4c). Owing to the sensitivity of questions about economic data, we have included two versions in the questionnaire, so the interviewer can decide during the interview whether exact data or just estimated values are available. For the first version, the individual cost items for investment costs, operation and maintenance costs, and revenues from electricity, heat, fertilizer or other co-products are specified. In addition the structure of the financing as well as the terms of any loans and interest rates are assessed.

For the second version, no questions about costs or revenues are asked. To assess expenditures for operation and maintenance, questions will be asked about the amount of work for the individual activities per month. Investment costs will have to be estimated by making enquiries with the manufacturers. Other costs such as insurance, taxes etc. will have to be estimated by identifying typical prices in Thailand for plants of such as size. As regards the financing structure, questions will be asked about the percentage of equity and debt capital. Revenues will be determined by asking about the amounts of electricity, heat or fertilizer that are used privately and that which is sold to other users. When calculating the electricity revenue, the Adder tariff can be used; for heat or fertilizer typical market prices will have to be identified.

Environmental benefits

This section concludes with questions about any environmental benefits and was added addtionally. Environmental benefits are not a focus of this analysis. However, the purpose of this section is to collect information about any additional benefits accruing to the plant owner and also to local residents (4.c). Further it allows verification of whether the plant is being operated in accord with license and permit requirements (3.b).

5.5 Preparation of the expert discussions

The aim of the expert discussions was mainly to gain an overview of currently discussed issues in the Thai biogas market, so that the interviews with the biogas plant operators could be made relevant to the actual market conditions. For this reason, a deliberate objective was to exert as little influence as possible on the respondents, allowing them to express their own market observations. We chose “guided interviews” as the most suitable interview technique. The starting points during these interviews were open questions about:

- Market potentials
- Feedstocks
- Project structures
- Environmental issues
- Financing
- Technology
- Costs and benefits
- Planning and design
- Critical issues
- Future developments

Then, according the answers received, we went into greater depth using more focused questions. The nature of these varied from respondent to respondent depending on their knowledge.

5.6 Conduct of the interviews: a critical evaluation of the field research

When undertaking the field research only a fraction of that data planned and necessary for an in-depth assessment was able to be collated. The main problems which arose can be put down to a) gaining access at all to interview partners and b) gaining access to the right interview partners. Therefore when reviewing the success of the current study we have looked at other research into such assessments and the problems that can occur when trying to undertake effective field research.

A study undertaken by Johl and Renganathan describes the process of gaining access to interview partners as being a major barrier during field research: “One of greatest pitfalls in conducting research successfully is the inability to obtain access to the research fields.” However, apart from ethnographical studies, few researchers tackle this issue: “Many researchers do not even describe their fieldwork practice in their research report. It is only in ethnography based research access to the research field is often described explicitly.(…) The hurdles are often neglected or it is seen as merely tactical issue.”[99] Their study develops a four-stage access model: getting in, getting on, getting out, getting back; we will critically evaluate our own experience using this model.

Pre-Entry: Getting in

The first hurdle to overcome was to find any interview partners at all. Johl and Renganathan underline four points for “getting in”: the employment of either formal or informal ways of communication to make contact with potential interview partners; the fixing of appointments based on interviewees’ availability; the need to emphasize the benefits of the research and reassurance concerning confidentiality. For our case studies in Thailand, it was easy to gain access to conduct expert discussions with the aim of getting an overall overview of the market. The experts were partners within the giz network and they benefitted explicitly by taking part in the study. But at first, no biogas plant owners or operators could be found who were willing to take part in the study, although they were crucial to the data collection process. The fact that at least some plant owners were eventually found who were willing be interviewed came down to our gaining access to a “gatekeeper”. A gatekeeper is a person who, because of his position in a political, economic or educational entity, can help to establish contacts to multiple informants.[100] In cases where an existing network is not sufficient, the integration of a gatekeeper can be crucial. Within the context of the present study, a gatekeeper would be, for example, the chairman of a biogas association or of another network related to biogas industry. In our case, the gatekeeper was actually the regional director of a biogas research unit. Before contacting a gatekeeper, it should be clarified whether they will benefit from supporting the project themselves, for example when they might have an interest in gaining access to the output of the project.

[99] Johl et al.: “Strategies for gaining access in doing fieldwork”, n.d.
[100] ibid., c.f. Johl et al.,n.d.

During-Fieldwork: Getting on

For this phase, Johl and Renganathan list the process of adapting to the cultural norms of the research site and the taking into account differences in language as important factors. In fact, language barriers and cultural norms became the main hurdles when conducting the interviews with plant operators. Neither the “gatekeeper” who accompanied us to the biogas plants, nor the plant owners spoke English. The presence of a translator was helpful, but turned not out to be a particularly viable way, since the process of translation from English into Thai and then back into English resulted in lengthy interviews and in loss of information. In addition, the fact they were being interviewed by a foreigner was enough to provoke a degree of caution and suspicion on the part of the interviewees, especially when they were supposed to talk about sensitive data. Hence our recommendation is that a native speaker with the same cultural background should be employed when collecting sensitive data.

After-Fieldwork: Getting out and getting back

The tasks identified by Johl and Renganathan once the interviews have been undertaken include the sending of a formal thank-you note, the sending of a copy of the results and the developing of a good rapport with the research site when leaving it, in case it might be required again in the future. Again, owing to the language barriers, we could not carry out these tasks.

6. Results of the field research

6.1 Expert interviews

Six expert interviews were conducted for the biogas technology evaluation. The interview partners included three plant designers, a bank, an expert on sustainability in the food production chain and a university institute carrying out research in the renewable energy sector.[101] In the following lines we will resume our findings according the topics discussed.

Market potential and feedstocks

The interviewed plant designers saw the highest demand and the biggest potential for the further exploitation of the biogas market as being in biogas plants processing waste water from starch, cassava and ethanol production and the residues of palm oil production. These feedstocks offer two advantages: there is a large agricultural industry to implement biogas plant to utilize the residues for energy production, and the feedstocks have a favourable nutritional

[101] The interview partners will be treated confidential.

value for the generation of methane. However some of these feedstocks have to be treated carefully. Exemplarily was mentioned molasses pulp from distillation processing. Molasses pulp has a very high COD content (200,000 mg/l) and therefore produces high energy yields, but it has to be ensured that the biogas is cleaned sufficiently, as it also has a high H_2S content.

Besides the above mentioned substrates, a recent focus of the support programmes subsidized with state funds from petrol tax has been for those plants processing waste streams from food and latex production. So far, these plants have been operated with only moderate success. Because of their low COD content, they place high demands on the technology, leading to sizeable investment costs. At the same time, they generate a low financial return because of their low gas yields. Therefore further research is necessary to improve the technology of these types of plant.

There is also a promising potential in the agricultural sector for the further exploitation of the heat that is co-generated when operating biogas plants and using this elsewhere in the production chain, e.g. for the drying of the starch. This option - of utilizing the waste heat - seems to be in its initial stages, and its use is not yet widespread. So far there are no programs to promote it. One plant designer estimated that the unused potential for heat utilization in palm oil and starch production alone could amount to 150 – 200 MW; ethanol production is not even included in this figure.

Common project structures

Most of the agro-industrial biogas plants are directly connected to their associated industrial plant and have the same plant owner. This business model results in a secure feedstock supply for the biogas plant with no additional costs, producing additional income for the plant owner and an environmentally friendly waste management process. Other business models have been less successful in the past, especially for smaller plants on farms where the farmer operates the plant which is owned by a different party because of a low equity share. This has resulted in disputes when the plant operator, e.g. a local farmer, realised that the owner was getting a high income from the plant, with little or no margin left for himself. At present, it appears that usually the owner of the farm or company is also the owner of the biogas plant.

Environmental standards

According to one of the plant designer’s statements, the official environmental standards for both air and water quality (emission values for air and effluents) have been set very high. They are determined by the Pollution Control Department of the Ministry of Environment. However, the level achieved in practice often doesn’t meet the required standards. Non-conformances occur due to a lack of regular inspections, e.g. because of the large distances between the plants and the office responsible for administering the standards. Another reason is the lack of a neutral and independent inspectorate.

Financing

Banks often finance biogas plants through the classic corporate financing scheme. In case of project finance, it has to be non-recourse financing. Projects proposed by suppliers without a track record have less chance of receiving a bank loan; suppliers need at least 10 years' market experience.

The operation and maintenance (O&M) contracts are checked by the banks very carefully and are considered an important criterion for receiving a loan. The banks also require the use of an established O&M contractor and that the responsible person for carrying out O&M has to be on-site all the times. From a bank's perspective, the three major risk factors are: the financial record of the investor, the technology (the gas cleaning technology is especially important here, otherwise insufficiently scrubbed gas would be produced), and the experience of both the investor as well as the company which will carry out the O&M.

Plant technology

Currently the average lifetime of a biogas plant is between 5 and 8 years, including one general overhaul. As many plants reach break-even only after 4-5 years, a lifetime of 5-8 years is too short to make them financially viable. This short life is mainly caused by the technical standard of the plant being too low. Furthermore it was mentioned by one of the interviewees, that often a coincidence occurs between the usual bank loan period of about 7 years and and a break down of the plant just shortly afterwards. However, new standards for the gas sector are expected to be introduced in the near future. A shift to improved quality standards can be already observed.

Gas cleaning has been a problem in the past, but this has improved now. Previously, often no cleaning facilities were installed and the high moisture and toxic content led to motor damage. Nowadays biological fluters are often used for cleaning and some plants also use chemical washing technology.

All the plant designers interviewed cited conflicts with foreign suppliers. The technologies used in Thailand have to be thoroughly adapted to meet the special climatic conditions of the country and the regional feedstock. In practice the imported technologies often cannot meet these requirements or they prove to be inadequate for the specific environmental conditions. Often the problems originate in the materials used. Another source of conflict arises from exaggerated margin expectations, which are unrealistic for the Thai market.

Costs and revenues

All interview partners had different ways of costing in the value of the current Adder incentive into their commercial viability calculations. One of the plant designers, for example, requires new plants to be economic viable without any Adder incentive at all. Others use the current value of the Adder in their viability calculations, estimating it as sufficent. One of the interview partners made distinctions by plant size, considering the Adder as being too low for plants smaller than 1 MW.

All interviewed parties agreed that the costs for biogas plant have increased. The main reason is higher costs for O&M, which have to be taken into account in financial calculations. One of the interviewed plant designers cited the increased requirements on O&M from the banks.

Another reason for the increased costs is the feedstock problem. When biogas plants started to become more popular, feedstock suppliers elevated their prices, in some cases by about 400%. To ensure feedstock security, plants today are increasingly built by the farmers and agricultural producers themselves, who then just process their own residues.

Safety

Safety is currently one of the biggest issues. A number of bad accidents have occurred recently. Plants have exploded because the covers of the gas storage reservoirs had not been fixed properly and had become loose during storms, allowing the highly concentrated methane to leak. It often occurs that inadequate materials are used for the covers or they are not securely fixed. Another accident occurred recently owing to inadequate working safety procedures, even resulting in fatalities at the plant. The accidents have resulted in a swift deterioration in the public image of biogas plants. Local residents now often consider biogas plants to be dangerous. As each new plant requires a “public hearing” before construction, in which the residents have to approve the new construction, these public hearings often result in the plant being rejected because consent is not given by the residents. Planning and design

Optimization of biogas plants regarding their dimensioning is another current issue. According the statements of the plant designers, many plants are not sized correctly, resulting in lower biogas yields than the original estimates and non sufficient economic returns.

Another problematic issue particularly for smaller plants which have been built within the context of support programmes is the question of responsibility for the planning and design process. Projects have been set-up in such a way that none of the involved parties have taken over overall project responsibility. This has resulted in badly performing plant and frequent technical failures.

6.2 Case Studies

6.2.1 Common characteristics and background information

In total, six interviews could be conducted with plant owners. These plants have many characteristics in common. Each plant had been built on a pig farm, using the pig manure as feedstock. The plants were located in the region of Ratchabury. All of these plants were participating in the "Promotion of Biogas Production in Animal Farms" program. In this program, plant owners receive financial support for their investment costs. The plant design was planned by the Energy Research and Development Institute (ERDI) of Chiang Mai University. This institute has been responsible for the development and implementation of over 200 MC-UASB systems at medium and large pig farms in Thailand since 2004. An external consultancy is responsible for the feasibility study and the construction. A university employee runs a local branch office of ERDI in Ratchabury. He monitors the plants and is called by the plant owners in case of technical problems. All plants are built as MC-UASB systems (Medium Channel-Up flow Anaerobic Sludge Blanket). Through the installation of biogas plants, the farms have been able to offset baseline livestock waste management from the former open lagoon systems and carbon dioxide emissions from the combustion of fossil fuels. The treatment of swine waste by anaerobic digestion leads to a biogas consisting of 60-70% methane. Through combustion, the farmers are able to replace conventionally-generated energy supplied through the grid with renewable energy. Extracts from the feasibility studies have been available for five out of the six plants.

Before we describe the findings of the interviews, in the following paragraphs we will shortly explain the "Promotion of Biogas Production in Animal Farms" program, regional characteristics and MC-UASB systems, to understand the common background and characteristics of all plants visited.

Pig farming in Thailand

Between 1992 and 2008, pig production in Thailand increased by 3.5 percent per annum, reaching a value of about 9 million pigs each year.[102] According the report from Kiratikarnkul, pig

[102] c.f. Kiratikarnkul: "A cost-benefit analysis of alternative pig waste disposal methods used in Thailand", 2010, p. 105

farming has changed from small-scale production on mixed farms to large-scale intensive production in this period. Smaller farms that combine crop production with animal husbandry have been replaced by monocropping and specialized "industrial" livestock production. This development has resulted in an increase in productivity but also in a waste disposal problem from these intensive farming systems. Live stock wastes were frequently managed by dumping them into a series of ponds. Applying this method, without a proper control the livestock wastes can be leacked or discharged into natural streams, resulting in environmental problems. "Among the problems which contribute to ecological imbalances are: severe eutrophication of surface water, leaching of the underground water table, and deposits of heavy metals which create pathogens harmful to humans and animals."[103] To release these problems, biogas technology has been considered an effective method for waste disposal.

