

Rapid deployment of industrial biogas in Thailand: Factors of success

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Abstract

Over the last decade, Thailand has experienced a remarkable increase in the deployment of biogas plants at industries such as starch mills, breweries and palm oil mills. Industrial biogas has become a main stream technical option, particularly for cassava-based starch mills, and is seen as a way to enhance productivity and competitiveness. While 10 years ago financing was difficult to obtain for these projects, currently several local banks are providing financing.

This paper provides an assessment of the rapid development of the industrial biogas sector in Thailand, with the objective to identify driving factors and extract lessons that could be applied elsewhere. Technical and financial government support to renewable energy, in particular the ability to sell excess electricity to the grid, as well as the strength of the industrial sector, are considered the main driving factors for the rapid industrial biogas development.

Introduction

In the early 2000s, there were only a handful of biogas systems at industrial facilities in Thailand. Since then, more than 100 biogas projects have been implemented, which provide considerable savings in energy expenses and reduce environmental impacts by efficiently treating large volumes of waste water. Furthermore, they provide additional revenue streams from the sales of electricity and emission reductions.

In parallel, financing for biogas has undergone a rapid development. While 10 years ago financing was hard to obtain, currently several local banks are providing financing for industrial biogas projects. In contrast, biogas developments in neighbouring countries such as Vietnam and Indonesia have been lagging.

In order to learn from this rapid development, a study was undertaken to identify driving factors. In particular, the study reviewed financing mechanisms and the role of the banking sector, as well as regulatory and institutional settings that have figured in the sector's development. The assessment is based on a review of background materials, discussions with representatives from banks, investors, developers and industries, as well as the author's experience in clean energy financing in South-east Asia.

Institutional Framework

This section reviews the institutional and regulatory setting in Thailand to provide a context for the discussion of the development of industrial biogas. It also reviews the main government support measures in place for renewable energy (RE) and energy efficiency (EE).

KEY ENERGY AGENCIES

The main government agency in charge of the energy sector is the Ministry of Energy (MOE), established in 2002 to overcome the lack of coordination among more than 20 institutes under 9 ministries involved in energy issues. MOE has overall responsibility for managing the energy sector and developing national strategic energy plans and targets. The ministry

oversees a number of agencies and state-owned enterprises, of which the following are most relevant for EE and RE (USAID, 2007):

- *Energy Policy and Planning Office (EPPO)*: implementation arm of the National Energy Policy Council chaired by the prime minister, responsible for developing energy policies, measures, and plans;
- *Department of Alternative Energy Development and Efficiency (DEDE)*: main implementing agency for compulsory and voluntary EE and RE programs, including EE promotion, energy conservation regulation, development of alternative energy, and dissemination of energy technologies. DEDE publishes (since 2005) annual statistics on alternative energy, including an alternative energy balance;
- *Electricity Generating Authority of Thailand (EGAT)*: state enterprise responsible for generating and supplying electricity nationwide through two other state enterprises, the Metropolitan Electricity Authority (MEA) and the Provincial Electricity Authority (PEA).

In addition, the passage of the Energy Industry Act, in 2007, established the Energy Regulatory Commission (ERC) as the independent regulatory agency for the sector. ERC's main responsibilities are monitoring the energy market, electricity tariff regulation, licensing and dispute settlement.

POLICIES AND REGULATIONS

Thailand's economy depends highly on imported fossil fuels, with 85 % of crude oil and 57 % of coal imported in 2011. This has been a driver for stimulating RE development over the last two decades. The Thai government has been actively promoting and supporting energy conservation and renewable energy through a variety of policies and regulations.

ENCON Act and Fund

In 1992, Thailand took a pivotal step in the promotion and implementation of EE and RE with the decree of the Energy Conservation Promotion Act (ENCON Act). The Act includes a number of programs to stimulate energy conservation investments in factories and buildings. The compulsory program, implemented by DEDE, requires that designated¹ factories and buildings conduct energy audits and submit energy conservation plans every three years. The voluntary program, implemented by EPPO, promotes and supports EE and RE programs, e.g., public awareness campaigns and promotion of natural gas vehicles (NGVs). In addition, EGAT conducts labelling for electrical appliances such as air conditioners, refrigerators and rice cookers.

Following the ENCON Act, the government also established the Energy Conservation Promotion Fund (ENCON Fund). Its main source of funding is the Petroleum Fund, which is based on a levy on the domestic sales of gasoline, diesel, kerosene, and fuel oil. The ENCON Fund has an annual budget allocation of about THB 150 million (APERC, 2010). Through the ENCON Fund, the government has been able to promote and

support hundreds of EE and RE programs and projects since 1995 (USAID, 2007).

MOE has used significant funding from the ENCON fund to directly stimulate investments in EE and RE, mainly through these initiatives:

- *30 % Subsidy Program*: Implemented during 2002 and 2003, the program's objective was to support designated factories and buildings to implement EE projects. DEDE covered 30 % of the capital costs as a grant, with the project owner covering the rest (USAID, 2007).
- *Energy Efficiency Revolving Fund (EERF)*: Launched in 2003, with an initial budget of THB 2 billion (€50 million), the fund provided low-interest² loans to local banks for on-lending to clients. The maximum loan size was THB 50 million (€1.25 million) and the maximum interest rate banks could charge their clients was 4 %, with a maximum term of 7 years. By 2011, a total of 13 public and commercial banks were participating, extending some US\$500 million loans in support of around 250 projects. The program ended in late 2011.
- *ESCO Venture Capital Fund*: Launched in 2008, with an initial capital of THB 500 million (€12.5 million) the fund aims to address the lack of equity capital for RE developers. The Fund invests equity capital up to 50 % of total equity. In the case of very small projects, it provides equipment leasing (APEC, 2010).
- *Tax Incentives*: Investments in the purchase of EE and RE equipment/machinery can be reclaimed through corporate tax deduction (APERC, 2010).

Private Sector Power Producer programs

To reduce the investment costs of the Electricity Generating Authority of Thailand (EGAT), a number of programs promote private sector investment in power generation. These include the independent power producer (IPP), small power producer (SPP), and very small power producer (VSPP) programs, of which the latter is the most relevant to biogas.

The VSPP regulations allow customers with renewable energy generators to connect to the grid and to offset their consumption at retail rates. The distributing utilities (PEA and MEA) are obliged to purchase the net surplus of electricity generated, at the same tariff that they purchase electricity from EGAT. Initially restricted to projects up to 1 MW, in 2006, the program was expanded to include RE generators up to 10 MW. At the same time, a subsidy called an 'adder' was introduced, which is paid in addition to the base tariff for a period of seven years. The cost of the adder is financed by a pass-through mechanism to all electric power customers. The value of the adder depends on the renewable energy fuel. For biogas, projects below 1 MW receive an adder of 0.50 Baht/kWh (~1.2 Euro cents), and projects above 1 