Figure 13: Typical open-wall pig farm in region of Ratchaburi

Source: own image

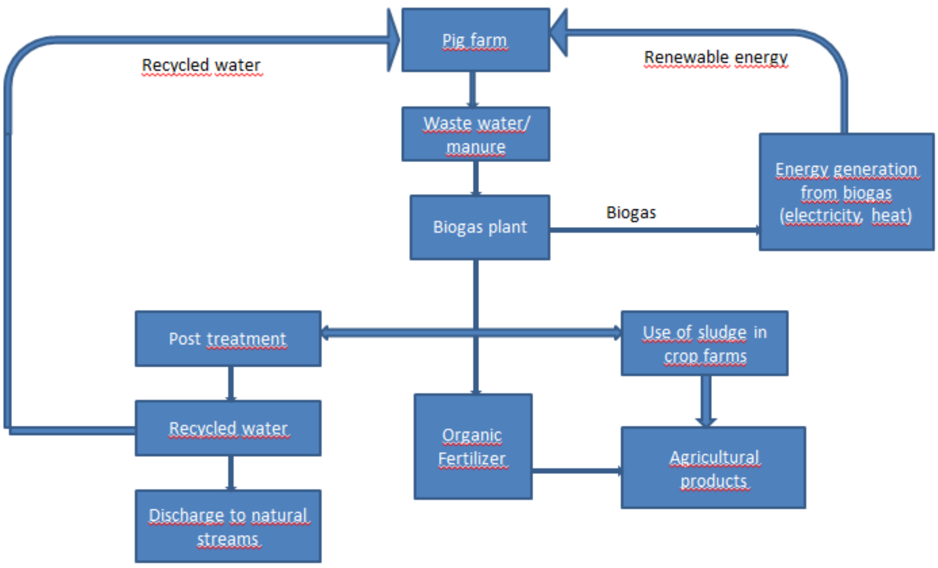
The program

In 1988, the Chiang Mai University founded its Biogas Technology Center. The Center started as a joint venture with the Department of Agricultural Extension and was supported by the GTZ through the Thai-German Biogas Program. Its two main objectives were: "promoting the use of locally available energy resources and addressing environmental problems caused by livestock farms"[104], especially on pig farms. At the beginning of the 90s, the Technology Center was transformed into the Biogas Advisory Unit (BAU), and received funding by the National Energy Policy Office (NEPO[105]). The objectives of BAU, compared to the Technology Center, have been extended, integrating the research of new technologies for waste water management, the dissemination and implementation of the technology and teaching. The Thai-German Biogas Program was considered a success, and so in 1995 the BAU initiated its successor: the "Promotion Program for Biogas Production in Small and Medium Sized Livestock Farms". Through the support of NEPO, farms can obtain a partial subsidy covering up to 38% of their

[103] ibid., c.f. Kiratikarnkul, 2010, p. 106
[104] Shrestha et al.: Report on Role of Renewable for Productive Uses in Rural Thailand, 2006, p. 38
[105] Today it is EPPO.

investment costs, aiming to overcome one of the hurdles of the technology, the high capital investment costs[106]. In the first phase of the program, from 1995 to 1997, a total of 10,000 m^3 of digesters were installed; in the second phase from 1997 to 2002, 40,000 m^3. In 2002 the program was extended for a further seven years, and also added incentives for large scale plant. The aim was to implement 150,000 m^3 of digesters by 2008. It was expected that by the end of the program biogas plants would have been implemented in almost 50% of large farms.[107] Within this program, the university has used the UASB technology and adapted it to specific requirements of Thai livestock farms. On most farms, a channel digester (CD) is been installed before the UASB tank, predigesting the substrate before discharging it into the UASB tank. By means of the biogas technology developed at Chiang Mai university, COD removal rates of 86% can be reached, which will be even increased after the post treatment of the effluent.[108] Farmers can produce their own energy, fertilizer and reduce odours.The following flow scheme reflects the treatment of manure on pig farms through biogas plants and the hereby generated value chain:

Figure 14: Flow scheme of biogas production on pig farms



Source: Senthong: "The Biogas Technology Center", n.d.

[106] ibid., c.f. Shrestha et al., 2006, p. 34

[107] At the time of writing this paper, the author did not have any information available whether this aim was likely to be achieved.

[108] c.f. Senthong: "The Biogas Technology Center", n.d.

A report on renewable energy for productive use in rural Thailand from 2006[109] identifies the key factors which have been considered important for the success of the project: the subsidy offsetting the investment costs; the linking of the subsidy with a duty to construct the plant according the CMU design; an obligation on the owners to properly operate, maintain and monitor the plant for a full year after implementation.[110] Nevertheless, the success of the program has not been without controversy. "The program (…) so far has given mixed results. Biogas digesters installed in large farms have a [acceptable] payback period of about 5 years. However, more robust and integrated systems have to be designed in order to avoid technical failures, complicated operation and costly maintenance especially for medium size digesters."[111] The report mentions also the "lessons learned". In detail the "lessons learned" were[112]:

- The technology is economically profitable. When the gas is fully utilized, the payback period for large farms is 5 years.
- The economic return from biogas plant is more profitable for farmers than other methods of waste treatment.
- Market incentives should be used to promote the use of biogas technology besides just relying on the enforcement of pollution laws.
- The systems should be delivered in a complete package instead of separate modules.
- The owners should understand how the system works. Past failures show that proper operation and maintenance of the system is crucial.
- The applied technology should be developed to be cheaper, more tolerant and less sensitive. In many cases, a trained technician has to be hired for proper maintenance, which is only affordable for large scale farms, not for medium sized farms.
- Many of the farms use modified diesel engines to generate electricity, so as to save on investment costs. This places higher requirements on maintenance and results in damage through corrosion. In this case a major overhaul often becomes necessary every 3-5 years. Longer lasting gas turbines would have to be imported from abroad at higher costs.

Technology applied

The MC-UASB biogas system used basically consists of four phases: waste water collection and pre-treatment, the bioreactor, post-treatment and energy utilization.

[109] ibid., c.f. Shrestha, 2006, p. ii
[110] ibid., c.f. Shrestha, 2006, p. 38
[111] ibid. Shrestha, 2006, p. ii
[112] ibid., c.f. Shrestha, 2006, p. 38

In the first phase, the waste water from the farm activities is collected in concrete waste water channels, which also separate the waste water from rain. Swine barn flushing waste waters consist of a combination of swine manure along with wash-water used for barn flushing. The waste water is then channelled to the collection tank, which is sunk into the ground. Here, bacterial sludge from the digester is blended with the waste water to stimulate the organic matter digestion and enhance the biogas production capacity. Following this, the waste water passes through screens to filter out any pig fur, and a sand trap to separate out sediments such as sand or cement.

Figure 15: Waste water collection tank

Source: own image

In the second phase, the cleaned waste water is feed into the MC-UASB treatment system, consisting of the channel digester and the Upflow Anaerobic Sludge Blanket. The digester works as a separator for the solid and liquid fractions of the waste water. Furthermore, this configuration allows the majority of enzymatic breakdown of the solids fraction to occur isolated from the other main steps of the digestion process. The separation of this step prevents clogging of the sludge blanket. In MC-UASB systems, the waste heat from the biogas engine is used to heat the channel digester through a series of water pipes. The liquid fraction is channelled into the UASB tank with an integrated Sand Bed Filter. The Sand Bed Filter is connected with the Channel Digester and receives the discharged fermented slurry directly. The hydraulic retention time is between 20 and 30 days.

Figure 16: Channel digester with polyethylen cover behind a hybrid oxidation pond

Source: own image

The post-treatment system in the third phase usually consists of a biofluter, hybrid oxidation pond and drying beds for the solid waste from the Sand Bed Filter. In the biofluter, the biogas is cleaned from H_2S and other toxic elements. In the hybrid oxidation ponds, the effluents are treated according to the environmental standards. The treated waste water can then be reused for farm's activities. The drying beds serve to dry the remaining sludge from the digester by depositing it on top of a sand bed filter where it dries in the sun. After drying, this solid material can be used as fertilizer.

Figure 17: Sludge drying bed

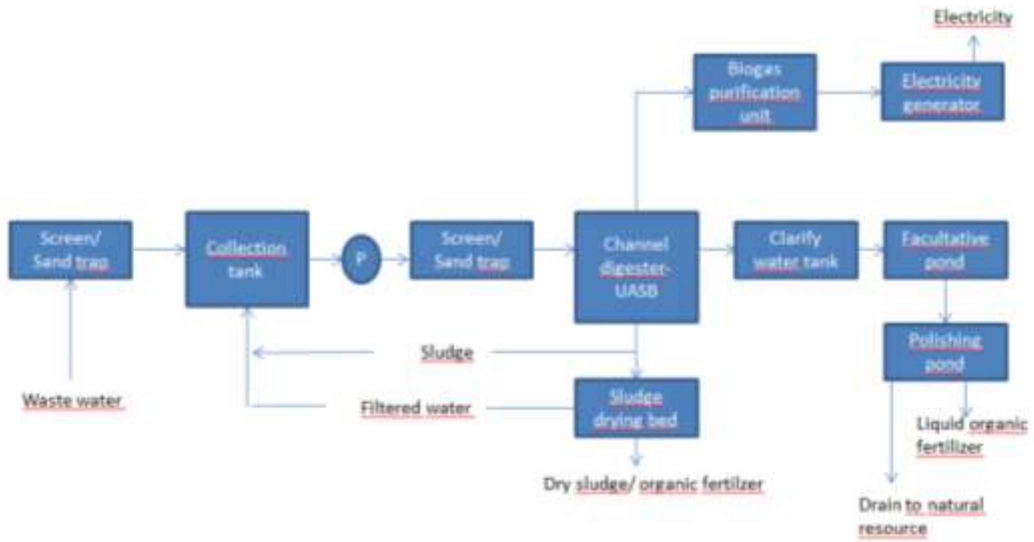
Figure 18: Biofluter

Sources 18 and 19: own images

The energy utilization system in the fourth phase consists of the biogas storage, a flare (when installed) and the biogas conversion unit. The biogas is captured and stored under a polyethylene cover placed over the channel digester tank. The flare is used to release and burn the over production of biogas to the atmosphere. The energy conversion unit is either a modified gasoline engine, diesel engine or a stream engine.

The following flow scheme demonstrates the elements of the UASB system:

Figure 19: Flow scheme of an UASB system



Source: Senthong: "The Biogas Technology Center", n.d.

The waste water from the flushing of the pig pens is composed of swine manure and the wash water used for the barn flushing. It usually has a high organic strength with COD values about 10,000 – 15,000 mg O_2/l and a high level of suspended solid content at about 10,000 – 15,000 mg TSS/l. The organic load rates can be reduced by about 90%. After the final treatment in the ponds, the COD should be less than 120 mg/l.

6.2.2 Findings of the interviews

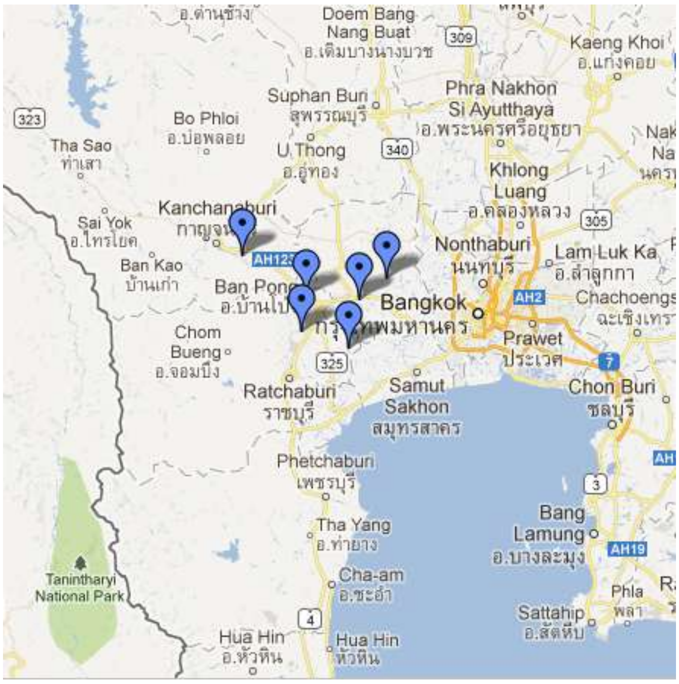
Geographical data, motivation, energy usage, project structure

(Farm names have been made anonymous by the use of depersonalised letters.)

All farms are located close to Ratchaburi, where the ERDI branch office is located, in the provinces Ratchaburi, Kanchanaburi and Nakhorn Pathom, i.e. about 100 km west of Bangkok. Ratchaburi possesses the highest number of pig farms in the country, comprising about 25% of

Thailand's total pig production with about 2,300,000 pigs (2009)[113]. The following maps indicates the locations of the farms visited:

Figure 20: Geographical locations of biogas plants visited during field research



Map developed in: Google maps.

Regarding their main objective for installing a biogas plant, three farms cited a reduction in electricity costs (farms A, B and F). For farm D too, the saving on energy costs was an important reason, but the main problem for this farm was different from the rest – finding a solution to the problem of frequent blackouts. This farm is located in a border zone of the public grid, and before the biogas plant was installed it suffered from many electrical power outages, particularly at peak times. Here, the farm could have invested in an extended grid connection, however, for this it would have had to spend almost the same amount of money as necessary for implementing the biogas plant, but without gaining any of its additional benefits. For farm E, savings in electricity costs were a secondary reason, but the main objective for this farm was to generate energy for the heating of pig oil to sell on food markets.

The second main reason for installing the plant concerned the environmental problems associated with the pig manure. Four of the farms indicated that they wanted to reduce the problems arising from smell and flies by improving the waste management with the biogas plant

[113] ibid., c.f. Kiratikarnkul, 2010, p. 106

(farms A, C, D, F). Two of the farms had planned to generate additional income through CDM credits (farms A, B), but neither has been accepted to date.

In all farms the biogas is converted into electricity. The electricity is used privately, on the farms themselves; none of the farms feeds it into the grid. The ratio for the replacement of conventionally generated electricity by private generation varies between 50% (farm A) and 100% (farm E). The average was 90%.

In all farms, the farm owner is also the plant owner. Farm B has hired an operator who is also responsible for maintaining the plant. On the other farms, the plants are operated by the farm owners. The maintaining is done by the farm employees.

Location and logistics

Five farms are situated in a rural setting, being surrounded by fields and isolated from populated areas. Only farm D is situated within a village. All use the feedstock produced on their own farms, so no distance is involved for delivery. The same applies for the generated electricity. The fertilizer is used on agricultural land nearby.

Feedstock

The farmers could neither quantify nor qualify the feedstock; so we can only use the number of pigs in our calculations. The farm size ranges between 2,000 (farm C) and 60,000 pigs (farm B). Three farms have 5,000 pigs (farms D, E and F) and one farm has 10,000 (farm A). The pigs are held in single-storied buildings. Most of these have open walls, only farm F houses the pigs in closed buildings which need to be ventilated. The farm waste is managed by flushing 1 – 2 times per day.

Energy yields

Whilst the fermenters on all farms are operated continuously over the whole year, the generators are not. Unfortunately, the farmers could not specify the number of days per year the generators are in operation. The total fermenter capacity on the farms ranges between 700 m^3 (farm C) and 12,000 m^3 (farm B), (but the last one is divided into individual fermenters of 6,000 m^3 each). Farm D, E and F all have fermenters of 1,000 m^3, farm A of 1,250 m^3. Only two farms could answer the question concerning its biogas production rate – farm D indicated that the plant produces 560 m^3 biogas per day, farm B about 10,000 m^3. The amount of electricity produced had to be estimated from the farmers' estimates of the percentage of conventionally generated electricity replaced, and the total electricity consumption of the farms mentioned by the farmers. It is particularly of note that four out of the five farms aren't achieving the level of electricity production forecast in the feasibility study. Only on farm B does the electricity output exceed the forecast, but even here this is with a biogas plant that is double the size of that projected in the feasibility study. On the other farms, the output is about one third lower than originally estimated.

Digestion process

No data about process parameters of the fermenter could be collected. Monitoring of biological or technical parameters of the biogas plants is virtually non-existent. The required measuring instruments were not installed, because they would have increased investment costs. Moreover there are no regular biological inspections by an external laboratory. Usually the plant owners contact the local ERDI office only in the case of problems. According to the plant owners of all farms, the fermentation processes work trouble-free.

Planning and construction

The six biogas plants have all been planned according to the Chiang Mai University Design. A local design company has adapted the overall design according to the particular requirements of the sites. Local workers were hired to build the plants. The construction period was around 6 months, but two of the plant owners experienced problems during the building process. At farm C there was a one year slip, partly due to a long period of heavy rain during which building had to be interrupted, but also because of problems with the workforce reliability where the workers “sometimes did not show up”. Also on farm E there were delays in construction owing to fraud. According the information from the plant owner, the parties involved tried to save on costs and pocket the savings, because “it was just government money”.

The plants went into operation between 2008 and 2009. Highly diverging estimates were given for the forecast operational life; three plant owners (farms A, D, F) indicated 10 years, farm E 20 years, and farm B and C could not provide any information.

Technology

Two of the plants were purchased as turn-key plant (farms A and D), four plants consist of individually combined components (farms B, C, E, F). For electricity generation, the plants have between one and three generators: farm A has two of 60 kW each, farm B three of 220 kW each, farm C two of 35 kW each, farm D one of 40 kW, farm E two of 50 kW each, farm F one of 40 kW. Since the generator is the main source of technical problems, the use of an architecture where electricity generation is split across two generators ensures continuity of power production even when one generator is temporarily out of order. Also, in most of the farms, one of the generators is taken out of service for a few hours each week. On farm C the generators always run alternately. During the field visits one of the generators was undergoing repairs on two farms

(farms A, B). Farm A reported that at one time both generators failed for a week. On farm C the fuel consumption of the generators fluctuates. The main issue with repairs for the farmers is that they usually cannot be done by a local technician, but only by the supplier. Two of the farms use a modified machine where outer sets and inner parts come from different suppliers.

Two of the farms (farms B, E) sometimes experienced sand blockages in their residue pipes. (None of the farms undertook pre-treatment of the substrate). Farm E stated that it was reluctant to clean the pipes regularly because of gas losses that occur when cleaning. Three of the farms indicated problems during the rainy season: farm D experiences a 30-50% reduction in gas production, farm E a 20% reduction owing to the temperature drop in the fermenter. The temperature in the fermenter should be 35°C, however if the pipes for waste water and rain are not kept separate, the required temperature cannot be maintained during heavy rainfall. One farm reported problems with the ponds during the rainy season owing to overflow. Farm B also reported a problem with the drying of the fertilizer, but did not specify the problem. The farm cannot sell any fertilizer because it has problems with the drying process.

Regarding safety standards, three of the farms have installed a flare (farms A, B, C). Two of the farms have an extinguisher- or sprinkler-based system (farms B, F). Two of the farms have control boxes which automatically cut off electricity in case of problems (farms B, E). Two of the farms indicated that they have safety rules for the personnel, such as a ban on smoking and open flames close to the fermenter (farms D, E). At the same time, farm E reported that the rules were difficult to enforce. Two of the farms release excessive amounts of gas into the environment (farms B, F).

Only one farm (farm B) stated that it has any guarantees on its technical components (the engine); this was valid for the first two years of operation.

Insurance, contracts, permissions

All of the farms were subject to a public hearing within the community before they could construct the biogas plant. According the plant owners, the public hearings passed off without any problems. In most of the cases the construction of the biogas plant was beneficial to the whole community because of the reduction in smell. Only three of six farms indicated that they had to ask for a construction permit (farms B, E and F). The other three farms stated they would not have needed any permit because they are situated outside of the municipal area. Specialist insurance for damages to the biogas plant (other than the usual farm insurance) doesn't exist.

Expertise of staff

Only the largest farm (farm B) has hired a technician who is solely responsible for the operation and maintenance of the biogas plant. In the other farms, operation and maintenance is either done by the owner themselves or by other workers whose main role is farming. None of the involved technicians or farmers had had any previous experience with biogas technology.

Environmental benefits

All plant owners commented that they were satisfied with the reduction in smell and fly problems. ERDI were going to send us a report of the values they had measured about the reduction in organic load rates, but we have not received this to date.

Expenditure and revenue

Regarding expenditure and revenues, we could only collect very rough estimates, because the farmers were either not willing or capable of giving us precise data. The revenue for electricity had to be estimated according the percentage replaced, as indicated by the farmers. When it came to the revenue for the replacement or selling of fertilizer, the farmers could not provide any figures at all. Two of the farmers (farms D and E) gave rough estimates for their investment costs, both at about 3,000,000 Baht. The other four farmers said they could not remember. However they were more forthcoming about operation and maintenance costs, where the interview partners were able to produce rough estimates on either a monthly or an annual basis. The range lies between 4,000 Baht per month (farms C and D) and 23,000 Baht per month (farm B)[114].

6.3 Interpretation of the case studies data

Initially, we had set-up an evaluation scheme consisting of four categories with two to three performance criteria each, and a range of variables which help to interpret the performance criteria. Unfortunately we were not able to collect enough data to calculate the performance criteria for three of the categories (operational functionality, technical functionality and socio-economic functionality). To calculate these we would have needed figures on biogas yields, biogas composition, the number of hours plants are out of operation, the theoretical and actual electrical efficiency, and the operating time of the engine. These are all parameters that are not monitored or measured by the plant owners. For the financial performance criterion, the estimates from the feasibility studies were available for five of the plants. So we have decided to adapt the approach for evaluating the financial performance to the data actually present: the focus is therefore being adjusted to comparing the (estimates of) the actual financial performance with the figures from the feasibility studies. In addition we have undertaken a number of sensitivity analyses so as to be able to draw further conclusions.

[114] Figures will be indicated in the following chapter on Financial viability.

In the following paragraph we will calculate the financial performance criteria as described above. Then, in the subsequent paragraph, we will interprete the financial performance category. For the other three categories, we will use the assessed variables for a preliminary interpretation.

6.3.1 Calculations of performance criteria for the financial performance category

As mentioned above, we were only able to collect rough data, so the calculations for the actual performance should be regarded as being provisional. Regarding costs, only approximate estimates were received, and for revenues, while the plant owners were able to estimate how much grid-based electricity they could offset from the plant, incomes from the selling of fertilizer could not be quantified in most of the cases.

To conduct a meaningful comparison, we have adapted our calculation methods to match those of the feasibility studies. For each biogas plant we calculated a series of monthly accruing costs and revenues over the estimated 15-year lifetime of the plant to generate the annual cash flows. We took the following variables from the feasibility studies:

- Interest rate: 8%
- Discount rate: = interest rate
- Inflation rate: 3%
- Energy value added: 4.5%
- Manpower costs added: 2.8%

Using the cash flows we calculated the NPV, IRR, and payback period for each plant, comparing our calculations with those of the feasibility studies.

We have detailed below the process of calculating costs and revenues.

Revenues from generated electricity: In the feasibility studies, the amount of electricity produced has been calculated by multiplying the volume of biogas produced by a replacement ratio and a replacement fraction. The replacement ratio corresponds to the amount of biogas used to generate electricity. The value of the replacement fraction depends on type and size of the electricity generator.[115] Since we could not collect data about the volume of biogas produced daily or generated electricity, we had to use the approximate estimates the plant owners gave us for the electricity replaced annually. The electricity price per kWh is 3 Baht.

Revenues from fertilizer or other co-products: The second source of revenues comes from the selling of fertilizer or replacing of mineral fertilizer. The price assumed in the feasibility studies for the fertilizer is 0.5 Baht/kg.[116] Two farms could indicate their revenues from fertilizer on a monthly basis (farm A, E). One farm did not produce any fertilizer at all (farm B), which we took into account in the revenue calculations. Two plant owners were able to indicate the price per bag of fertilizer sold, but did not know how many bags they sold per year (farm C, D). Here we used the revenues calculated in the feasibility studies. Farm E generates an additional income by the replacement of cooking gas by biogas.

Investment costs: The investment costs have been divided into the costs for the biogas system; costs for the energy converter,; costs for consultancy, system design, construction and installation; and a tax rate of 7%. All farms received financial support as part of the Promotion of Biogas Production in Animal Farms program, which amounted to 25% of the investment costs and all costs for consultancy, design, construction and installation. Two of the interviewed plant owners indicated the approximate size of the investment costs, which we used for the calculations (farm D, E). For the other farms, we took the numbers from the feasibility studies.

Annual expenses: The annual expenses listed in the feasibility studies comprise the electricity costs, manpower costs, maintenance costs of the biogas system, maintenance costs of the generator and interest. The electricity costs came to two percent of the product of the fermenter size, waste stream volume and operating days of the biogas plant. The manpower costs are determined according plant's location. The annual maintenance costs for the biogas system were estimated as two percent of the biogas system investment costs. Additional maintenance costs occur every five years for changing the plastic cover. They have been calculated at 250 Baht per m^2. The maintenance costs for the generator are the two percent of the product of the electricity produced daily and the annual working days of the generator. Additionally, every four years additional costs occur for overhauling the generator. These amount to 35% percent of the generator investment costs. We used costs for electricity and staff wages from the feasibility

[115] Values of the replacement fraction are: 1,2 kWh/m^3 for a domestic generator with a capacity less than 50 kW; 1,4 kWh/m^3 for a domestic generator bigger than 50 kW; for a generator type "Deutz" 1,7 kWh/m^3; for a generator of type "Guascor" 2,0 kWh/m^3

[116] We could not find any information how the amount of daily produced fertilizer was calculated.

studies, and used the data collected during the interviews for the maintenance costs for the biogas system and generator.

The comparison of the feasibility studies and the actual performance figures for the plants revealed that four out of five plants generate less electricity than originally estimated (farm A, C, D, E); this therefore reduces the income for the replaced electricity. Two farms have a lower energy output despite the generator being larger than that indicated in the feasibility study (farm A, E). One farm has installed just one instead of two generators, and is therefore running at half the originally calculated generator capacity (farm D). Whether the lower energy production results from a reduced biogas production or from problems with the generators is not clear. Only two farms could state their biogas production volume (farm B,D). In farm D, the biogas output is less than the theoretical value calculated from waste stream volume and fermenter size.[117] Regarding fertilizer production, one farm loses all income from fertilizer because it cannot sell this as a by-product owing to of problems with drying it (farm B). One farm has a lower (farm E) and one a higher income (farm A) from fertilizer than that calculated in the feasibility studies. For the two farms that could not quantify the incomes from fertilizer (farm C and D) we made the assumption that the monetary value corresponds to that indicated in the feasibility study. For the two farms where we could collect data about investment costs (farm D, E), the results showed that the investment costs were lower than the original estimates.

In all farms, the operation and maintenance costs were dramatically lower than those calculated in the feasibility studies. This could be interpreted as meaning that less effort is being spent on operation and maintenance, which could eventually result in a lower life of the plant. However, through this any losses due to reduced energy production could be partially offset, the end result of which was that the financial results, outlined below, turn out to be not as negative as might have been expected from the diminished electricity production.

The net present values were positive for all farms. For farms C and E the NPVs reached roughly those values calculated in the feasibility studies, despite the lower electricity production. Both these farms managed to save on O&M costs compared to the feasibility studies. Farm C also financed the plant in practice without any loan, while the feasibility study was calculated on the basis of a 100% loan. Farm E realized additional savings against the investment costs and also manages to generate additional income by using the biogas not only to generate electricity, but also for the heating of the pig oil. For farms A and D, the net present values are lower than those predicted in the feasibility studies. On both farms, electricity production is significantly lower

[117] As in farm B the fermenter volume is double the size indicated in the feasibility study, it does not serve for a comparison in this point.

than estimated: farm D only produces almost about 70% less of that predicted, for farm A the figure is around 50%. Even if the NPvs are positive for all farms, farm E is the only farm where the NPV is higher than the investment costs. The pay-back periods ranged between 3 and 6 years. Regarding the internal rate of return, all farms managed to reach the hurdle rate of 15%. Farms C and E achieved a value slightly higher than indicated in the feasibility studies. Farm E, which is the plant generating additional revenues, and farm B, which is the biggest plant, have the highest internal rates of return. For farms A and D, the farms that also showed lower net present values, the IRR was only 18% and lower than originally estimated.

The following table displays a resumé of the financial results:

Table 9: Resumé of financial results from feasibility studies and interview data

	Unit	Farm A Interview data	 Feasibility study	Farm B Interview data	 Feasibility study	Farm C Interview data	 Feasibility study	Farm D Interview data	 Feasibility study	Farm E Interview data	 Feasibility study
Number of pigs		10,000	10,000	60,000	10,000	2,000	2,300	5,000	5,910	5,500	4,850
Fermenter size	m^3	1,250	1,250	12,000	5,250	700	500	1,000	1,000	1,000	1,000
Biogas production	m^3/day	n.s.	1,020	10,000	4,284	n.s.	408	560	816	n.s.	825
Electricity consumption of the farm	kWh/month	40,000	n.s.	450,000	n.s.	13,000	n.s.	10,000	n.s.	> 10,000	n.s.
Electricity provided by biogas plant	kWh/month	19,993	33,660	385,000	164,934	9,680	13,464	9,488	30,788	> 10,000	30,810
Generator capacity (theoretical)	kW	120	90	660	250	70	n.s.	40	80	100	80
Investment costs (without financial support)	Baht	n.s.	4,682,175	n.s.	20,012,900	n.s.	1,977,998	3,000,000	4,079,276	3,000,000	4,079,276
O&M costs	Baht/month	7,167	16,602	22,667	67,288	3,750	10,657	3,917	11,679	8,000	14,681
Electricity savings	Baht/month	59,978	100,980	1,155,000	494,802	29,920	41,616	28,463	92,363	59,978	92,400
Fertilizer selling	Baht/month	20,000	12,410	0	52,122	n.s.	9,916	n.s.	19,862	15,000	20,075
LPG Savings										25,000	n.s.
Fertilizer production	kg/day	n.s.	816	0	3,427	n.s.	330	n.s.	653	100	660
Net present value (NPV)	Baht	3,343,690	5,501,228	87,936,067	31,273,730	1,336,449	1,335,491	2,654,763	7,021,365	6,711,819	7,085,700
Net present value (NPV)/ m^3 fermenter	Baht/m^3	2,675	4,401	7,328	5,957	1,909	2,671	2,655	7,021	6,712	7,086
Payback Period (PBP)	Year	5,64	5,21	4,07	4,58	5,11	5,65	6,44	3,82	3,86	3,91
Internal rate of return (IRR)	%	18%	22%	30%	26%	19%	18%	18%	30%	33%	30%

Data source: Figures in the right columns from feasibility studies. Figures in the left columns own calculations.

The differences between the figures in the feasibility studies and those for the plants in operation are caused by a number of factors observed during the field research compared to the projected performance. These are summarised in the following table[118].

Table 10: Factors which were different during field research compared to feasibility studies

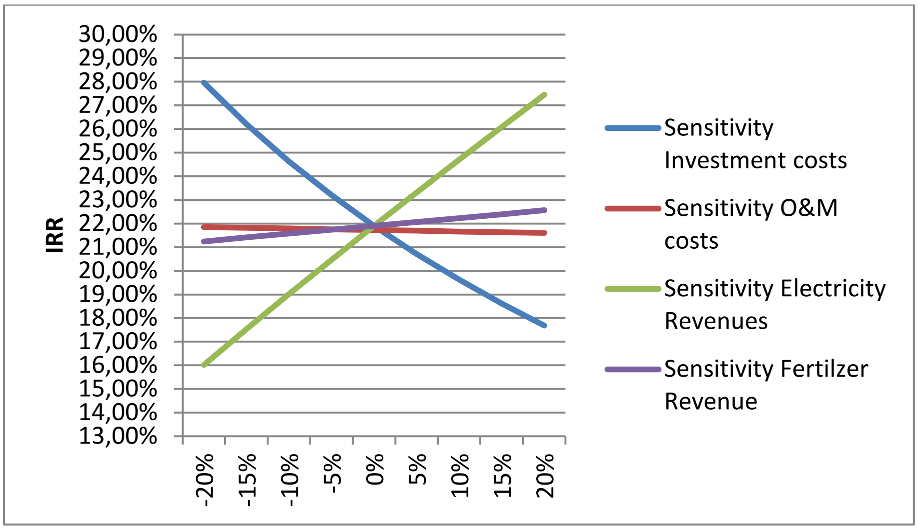
Factor	Farm A in practice	Farm C in practice	Farm D in practice	Farm E in practice
Need to take out a loan	No loan	No loan		
Investment costs			Lower	Lower
O&M costs	Lower	Lower	Lower	Lower
Electricity production	Lower	Lower	Lower	
Sale of fertilizer	Higher			Lower
Additional income through other co-products				Yes

6.3.2 Sensitivity analysis of financial performance

In the next step we have undertaken a sensitivity analysis of the key performance statistics that emerged in the original calculations as being functions of IRR or NPV, using farm A as an example. First we have analysed the investment costs, O&M costs, electricity revenues and fertilizer revenues, changing their values within a range of +/- 20%. The impact of investment costs and electricity revenues on the IRR is very high, while variations in the O&M costs and fertilizer revenues were found to have little effect.

118 Plant B has been excluded from the comparison. For this plant its final built size was double that projected in the feasibility study, and so the operating parameters are not comparable any more.

Figure 21: Sensitivity analysis on the IRR of farm A when alternating investment costs, O&M costs, electricity revenues and fertilizer revenues +/- 20%

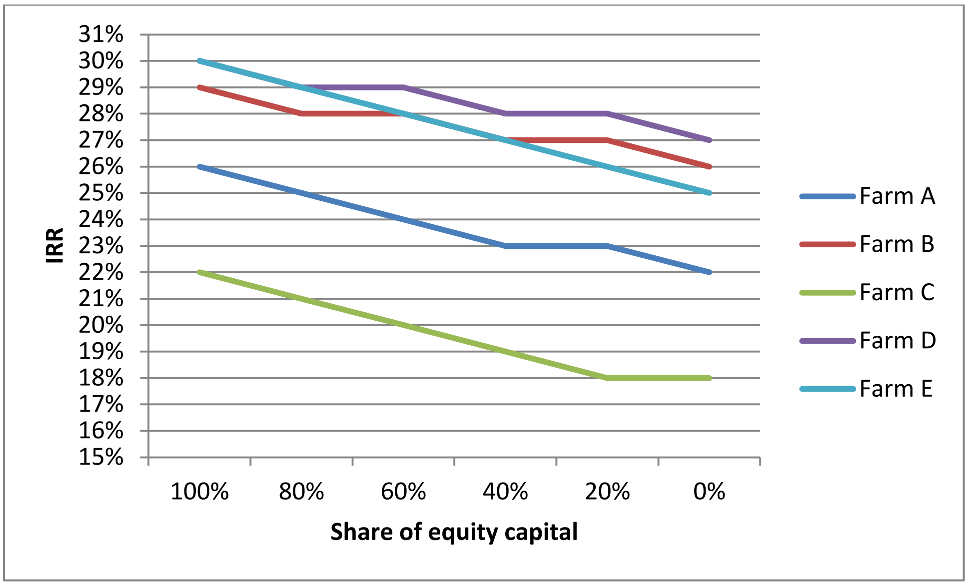


The electricity generated from the biogas was assumed to be used on the farm, thus removing the need to purchase electricity at the retail price (which was fixed at 3.0 Baht/kWh). The graph below shows the effect on IRR and NPV of varying the electricity price from 1 Baht/kWh to 9 Baht/kWh. The NPV becomes positive at an electricity price of 2.0 Baht/kWh. Below this price the NPV is negative. The IRR reaches the hurdle rate of 15% at an electricity price of 2.5 Baht/kWh.

Figure 22: Sensitivity analysis on the IRR and NPV of farm A when alternating the electricity price

A further analysis showing the influence on the owner's share of capital investment (between 100 and 0%) on the IRR is displayed in the graph below. Even with 0 % equity capital, the IRR reaches the hurdle rate of 15% for all farms:

Figure 23: Sensitivity analysis on the IRR of farm A,B, C, D and E when alternating the share of equity capital between 0 and 100%



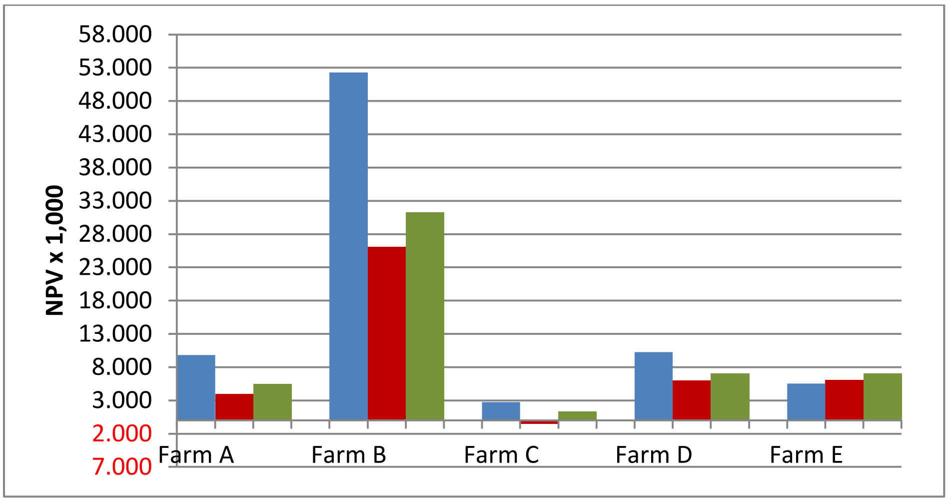
Scenario analyses

As demonstrated above, both investment costs and electricity generation have a high impact on financial viability. For the investment costs all plant owners received a subsidy amounting to more than 25% of the equipment costs, plus construction and design costs. Our interviews showed that the amount of electricity produced in most of the farms was far too low. At the same time, we have also seen that the engine is the weakest component in all plants. Based on these two aspects - investment costs and the volume of electricity produced - we have now developed two corresponding scenario analyses to examine their influence on IRR and NPV:

In one scenario we have calculated the IRR and NPV of the plants assuming that they don't receive any subsidy or financial support for the construction costs. For the construction costs we have assumed 5% of the total investment costs.

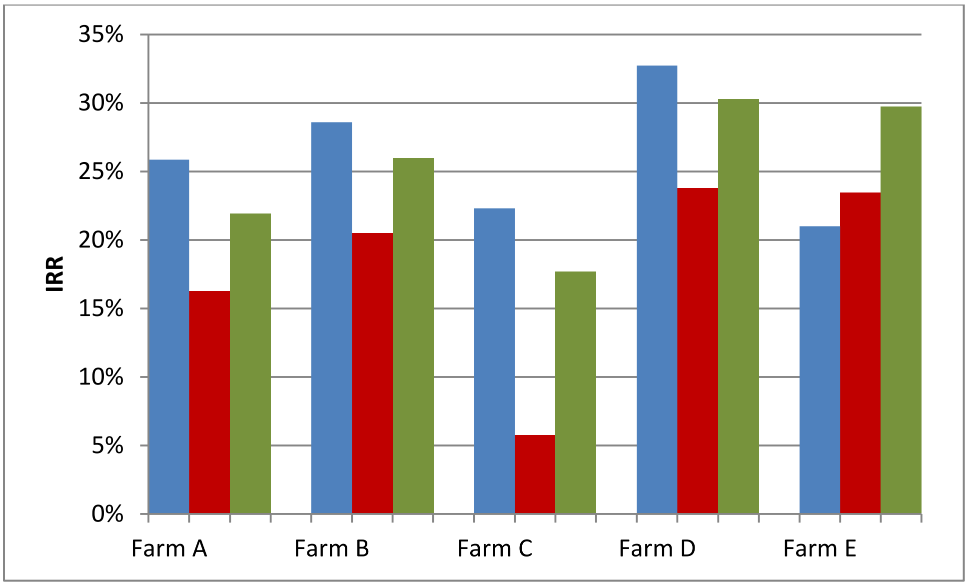
In the other scenario, we have assumed that the low electricity output is being caused by the use of inexpensive generators. We further propose that, by investing more capital in more expensive and high-quality generators with a better performance, electricity generation can be increased and maintenance costs for the generator can be decreased. Therefore, in our scenario, we have doubled the price of the generator and reduced the cost of the 4-year engine overhaul. The engine overhaul costs have been calculated in feasibility studies at 35% of the purchase price. We have assumed 30% for our scenario. We have also assumed that, because of the improved generator, the electricity output will be higher. To determine the increased output, we used the replacement fraction that could be achieved with a generator of type "Guascor" - the feasibility study lists the output of this model at 2.0 kWh/m² instead of the 1.2 kWh/m² for the generator used. The graphs show the impact of both scenarios on NPV and IRR, as compared to the feasibility studies. Without the subsidy, four of the plants were still financially viable; just the smallest plant has an NPV below 0 and an IRR of just 6%. Investing in a better engine turns out to be highly profitable, assuming that the electricity output can be increased as a result:

Figure 24: Scenario analysis of farm A, B, C, D and E and effect on the NPV when assuming a higher electricity output (left columns), deleting investment subsidies (middle columns); compared to feasibility study (right columns)



Blue: More expensive engine, higher electricity output
Red: Without subsidies plus construction costs
Green: Feasibility study

Figure 25: Scenario analysis of farm A, B, C, D and E and effect on the IRR when assuming a higher electricity output (left columns), deleting investment subsidies (middle columns); compared to feasibility study (right columns)



Blue: More expensive engine, higher electricity output
Red: Without subsidies plus construction costs
Green: Feasibility study

6.3.3. Final results for the four categories

The original objectives of the farm owners in installing a biogas plant were able to be achieved. All interviewed farmers indicated that they had been able to solve their problems with odour and flies and were able to offset between 50 and 90% of their electricity consumption through electricity generated by the biogas plants. One farm could secure their electricity supply through the biogas plant. In the following paragraphs we will evaluate the four performance categories. For the financial performance category we can use the performance criteria of NPV, IRR and SPB as calculated. For the other three categories, we have just a selection of variables. Even if we cannot rate the criteria of these categories to draw any final conclusions, we will still evaluate the variables involved. We will also take into consideration the "lessons learned" cited by Shresta about the same program in 2006.

Financial performance

The pig farm program has been successful in terms of financial profits for the plant owners. Even if the originally calculated NPVs and IRRs are not being achieved by two of the plants, they are all still reaching a positive NPV and an acceptable IRR, which is higher than the hurdle rate. One of the smaller farms is even achieving a higher IRR than planned. Since this is the plant which uses the biogas to produce electricity and additionally to generate heat for cooking, it clearly demonstrates the influence of co-utilization of the produced biogas on financial viability.

The subsidies available against capital costs were considered as being a key success factor. Our calculations have underlined their high impact on the financial viability, but they also show that bigger plants can produce a positive NPV and IRR without these subsidies. On the other hand, for smaller plants the investment subsidies are crucial, as they might not even reach a positive NPV without the subsidies.

One reason for the lower NPV and IRR values compared to those calculated in the feasibility studies is the lower electricity output. Since the farmers do not measure the biogas production rate, we have no indication as to whether the plants are producing less biogas in practice, or if the reason rather lies in the conversion of biogas to electricity. Here, it would have been interesting to compare different performance criteria, such as the specific biogas volume, the availability factor and the manpower input. We have identified variables from different performance criteria which might lead to the reduced gas production, although we were not able to calculate values for the criteria involved, and so the following observations must be taken as assumptions:

- The investment costs for the farms were all lower than in the original estimates. This could indicate cost cutting by means of buying cheaper technology with lower performance, in order to achieve higher short-term profits.
- The O&M costs were all lower than calculated the original estimates. This could be an indicator that not enough effort is being spent on proper operation and maintenance, leading to lower gas production. The frequent occurrence of sand blockages noted by the farm owners would support this conclusion.
- Even as far back as 2006 the evaluation report recommended that trained technicians should be present on site. This is now also required by financing banks. However, our interviews showed that many farm owners consider trained technicians to be too expensive, and instead just use their regular farm workers to maintain the biogas plant.
- As also indicated in the evaluation study of 2006, the use of modified diesel engines is very common in Thai biogas plants. By doing this, plant owners can save in capital expenditure because these engines are cheaper. However, maintenance is more expensive and these engines require a general overhaul every 3-5 years. Most of the interviewed plant owners indicated having had problems with the engines, with the plant frequently being brought to a standstill. At the same time, our calculations have shown that the use of more expensive engines might result in higher profits owing to the increased electricity production.

Operational functionality

The evaluation of 2006 emphasized that more robust systems are necessary to avoid technical failures and complicated operation and maintenance. This advice seems to have been heeded now in terms of the fermenter. None of the farmers had any problems with the fermentation process, so the Chiang Mai Digesters can be seen as being very well adapted to the requirements of the pig farm biogas plants. However, here we only have the the statements of the plant owners and of ERDI to go on - since we did not obtain any data about operating parameters we cannot make any statements as to how this assumption matches the facts. The fermentation process might be stable, but still not reaching optimal values, so that the biogas production is not actually producing optimal yields.

Socio-economic efficiency

The evaluation study recommends linking the subsidy with an obligation on owners to properly operate, maintain and monitor the plant for a full year after installation. According to our experience this mandatory period of one year is not sufficient. Lack of attention to both operation and monitoring could be observed on almost all plants. At the same time the visited biogas plants showed a high potential for performance improvements, therefore proper operation and maintenance is a crucial precondition. ERDI has already been putting effort into improving the O&M on farms and into enhancing the plant owners' knowledge of their plants. It is distributing a guideline covering all operational steps and the maintenance work that has to be carried out.

Another area for improvement lies in the area of manpower management, for example, the absenteeism we noted during construction, giving rise to construction delays.

The variation in the planned life of the plant, as stated by the plant owners, demonstrates the lack of a long-term management strategy for the plant's commercial use. The owners' apparent indifference to its economic performance during the interviews also reflects this fact.

We don't have any data whether the obligatory environmental standards have been met. The release of excessive gas into the environment and the outstanding CDM approval of two of the biogas projects could be seen as indicators that emissions still have to be improved. Another indicator for this assumption is that none of the farms needed any permits, even those situated within a village.

Technical functionality

For some of the plants the design had not been carried out properly, particularly in that the special requirements for the rainy season had not been taken care of. This was illustrated by the lower gas production during the rainy season - because the waste water and rain pipes had not been separated. This failure has a high impact on profitability. Another indicator here was the overflowing of the ponds in the rainy season, probably because they are under-dimensioned.

The 2006 study recommends that systems should to be delivered in turn-key form, and not as separate modules. Our findings failed to find any connection between the installation of a turn-key plant and the attaining of higher profits. Rather, to the contrary, the farm which operates as calculated beforehand in the feasibility study is made up from components from different suppliers. Nevertheless, because of the limited number of interviews conducted, no general assertion can be made here.

The lack of safety technology and health & safety measures on almost all of the farms was striking. Only one farm had implemented a combination of safety regulations and technical measures. On the other farms, either a flare, or an extinguisher, or control boxes were installed, so not all dangers are covered. The missing safety measures combined with a lack of insurance are assessed as being a high risk factor.

We have already mentioned the problems that are occurring through the use of modified diesel engines. One might assume a better solution would be to buy special biogas plant engines. Two of the farmers had done this, only then to encounter problems with the services provided by the manufacturer. The engine suppliers use security technology to tie customers in to their own maintenance services. For owners of smaller plants, this might not always be the best solution because of the disproportionally high costs.

6.3.4 Barriers identified by a literature review

We have found few other studies which evaluate the Thai biogas market. A recent study conducted by the IUJ Research Institute of the International University of Japan aimed to identify typical barriers for the implementation and operation of CDM biogas projects in Thailand.[119] The authors analysed 48 Thai CDM projects which generate biogas from starch, tapioca and palm oil industrial waste. The study consists of two parts – analyses of the barriers before the installation of biogas plants and during their operation. The barriers involved before installation of the plant cited by the study were mainly the lack of skilled and trained staff, the lack of local technology providers and the high sensitivity of AD systems owing to the operating parameters. The barriers during the operational phase according the study involve again the lack of training and know-how on the part of both operators and plant managers, lacking management strategies and of supervision (since a biogas business is usually only a marginal activity amongst other commercial activities) and over-optimistic figures from the suppliers of the technology.

The report entitled “Role of Renewable Energy for Productive Uses in Rural Thailand”[120], already mentioned before, distinguishes between the barriers to promoting the technology and the barriers to its proper utilization and maintenance. Barriers to its promotion are financial, owing to the high amounts of capital involved and the difficulties in estimating the size of investment due to the fluctuating prices for the fuel used. In addition, informational barriers such as lack of awareness and technical barriers like the non-availability of products suited to local needs and institutional barriers are mentioned by the authors. The barriers to proper utilization have two aspects. One involves the hierarchical approach used in government projects, where communities do not become involved in the decision making process and, for example, are not able to choose the most suitable technology by themselves. The other is that some biodigesters are very sensitive to the quality of the organic matter, resulting in high operation and maintenance effort.

[119] c.f. Suzuki et al.: 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, 2010
[120] ibid., c.f. Shresta, 2006

Papong identified institutional barriers, policy barriers, technical barriers and informational barriers. Institutional barriers result from poor conditioning among different government agencies and with the private sector. Regarding policy, technical and informational barriers, the study cites: “Government policy to support SPPs through bidding process has drawn interest and private sector investments, but this measure seems to bias in favour of large scale and low power production cost SPPs. Technical barriers occur due to a lack of standards on bioenergy systems and equipment. Information barriers consist in a lack of awareness in available new and renewable source of energy technologies.”

7. Evaluation

7.1 Final evaluation of the Thai biogas market taking a multi-dimensional perspective

In this paragraph we want to classify the information resulting from our own findings as well as from the literature review according the multi-dimensional approach, taking into account the different project phases in the biogas energy value chain and the interests of different stakeholders. As the data we collected are just from a limited number of plants, which we don’t considerate sufficiently to be representative for the whole sector, we will make a number of assertions concerning the barriers to bankability for the project stakeholders during the main project phases. These assertions will have to be verified in further assessments where more detailed data is available.

1. Initial project phase: project assessment

This is the phase when a project idea is born and a go/no-go decision is taken as to whether a project will be initiated or not. This decision will depend upon the answers to the questions about the availability and conditions of finance, appropriateness of the project site, availability of both, feedstock and appropriate technology and the estimated benefit.

Assertion: Training for banks on adequate financing mechanisms would increase the number of biogas projects which receive a grant and therefore also increase the total number of biogas plants constructed.

Depending on the type of investor or financing institution, requirements for the bankability of a biogas project can vary. “While banks typically emphasize the impact of stable cash flows on the project’s long-term debt service, equity investors tend to focus on their expectations on investment returns, possible tax incentives and their portfolio strategies."[121] Nowadays, Thai banks appear to be fairly familiar with financing of biogas projects[122]. Siteur recently collected data on the number of biogas projects financed by major Thai banks, and came up with a number between 21 and 23. Considering the total market potential, this is rather a moderate number. According our expert discussions, Thai banks still finance most biogas projects according a corporate financing model instead of a project finance mechanism. Therefore weak financial performance on behalf of the proposing company is seen as one of the major risks when lending money for biogas projects. Furthermore, this has a number of disadvantages for the borrower, as it does not permit off-balance sheet treatment of the finance.

Assertion: The assessment criteria used by banks hinder the development of innovative biogas technologies.

Another risk factor which is considered to be high by the banks is technological risk. One measure for keeping this risk under control is by asking for a minimum of 10 years' experience on behalf of the technology provider. This presents a conflict of interest between innovative technology developers and the requirements of the banks. If younger technologies don't have the chance to receive finance, the development of innovations will be stifled.

Assertion: Preferential treatment when financing bigger biogas projects hinders the further development of smaller biogas plants.

Besides the financing of biogas projects by banks, capital is also provided by private investors, frequently by the BOOT model (Build-Own-Operate-Transfer). The very successful and first fully commercially-financed industrial biogas project was the Khorat Waste to Energy project (KWTE)[123]. The advantage of BOOT capital is that it is available for new and innovative technologies – such as was the case for KWTE at that time. Currently about 20 BOOT projects are under way[124]. Nevertheless, both bank financing and private financing through the BOOT scheme favour large scale projects[125]. In the future, this fact could turn out to be a hurdle for the further exploitation of the country's biogas market, since the most of the unexploited potential seems to ly with smaller agro-industrial companies.

A third form of financing used in Thailand is Carbon Finance under the Clean Development Mechanism (CDM). Two of the projects we visited have applied for Certified Emission Reductions but are still waiting their approval. This form of financing is also more suitable for projects above

[121] ibid. Hampl et al., 2011, p. 3
[122] Siteur: Rapid Development of Industrial Biogas in Thailand: Factors of Success, 2012
[123] Plevin et al.: "Converting Waste to Energy and Profit", 2004
[124] ibid. Siteur, 2012
[125] ibid. c.f. Siteur, 2012, Shresta et al., 2006

a certain size. “Registering a project under CDM is complicated, lengthy and expensive.”[126] Adequate resources are necessary if a company wants to go through this process.

Assertion: New business models are necessary if the full potential of the Thai biogas market is to be developed.

The pig farm biogas project was a program aimed at promoting the implementation of biogas plant in small to medium sized farms. According to our current understanding, few other programs exist that target smaller farms. Most biogas plants build in the last decade are installed at large agricultural concerns, however the number of such concerns is limited. To allow the full potential of the feedstock available to be exploited, business models are necessary which will incentivise the implementation of biogas plants using the feedstock available on smaller farms. Therefore further research is necessary e.g. about community based concepts. For example, it might be possible to implement biogas plants in communities (with participation of the farmers) to produce decentralized energy for a village using the collected feedstock from a number of smaller farms - and to distribute the profits to a variety of shareholders.

Assertion: Subsidies for capital costs are essential for smaller plants, while bigger plants can be financially viable even without subsidies.

The impact of investment costs is particularly high for smaller plants. In our calculations, subsidies for capital expenditure have been found to be a precondition for the financial viability of plants smaller than 1000 m^3 fermenter size. Bigger plants on the other hand can operate at a positive NPV without this subsidy. Therefore subsidies on the investment costs encourage the spread of the technology, but a stronger distinction should be made about plant size if the development of biogas plants on smaller agro-industrial companies is to be encouraged too.

Assertion: The encouragement of heat utilization and co-generation could considerably improve the financial viability of biogas plants and could open up a huge field of optimization of Thai biogas plants.

To date, no market incentive exists to promote the use of the other forms of energy that are generated by biogas plants. As many Thai biogas plants are directly connected to industrial concerns, the use of the heat produced as well as the electricity should be advantageous. Our interviews have shown that few plants use this heat, even though the calculations in section 6.3 demonstrated that it can improve the plant’s profitability.

[126] ibid. Siteur, 2012

2. Planning phase

In this phase the biogas plant is designed, contracts with suppliers and other project partners are finalised.

Assertion: Thai R&D centres have developed effective biogas systems suitable for the specific regional requirements, but more effort should be given to the development of local manufacturers.

Our research shows that over the last decade effective biogas systems suitable to the feedstock and environmental conditions of the Thai biogas market have been developed. This is probably mainly due to the biogas research centres such as that at Chiang Mai University, at the King Mongkut`s University of Technology Thonbury (KMUTT) or at the National Center for Genetic Engineering and Biotechnology (BIOTEC). The technologies such as UASB and others show high degradation rates for organic matter and are widely used on tapioca-, palm oil or animal farms. They have even been exported to other countries, such as the AHR plant of the company ECO Waste, which has been exported to Nigeria[127]. However, a lack of equipment and of any local technology providers was reported in the other studies consulted for the current thesis[128]. This lack of equipment has been verified by our own research regarding the availability of locally produced engines, which formed the weakest part of the swine farm biogas plants we visited. The farmers had either to use modified diesel engines (resulting in energy losses and need for frequent repair), or to import engines at higher cost and with higher associated maintenance costs (since the repairs can only be undertaken by the foreign companies themselves). We could not find any data as to whether the same problems occur for other components of high-tech plants; additional research would be necessary here. Our hypothesis is that there is a gap regarding the overall biogas industry value chain: research and development should more tightly coupled to industry, so producing a more practical approach to the needs for further research locally.

Assertion: Lack of data on biomass availability and its typical characteristics gives rise to uncertainties in calculations on plant size, energy output and the selection of suitable plant location.

Estimations of the exact feedstock potential differ, the same for their geographical distribution. This might result in difficulties regarding the planning of the number (total market capacity) and plant size (individual plant capacity) for additional biogas installations in the next years.

[127] c.f. Pongrai: "The biogas boom", 2010

[128] ibid., c.f. Suzuki, 2010

A lack of data could also be observed on the level of feedstock quality regarding its characteristics, which are crucial for planners to calculate plant dimensioning and energy yields. Here, an official guideline and official data would be necessary, similar to those provided by the KTLB[129] in Germany, which can be an important instrument to improve the quality of the whole planning process. Nevertheless, to collect these data governmental support would be required.

Assertion: A lack of technical standards in combination with the absence of domestic technology suppliers, results in the import of inadequate technology not adapted to specific climatic requirements.

According the interviews conducted with plant designers, foreign biogas technology imported to Thailand frequently manifests problems during operation. A main source of failure is the material used to make the equipment. Often the longevity of components in hot and humid conditions is not ensured. This could be avoided by standardizing e.g. material requirements.

Assertion: Incorrect dimensioning of biogas plant is a frequent occurrence and leads to the underperformance of many biogas plants.

According the statements of those plant designers interviewed, wrong dimensioning of biogas plants is a frequent cause for bad performance. This might be the result of the absence of reliable data about feedstock characteristics mentioned above. Nevertheless, the collected data is not sufficient to draw a final conclusion.

Assertion: Particularly on small-scale plants, incentives should be given to hinder short-term savings on the equipment purchase at the expense of long-term profits.

The conducted interviews had proven savings on equipment costs at small-scale plants. In our scenario analysis we have found undiscovered potentials to improve the plant performance by applying high-quality equipment (engines). Financial incentives or education measures could help to promote the positive long-term effects on financial return when applying quality of better quality.

3. Construction phase

After all contracts are concluded, the building permits have been obtained and the construction plans have been finished, the biogas plant will be built.

Assertion: The lack of a single stakeholder who takes overall responsibility for the construction process often results in difficulties during the building of biogas plants in Thailand.

[129] "Kuratorium für Technik und Bauwesen in der Landwirtschaft"

Our interviews have uncovered a multitude of problems during the construction phase. The main hurdle seems to be the missing of single responsible stakeholder for the overall process. We suspect that that a contractual gap occurs when biogas plants that have been developed according to one of the university digester designs are realized by a private building company. Especially in the case of biogas projects promoted by the Thai government, such as for the pig farm program, the biogas plant design developed by a research centre is used as the basis for the actual implementation. Usually a private plant designing company adopts the university design to meet any specific local requirements. Here, questions of liability should be clearly defined between the research centres, the plant designer and the building company.

Assertion: A lack of responsibility occurs when handling government subsidies.
Our interviews have uncovered problems during the construction process, particularly where subsidies are involved. Therefore, control mechanisms should be implemented during the construction phase to prevent fraud when government subsidies have been granted.

4. Operational phase

During the operational phase a continuous and high gas production should be maintained. A proper operation and maintenance ensures a long life-span of the plant.

Assertion: Although O&M is an important issue for financing institutions, there is still a lack of knowledge about the benefits and costs of O&M amongst plant operators.
An effective O&M strategy is crucial for banks when making a loan as it lowers the risk of bad performance, and certainly has a strong influence on the long-term stable functioning of the plant. Effective O&M is also of overall importance for the plant owner as it assures their income. Effective O&M means: ensuring efficient, safe and reliable process operations; being aware of the status of all equipment; conducting maintenance in a safe and efficient manner with the aim of optimizing the performance of the plant. All these processes lead to an optimal plant performance and ensure high energy yields dependant on the plant's size. However, smaller farms in particular appear to try to save costs, especially in the area of operation and maintenance, by disregarding the above. Calculations in the sensitivity analysis have shown that increased O&M costs lower the IRR or NPV just slightly, so it would be better to spend more money and effort on these in order to improve the revenue through reliable performance of the plant.

Assertion: For many plant owners the biogas plant is only a secondary business activity; this is reflected in lack of attention being paid to the biogas business by management.
Having a long-term business strategy for the biogas plant is part of its effective administration by

the plant owner. The hypothesis that these plants suffer from lack of management attention, which has also been verified by other studies[130], was confirmed during our interviews by the low effort spent in monitoring, the lack of concern about the actual life-time of the plant and the low interest about the potential for increase revenue through higher energy production. The reason given by the IUJ study is that generating biogas is only a marginal activity in between other commercial activities. Another reason - especially for smaller plant - is the additional expenditure which would be necessary for monitoring equipment. Since the result of this lack of attention runs contrary to the interests of a plant owner in increasing their revenue, it can only be put down to being due to a lack of awareness.

Assertion: The lack of technical standards results in frequent technical failures and can shorten the lifetime of biogas plants, so resulting in a financially unviable plant.

According our understanding there are no common technical standards published on the Thai biogas market regarding feedstock processing, plant materials, laboratory controls or design and construction. The effect of these missing standards is apparent, for example, in the frequent engine damage observed on the plant during the field research visits (which were probably due to an excess concentrations of H_2S and insufficient gas cleaning) as well as in the frequent occurrence of accidents. The introduction of technical standards would benefit all stakeholders. The production of standardised equipment by the manufacturers increases the quality of the technology. Standardised processes, materials and components increases the reliable functioning of biogas plants, improving energy yield for plant owners and facilitating the work of operators.

Assertion: Safety issues in biogas plants impair the public image of biogas technology and are a risk to the surrounding environment of a biogas plant.

Because of their sensitive operational sensitivity, biogas plants are a potential source of accidents. Leaks in gas conveying systems caused by cracks in the foil roof, corrosion of gas pipes, incorrectly installed gas pipes can all lead to explosions, as has occurred in the past. Too high a concentration of H_2S can lead to engine damage or to injury to people. The fermenter can collapse because of faulty mechanical structures. Other sorts of damage can occur in the agitators, tanks and control equipment. It is important that safety measures, such as adequate distances, fire and explosion protection measures and safety devices such as gas measurement systems, flares, flashback arresters, and central emergency stop-systems are used together with the implementation of shut-down criteria and general and occupational safety regulations. A series of serious accidents in Thai biogas systems have already resulted not only in injuries and even the death of workers at biogas plants, but also in damage to the public image of biogas

[130] ibid., c.f. Suzuki et al., 2010

systems.

Assertion: Training for plant owners and operators would help to prolong the life of biogas plants and increase their efficiency.

Most AD systems are very sensitive because of their delicate operating parameters; they react to even the smallest changes in quality of the organic matter and fermenter biology. A shortage of suitably skilled labour on the Thai biogas market has been noted in many studies[131]. Training about the concepts of anaerobic digester systems at a management level and about operations for technical personal could help rebalance the experience shortfall and enhance the employees' understanding of the complex biological processes involved.

Assertion: Although high environmental standards exist in Thailand, the potential for environmental protection and emission reductions through biogas plants have not been fully exploited.

Biogas plants have a high impact on environmental protection and make an important contribution to emission reductions through the use of agro-industrial waste in Thailand. Nevertheless, our interviews have shown that inspections are neither conducted on a regular basis nor by an independent institution, resulting in a lack of control of actual emissions.

Assertion: Particularly on smaller plants, not enough attention is given to the monitoring of process parameters. This hinders any attempt to optimize the biogas production and energy generation.

None of the farms visited during our field research had the necessary equipment to monitor basic process parameters. According our interviews with other stakeholders, biogas plant owners frequently try to lower their investment costs by cutting expenditure on monitoring equipment. In the long term these cost cutting measures can produce exactly the opposite result, especially when biogas or energy yields are not optimal, because no analysis is possible into the reasons for the low output.

7.2 Evaluation of the methodology and further recommendations

In our original considerations for assessing the financial viability or the "bankability" of renewable energy plants, we proposed that focusing exclusively on typical financial ratios is not sufficient. Depending on the individual perspectives of the different stakeholders, the term "bankability" can take different meanings. Therefore, a comprehensive performance analysis is

[131] ibid., c.f. Suzuki et al., 2010, CDM Validation Report N. 2010-IQ-27-MD, Prasertsan, 2006

necessary in which additional metrics are included; these in turn can have consequences for financial metrics such as NPV or IRR.

Based on an analysis of the stakeholders involved in the various project phases of planning, building and operating a biogas plant, we have devised an assessment scheme consisting of 4 categories, each with two to three indicators (performance criteria). These are in turn influenced by a variety of variables. Using the categories operational functionality, technical functionality, socio-economic functionality and financial performance, a description is possible of the bio-chemical process parameters in the fermenter, the technology, organizational structures and management actions along side the financial results.

Using the example of the 5 biogas plants examined here, we have seen how all the plants achieved good to excellent results in terms of financial performance. In respect of the IRR all plants were above the hurdle rate. The NPVs for all systems were positive, such that not only has the investment been recouped, but additional profits are also being generated. However, a comparison between the NPVs and IRRs originally forecast in the feasibility studies suggests that, in spite of the above, the plants are not yet running optimally, since the values obtained in practice mostly came in under the forecasts. An examination of a selection of the variables from the other 3 categories has confirmed this suspicion, even when, unfortunately, the characteristic values for these categories could not be calculated - which would have provided conclusive proof of our results. It has come to light that in the areas of technical functionality and socio-economic functionality, several variables do not reach their optimum values. In the category of biogas production, unfortunately our data is too patchy to allow any conclusive statements.

The discrepancy between the financial performance and the other two categories shows that our approach to the evaluation of biogas plants is a viable option that can deliver findings about overall performance and reveal the potential for improvement. Since we could only calculate performance criteria for financial performance, we are not able make any statements about the quality of these criteria. This should be verified in further studies using concrete data. The exact assignment of the variables to the different categories should also be checked to see if it is actually warranted in practice.

Great difficulties arose however in the collection of the data. Looking back, we can see four areas of weaknesses lay in: the planning of the field survey in terms of the research design, the interview preparation, inadequate adaptation of the survey to the cultural norms and conventions of the country concerned, and in practical issues when actually conducting the interviews in the country.

In planning the survey for the research, the boundaries for the objects to be studied were defined inadequately. Only a loose definition was made - that 7 plants processing agricultural residues and 7 processing waste streams should be investigated. Here, further differentiation of the substrates as well as additional definitions such as narrowing down the size of the plant should have been made.

When preparing for the survey, the issue arose that when actual interviewees had to be found and appointments set for interviews, no interviewees could be found who were willing to participate in the planned survey. It was only after a "gatekeeper" was found that it became possible to motivate interviewees to participate in the survey. Here, our recommendation for further studies is to identify and involve a similar gatekeeper at an early stage. It should also be borne in mind that this may require a significant lead time.

The developed questionnaire was not adequately tuned for the interview partners. During the interviews, it came to light that many of the parameters involved are not measured by operators of smaller or medium-sized plants in Thailand. This shows how a particular view of efficiency - based on the analysis of the values of characteristics - can not be transferred 1:1 to other cultures. Unfortunately, it was not possible to carry out any interviews with operators of large-scale plants, and we can only assume that the necessary measuring devices are probably installed here, so that the data could have been obtained for these. Therefore, this issue is connected with the first issue - a more precise definition of the research objects in advance.

In the actual survey undertaken in Thailand, language and cultural barriers were apparent. The necessity for translation shortened the effective time that was available for answering the questions, and at the same time led to the loss of information. On questions concerning sensitive data the interviewees showed clear evasiveness. We therefore recommend that interviews of this sort should be conducted by someone with fluency in the local language, who should ideally come the same culture as well from, so that the trust of the interviewee can be established more quickly. Here, the 4-step model "Getting access" in Chapter 5 was found to be invaluable.

8. Conclusion

Renewable energy technologies have already a long history in Thailand, particularly in the bioenergy sector, but their expansion was dominated by government programs until the beginning of the liberalization of the energy market 20 years ago. This changed when the country opened up the market for private participation in energy generation, with the aim of meeting the growing energy demand and securing the country’s future energy supplies, amongst other reasons. Today, Thailand has one of the most vigorous renewable energy markets in the ASEAN region, with active involvement of the private economy. However, the transformation of the energy sector is not yet complete, and it will only become successful in the long-term if it faces up to issues relating to both political and economic accountability, as well as transparency and involvement of the general public. The liberalization of the energy market is always a societal project, and there has to be consensus on a multitude of factors affecting many different areas if it is to be a success. These must include answers to questions covering issues such as training, standards, safety, technology, environmental standards, financial outcomes, to name but a few. In this study we have developed a multi-criteria approach to analyze the technology currently in place against a number of these factors.

The findings of the study have shown that the opening up of the power generation side of the energy market - through its partial liberalization with the introduction of Small and Very Small Power Producers - has driven forward the installation of new renewable energy systems. Barriers at a political level such as a lack of coordination between the different organizations involved in renewable energy technologies, identified in earlier studies, have been resolved, firstly through the establishment of the Energy Ministry in 2002 and subsequently through a clearer definition of responsibilities such as by the enactment of the Energy Industry Act in 2007. Through the introduction of financial incentives and research programs (in particular in the field of bio-energy) the growth of the market has already been and can still be further stimulated.

Nevertheless, in the absence of a specific renewable energy law, the further development of the renewable energy sector will remain uncertain irrespective of the official statements. This ambiguity at a political level has a concrete impact at the level of the practical application of the technologies. In the current study, we uncovered hurdles such as inadequate financing mechanisms that hinder the diffusion of new and innovative technologies; incomplete use of the generated energy potential, lowering the financial outcome; lacking availability of data as a basis for a reliable planning process; lacking safety measures resulting from inadequately defined technical standards and causing public resistance to the technology; under-performing plant, where cost-cutting measures had been imposed that adversely affected the most important components, and which arose out of poor education about the technology and its commercial use.

The development of a split market over the course of recent years is notable, with the growth of large-scale plants on the one hand (the main focus of interest of investors, manufacturers and other stakeholders in this period) and small-scale plants on the other. The latter segment is characterized by a large need for improvement in terms of the availability of finance, the applied technology, applicable business models and inadequate education of the owners (usually farmers).

Further, if the recently increased development goals for biogas plant capacity by 2022 are to be reached, it will be crucial to bring these small to medium sized plants into focus, because the potential amongst multi-feedstock, large agro-industrial concerns has already been exhausted during the boom years. And if the focus is really set on these smaller plants in the next phase of growth, this could also turn out to be advantageous for a weak point in Thailand's growing economy; that is by encouraging economic growth in rural areas where the remaining areas of poverty are concentrated. Biogas plants could contribute to value creation in these regions of the country.

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Annex

Questionnaire for biogas plants

Economic calculations feasibility study farm A

Economic calculations field research farm A

Sensitivity calculations farm A

Sensitivity calculations equity capital all farms

Energy reservers Thailand by EPPO 2011

Questionnaire for biogas plants

Personal data

Name:	
Role/ function (in respect of biogas plant):	

1. General data

Location of plant (name of town/region):

Ownership structure:

Please describe the project - structure and participants *(e.g. owner, operator, project developer, EPC-contractor, commercial or technical service provider, feedstock supplier, authoritiy, bank…):*

Stakeholder	Company or name	Contract or activity
e.g. EPC-contractor	*Company XY*	*Turn-key ready installation*

Objectives for implementation of biogas plant:

In case of off-grid plant:
Name of region/ town/ village to be supplied with electricity generated by biogas plant:

Size of geographical area:	
Number of habitants (total):	
Number of habitants to be supplied by plant:	
Prior electricity supply (fuel and quantity):	

Prior electricity consumption:		kWh/year
Percentage that must be provided by the plant:_____		%

Biogas is used on own facility: ☐yes ☐no

For which purpose?:	

Electricity consumption (total): ___		kWh/year
Percentage provided by the plant:		%

In case of grid-connected plant:

Do you use the electricity produced by the plant also for your own demand? ☐ yes ☐ no

Electricity consumption (total):		kWh/year
Percentage provided by the plant:		%

2. Location and logistics

The biogas plant is built in: ☐ a settlement area ☐ a rural area

Who owns the land the biogas plant is build on?	
Please describe if there are relevant local land use regulations:	

Please indicate the distances to:

Electricity feed-in point		meter
Or: Mean voltage cable		meter
Heat consumer I (e.g. own stable)		meter
Heat consumer II (other facilities, neighbours)		meter
Feedstock supplier I		meter
Feedstock supplier II		meter
Hydrant		meter

Is the plant connected to a public street? ☐yes ☐no

(In case of plants run by solid feedstock such as crops, agricultural waste etc.):

The feedstock: ☐ is delivered by supplier to the plant

☐ is picked-up by plant operator/owner
☐ is produced by the plant operator/owner on his own farm

How often do you receive a feedstock delivery?	
Which quantity of feedstock do you receive with each delivery?	

(In case of waste water plants):
The waste water is provided by: ☐ own farm/factory ☐ external farm/factory

Raw materials the factory/farm is processing:	
Length of pipelines to biogas plant:	

Can you describe any problems which occurred in the past related to the feedstock delivery?

3. **Feedstock**

Please indicate your feedstock supplier and costs:

Type	Supplier	Used amount	Price	Transport costs per year
		t/year	THB/t	THB
		t/year	THB/t	THB
		m^3/year	THB/m^3	THB
		m^3/year	THB/m^3	THB

Please describe the feedstock:

Feedstock	Used load per day in t/day	Concentration of dry matter in %	Concentration of organic dry matter in %	Gas yield in m^3/tFM	Concentration of methan in %

FM = fresh matter

Feedstock (waste water)	Used load per day in m³/day	Concentration of COD in kg/day	Concentration of Oil/Grease in kg/day	Gas yield in m³/tCOD	Concentration of methan in %

COD = chemical oxygen demand

4. Energy yields

Capacity of biogas plant		kW
Operating time of biogas plant		days/year
Annual biogas yield		m³/year
Biogas send to gensets		m³/year
Biogas send to flare		m³/year
Methan concentration before purification		%
Heating value of biogas		kWh/m³
Capacity of purification system		m³/day
Methan concentration after purification		%
Combined heat and power plant:		
Operating time of CHP		days/year
Electrical capacity		kW
Electrical efficiency indicated by manufacturer		%

Electrical efficiency reached		%
Thermal capacity		kW
Thermal efficiency indicated by manufacturer		%
Thermal efficiency reached		%
Annual electricity production		kWh/year
Amount of electricity fed into the grid		kWh/year
Amount of electricity sold to other users		kWh/year
Annual heat prodction		kWh/year
Amount of heat sold		kWh/year
Own electricity consumption of plants		kWh/year
Own heat consumption of plants		kWh/year

Do you have a possible use for the heat? ☐ yes ☐ no

How much heat can you use?		kWh/year
Where do you use the heat for or who do you sell it to?		

5. **Digestion process**

Biological control: ☐by plant operator ☐with support of manufacturer

others:	
Laboratory contract with:	
Periods of biological control:	

Please indicate the data of the fermenter processes:

Parameter	**Unit**	**Median**	**Min.**	**Max.**
Processing capacity per day	tsubstrate/day			
Fermenter volume	m^3			
Hydraulic retention time	m^3Fv/ tsubstrate per day			
Volumetric loading	kgODM/m^3 and day			

Or: Volumetric loading	kgCOD/m³ and day			
pH value				
Temperature in fermenter	°C			
Carbon	kg/tFM			
Nitrogen	kg/tFM			
Phosphate	kg/tFM			
Sulfur	kg/tFM			
Hydrogen sulfide	g/l			
Ammoniac	g/l			

FV = fermenter volume ODM = organic dry matter COD = chemical oxygen demand

Can you describe any problems which occurred in the past in the digestion process?

FM = fresh matter

6. Planning and Construction

Did you conduct a feasibility study? ☐yes ☐no
Did you conduct:a legal due diligence? ☐yes ☐no
a financial due diligence? ☐yes ☐no
a technical due diligence? ☐yes ☐no

Who carried out the planning?	
Who carried out the construction?	

Commissioning has been undertaken? ☐yes ☐no
A completion certificate is existing? ☐Yes ☐no

How long did it take to obtain the construction permits?	
Which other permits did you need?	

Construction commence:		month/year
Construction end:		month/year

Commercial operations date (planned):		month/year
Commercial operations date (achieved):		month/year
Commercial operations period planned (total):_____		years

7. Technology

In case of: Purchase of a turn-key facility:

Provided by the manufacturer:	
Please specify the guaranteeing (period, services):	

Did you obtain a completion guarantee by the contractor? ☐yes ☐no
Does the plant have a certification? ☐yes ☐no

If yes: according to which standard?:		
Planned economic lifetime:		years

In case of: Purchase of a facility composed of equipment from different suppliers:

Component	Manufacturer	Please specify the guaranteeing (period, services)	Please specify the certification	Planned economic lifetime

Fermenter and storage

	Number	Manufacturer	Design (e.g.concrete, steel, bricks…)	Capacity per unit in m³
Manure/waste storage				
Waste water lagoons				

Silo for feedstock				
Main fermenter				
Secondary fermenter				
Digestate storage				
Biogas storage				
Electricity storage				

Feedstock preparation

Technologies used for preparation	Manufacturer	Please specify the guaranteeing

Substrate injection in fermenter

Technology used for injection	Manufacturer	Please specify the guaranteeing

Stirring technology

Number of stirrers	Type of stirrers	Manufacturer	Please specify the guaranteeing

Purification system

Type of purification	Manufacturer	Capacity	Please specify the guaranteeing

Combined heat and power plants

Number	Manufacturer	kWel per unit	Guaranteed efficiency	Design	Please specify the guaranteeing

				☐gas engine ☐pilot injection engine	
				☐gas engine ☐pilot injection engine	

Monitoring technology

Type of monitoring technology	Parameter to monitor	Manufacturer	Please specify the guaranteeing

Did any problems occur with the technologies/ components indicated above? Please specify:

Component	Kind of problem	Could you repair the component?	Did you have to exchange the component?
		☐yes ☐no	☐yes ☐no
		☐yes ☐no	☐yes ☐no
		☐yes ☐no	☐yes ☐no

Could you indicate:

… the time the plant is out of operation due to damage?		hours/year
… the time the plant is out of operation due to revision?		hours/year
… the time the plant is out of operation due to other factors?		hours/year
Could you specify these factors?:		

8. Insurances

Do you have an insurance for: physical damage/ machinery failure ☐yes ☐no
fire damages ☐yes ☐no
accidents ☐yes ☐no
interruption of plant operation ☐yes ☐no

general liability ☐yes ☐no
construction work ☐yes ☐no

Other insurances:

---

9. Contracts

Do you have a: grid connection contract? ☐yes ☐no
power purchase agreement? ☐yes ☐no
heat supply contract? ☐yes ☐no
digestate supply contract? ☐yes ☐no
feedstock delivery contract? ☐yes ☐no

Other contracts:

---

10. Utility interconnection

Did you have to undertake a commissioning for the plant? ☐yes ☐no
Do you have a Power Purchase Agreement? ☐yes ☐no

Can you describe any problems which occurred related to utility interconnection?

12. Expertise of staff

Please describe the qualification of the plant operator (profession, degree, years of professional experiences):	

Has the operator worked with biogas plants before? ☐yes ☐no
Did the operator take part in any training course for biogas plants? ☐yes ☐no

Who takes care about repairings?: the operator ☐yes ☐no
a service company ☐yes ☐no

Others:

---

13. Economics

Could you specifiy your initial costs?:

Planning and design	THB
Construction	THB
Buildings	THB
CHB plant	THB
Fermenter	THB
Stirring technology	THB
Purification system	THB
Electronic components	THB
Pipelines	THB
Grid connection	THB
Land costs	THB
Other	THB

Financing

The plant was financed by equity capital only: ☐ yes ☐ no

% of total capital costs have been financed by debt capital.

Provider of debt capital:	
Debt term:	years
Interest rate:	%
	% of total capital costs have been financed by other sources.
Type or provider of other financial sources (grants, etc.):	

Operation and maintenance

Please specify the amount of work:

Job	Time	
Total time for construction		hours/ month
Operation of plant		hours/ month
Maintenance of plant		hours/ month
Repairing		hours/ month
Administration		hours/ month
Others:		hours

How much water do you need to operate the plant?:		liter/year
Do you need other fuels to operate the plant? If yes, which type (diesel, kerosene …):		liter/year
Electricity consumption of the plant:		kWh/year
Heat consumption of the plant:		kWh/yer

14. Co-products

Please specifiy the type and amount of co-products you sell:

(Co)-product	Amount	
Electricity		kWh/year
Heat		kWh/year
Steam		
Digestate		t/year
Other:		

Please specifiy the type and amount of (co)-products you use yourself:

(Co)-product	Amount	
Electricity		kWh/year
Heat		kWh/year

Steam		
Digestate		t/year
Other:		

15. Environmental benefits

Can you name and quantify environmental benefits, e.g. odor reduction, methan diffusion reduction, use of fertilizer):

Economic calculations for biogas plant

Farm A: data from feasbility study

Loan rate	8,00%	/year
Inflation rate	3,00%	/ year
Energy value added	4,50%	/ year
labor wage added	2,80%	/ year
Loan	4 682 175	baht/ year
Loan period	7,00	year
Working day of biogas system	365	/ year
Working day of energy production syst	330	/ year

Fundamental information			Energy replacement	replacement ratio	replacement fraction			unit price			Income	per day		per year	
- MC-UASB biogas production system size	1.250	m^3	Produce electeicity	100%	1,20	1.224	kWh/day	Electricity	3,00	baht/kWh	Produce electeicity	3.672	baht	1.211.760	baht
- Waste water load	266	m^3/day	Replace LPG	0%	0,46	0	kg/day	LPG	0,00	baht/kg	Replace LPG	0	baht	0	baht
- Produced biogas	1.020	m^3/day	Replace fuel oil	0%	0,55	0	litre/day	Fuel oil	40,00	baht/litre	Replace fuel oil	0	baht	0	baht
- produced fertilizer	816,00	kg/day	fertilizer trading			816,00	ton/day	Fertilizer	0,50	baht/kg	fertilizer trading	408	baht	148 920	baht
- water recycle	0	m^3/day	replace ground water			0	m3/day	Ground water	0	baht/m^3	replace ground water	0	baht	0	baht

Year	0	1	2	3	4	5	6	7
Investment								
- Biogas system construction	4.122.175							
- Energy converter (Generator,Burner,Boiler)	1.600.000							
- Consultant, survey, system design, construction, installatio	0							
-Financial support for biogas production system	1.040.000							
Total investment	4.682.175							
Income								
- Produce electeicity		1.211.760	1.266.289	1.323.272	1.382.819	1.445.046	1.510.073	1.578.027
- Replace LPG		0	0	0	0	0	0	0
- Replace fuel oil		0	0	0	0	0	0	0
- fertilizer trading		148.920	153.388	157.989	162.729	167.611	172.639	177.818
- replace ground water		0	0	0	0	0	0	0
- reduce electricity consumption from previous system		0	0	0	0	0	0	0
Total income		**1.360.680**	1.419.677	1.481.261	1.545.548	1.612.657	1.682.713	1.755.845
Expense								
- Electricity cost from biogas system		5.834	6.097	6.371	6.658	6.957	7.270	7.598
- labor wege		36.000	37.008	38.044	39.109	40.205	41.330	42.488
- Maintenance cost of biogas system								
per year		82.444	84.917	87.464	90.088	92.791	95.575	98.442
follow the maintenance program (plastic change etc.)	147.393					165.892		
- Maintenance cost of Generator, Burner, Boiler etc.								
per year		80.784	83.208	85.704	88.275	90.923	93.651	96.460
follow the maintenance program (overhaul etc.)					560.000			
- Interest	199.228	350.048	296.538	243.027	189.517	136.006	82.495	28.985
Total expense		**555.110**	507.767	460.611	973.647	532.773	320.322	273.972
Net cash flow	4.682.175	805.570	911.910	1.020.651	571.901	1.079.884	1.362.391	1.481.873
Cummulative cash flow	4.682.175	3.876.605	2.964.695	1.944.044	1.372.143	292.259	1.070.132	2.552.005

Year	8	9	10	11	12	13	14	15
Investment								
- Biogas system construction								
- Energy converter (Generator,Burner,Boiler)								
- Consultant, survey, system design, construction, installatio								
-Financial support for biogas production system								
Total investment								
Income								
- Produce electeicity	1.649.038	1.723.245	1.800.791	1.881.826	1.966.508	2.055.001	2.147.476	2.244.113
- Replace LPG	0	0	0	0	0	0	0	0
- Replace fuel oil	0	0	0	0	0	0	0	0
- fertilizer trading	183.153	188.647	194.307	200.136	206.140	212.324	218.694	225.256
- replace ground water	0	0	0	0	0	0	0	0
- reduce electricity consumption from previous system	0	0	0	0	0	0	0	0
Total income	1.832.191	1.911.892	1.995.097	2.081.962	2.172.649	2.267.326	2.366.170	2.469.368
Expense								
- Electricity cost from biogas system	7.939	8.297	8.670	9.060	9.468	9.894	10.339	10.805
- labor wege	43.677	44.900	46.157	47.450	48.778	50.144	51.548	52.991
- Maintenance cost of biogas system								
per year	101.395	104.437	107.570	110.797	114.121	117.545	121.071	124.703
follow the maintenance program (plastic change etc.)			192.314					222.944
- Maintenance cost of Generator, Burner, Boiler etc.								
per year	99.354	102.336	105.405	108.567	111.824	115.179	118.634	122.193
follow the maintenance program (overhaul etc.)	676.800				594.104			
- Interest								
Total expense	829.166	259.969	460.116	275.874	878.295	292.762	301.593	533.637
Net cash flow	1.003.025	1.651.923	1.534.981	1.806.088	1.294.353	1.974.564	2.064.578	1.935.731
Cummulative cash flow	3.555.030	5.206.953	6.741.935	8.548.023	9.842.376	11.816.940	13.881.518	15.817.249

Net present value (NPV, baht)	5.501.228
Payback Period (PBP, year)	5,21
Financial internal rate of retuen (FIRR, %)	22%

Economic calculations for biogas plant

Farm A: data from field research

Loan rate	8,00%	/year
Inflation rate	3,00%	/ year
Energy value added	4,50%	/ year
labor wage added	2,80%	/ year
Loan	4.682.175	baht/ year
Loan period	7,00	year
Working day of biogas system	365	/ year
Working day of energy production syst	330	/ year

Fundamental information			Energy replacement	replacement ratio	replacement fraction			unit price			Income	per day		per year	
- MC-UASB biogas production system size	1.250	m^3	Produce electeicity	100%	1,20	727	kWh/day	Electricity	3,00	baht/kWh	Produce electeicity	2.181	baht	719.730	baht
- Waste water load	266	m^3/day	Replace LPG	0%	0,46	0	kg/day	LPG	0,00	baht/kg	Replace LPG	0	baht	0	baht
- Produced biogas	1.020	m^3/day	Replace fuel oil	0%	0,55	0	litre/day	Fuel oil	0,00	baht/litre	Replace fuel oil	0	baht	0	baht
- produced fertilizer	816,00	kg/day	fertilizer trading			816,00	ton/day	Fertilizer	0,50	baht/kg	fertilizer trading	408	baht	240.000	baht
- water recycle	0	m^3/day	replace ground water			0	m3/day	Ground water	0	baht/m^3	replace ground water	0	baht	0	baht

Year	0	1	2	3	4	5	6	7
Investment								
- Biogas system construction	4.122.175							
- Energy converter (Generator,Burner,Boiler)	1.600.000							
- Consultant, survey, system design, construction, installation and operation	0							
-Financial support for biogas production system	1.040.000							
Total investment	4.682.175							
Income								
- Produce electeicity		719.730	752.118	785.963	821.331	858.291	896.915	937.276
- Replace LPG		0	0	0	0	0	0	0
- Replace fuel oil		0	0	0	0	0	0	0
- fertilizer trading		240.000	247.200	254.616	262.254	270.122	278.226	286.573
- replace ground water		0	0	0	0	0	0	0
- reduce electricity consumption from previous system		0	0	0	0	0	0	0
Total income		959.730	999.318	1.040.579	1.083.586	1.128.414	1.175.140	1.223.848
Expense								
- Electricity cost from biogas system		5.834	6.097	6.371	6.658	6.957	7.270	7.598
- labor wage		36.000	37.008	38.044	39.109	40.205	41.330	42.488
- Maintenance cost of biogas system								
per year		30.000	30.900	31.827	32.782	33.765	34.778	35.822
follow the maintenance program (plastic change etc.)	147.393					165.892		
- Maintenance cost of Generator, Burner, Boiler etc.								
per year		20.000	20.600	21.218	21.855	22.510	23.185	23.881
follow the maintenance program (overhaul etc.)					560.000			
- Interest								
Total expense		91.834	94.605	97.460	660.404	269.329	106.564	109.788
Net cash flow	4.682.175	867.896	904.713	943.119	423.182	859.085	1.068.576	1.114.061
Cummulative cash flow	4.682.175	3.814.279	2.909.566	1.966.447	1.543.265	684.180	384.396	1.498.456

Year	8	9	10	11	12	13	14	15
Investment								
- Biogas system construction								
- Energy converter (Generator,Burner,Boiler)								
- Consultant, survey, system design, construction, installation and operation								
-Financial support for biogas production system								
Total investment								
Income								
- Produce electeicity	979.453	1.023.528	1.069.587	1.117.719	1.168.016	1.220.577	1.275.503	1.332.900
- Replace LPG	0	0	0	0	0	0	0	0
- Replace fuel oil	0	0	0	0	0	0	0	0
- fertilizer trading	295.170	304.025	313.146	322.540	332.216	342.183	352.448	363.022
- replace ground water	0	0	0	0	0	0	0	0
- reduce electricity consumption from previous system	0	0	0	0	0	0	0	0
Total income	1.274.623	1.327.553	1.382.733	1.440.259	1.500.232	1.562.759	1.627.951	1.695.922
Expense								
- Electricity cost from biogas system	7.939	8.297	8.670	9.060	9.468	9.894	10.339	10.805
- labor wage	43.677	44.900	46.157	47.450	48.778	50.144	51.548	52.991
- Maintenance cost of biogas system								
per year	36.896	38.003	39.143	40.317	41.527	42.773	44.056	45.378
follow the maintenance program (plastic change etc.)			192.314					222.944
- Maintenance cost of Generator, Burner, Boiler etc.								
per year	24.597	25.335	26.095	26.878	27.686	28.515	29.371	30.252
follow the maintenance program (overhaul etc.)	576.800				594.104			
- Interest								
Total expense	689.910	116.535	312.380	123.706	721.562	131.326	135.314	362.370
Net cash flow	584.712	1.211.018	1.070.353	1.316.553	778.670	1.431.433	1.492.637	1.333.552
Cummulative cash flow	2.083.169	3.294.187	4.364.540	5.681.093	6.459.763	7.891.196	9.383.833	10.717.385

Electricity cost (baht/kWh)	2,42
Net present value (NPV, baht)	3,343,690
Payback Period (PBP, year)	5,64
Financial internal rate of retuen (FIRR, %)	18%

Sensitivity calculations farm A

		-20%	-15%	-10%	-5%	0%	5%	10%	15%	20%
Sensitivity Investment costs		27,97%	26,21%	24,63%	23,20%	21,90%	20,72%	19,63%	18,62%	17,68%
Sensitivity O&M costs		21,85%	21,82%	21,79%	21,76%	21,90%	21,69%	21,66%	21,63%	21,60%
Sensitivity Electricity Revenues		16,01%	17,53%	19,02%	20,47%	21,90%	23,31%	24,71%	26,08%	27,45%
Sensitivity Fertilzer Revenue		21,25%	21,41%	21,57%	21,74%	21,90%	22,07%	22,23%	22,40%	22,56%
Electricity Price		16,00%	18,00%	19,00%	20,00%	21,90%	23,00%	25,00%	26,00%	27,00%

Sensitivity calculations all farms

		Farm A	Farm B	Farm C	Farm D	Farm E
Owner's Sha	100%	26%	29%	22%	30%	30%
	80%	25%	28%	21%	29%	29%
	60%	24%	28%	20%	29%	28%
	40%	23%	27%	19%	28%	27%
	20%	23%	27%	18%	28%	26%
	0%	22%	26%	18%	27%	25%

TABLE 1.3-1
ENERGY RESERVES
31 DECEMBER 2011

ENERGY TYPE (ORIGINAL UNIT)	RESERVES* P1	RESERVES* P1+P2	RESERVES* P1+P2+P3	PRODUCTION 2011	AVAILABLE FOR USE (YEAR) P1	AVAILABLE FOR USE (YEAR) P1+P2	AVAILABLE FOR USE (YEAR) P1+P2+P3
PETROLEUM							
- CRUDE OIL (MMBBL.)	215	598	807	50	4	12	16
- CONDENSATE (MMBBL.)	239	545	671	28	9	20	24
- NATURAL GAS (BCF)	10.061	20.854	27.423	996	10	21	28
LIGNITE (M. TONS)	**1.181**	**2.007**	**2.007**	**21**	**55**	**94**	**94**

ENERGY TYPE (KTOE)	RESERVES* P1	RESERVES* P1+P2	RESERVES* P1+P2+P3	PRODUCTION 2011	AVAILABLE FOR USE (YEAR) P1	AVAILABLE FOR USE (YEAR) P1+P2	AVAILABLE FOR USE (YEAR) P1+P2+P3
PETROLEUM	**306.245**	**661.931**	**867.741**	**34.770**			
- CRUDE OIL	29.337	81.720	110.401	6.813	4	12	16
- CONDENSATE	29.706	67.822	83.548	3.476	9	20	24
- NATURAL GAS	247.202	512.388	673.791	24.481	10	21	28
LIGNITE	**339.752**	**577.222**	**577.222**	**6.135**	**55**	**94**	**94**
TOTAL	**645.997**	**1.239.152**	**1.444.962**	**40.905**			

ENERGY TYPE (MMBBL CRUDE OIL EQUIVALENT)	RESERVES* P1	RESERVES* P1+P2	RESERVES* P1+P2+P3	PRODUCTION 2011	AVAILABLE FOR USE (YEAR) P1	AVAILABLE FOR USE (YEAR) P1+P2	AVAILABLE FOR USE (YEAR) P1+P2+P3
PETROLEUM	**2.240**	**4.841**	**6.346**	**254**			
- CRUDE OIL	215	598	807	50	4	12	16
- CONDENSATE	217	496	611	25	9	20	24
- NATURAL GAS	1.808	3.747	4.928	179	10	21	28
LIGNITE	**2.485**	**4.222**	**4.222**	**45**	**55**	**94**	**94**
TOTAL	**4.725**	**9.063**	**10.568**	**299**			

REMARK: P1 = PROVED RESERVES, P2 = PROBABLE RESERVES, P3 = POSSIBLE RESERVES
SOURCES: * DEPARTMENT OF MINERAL FUELS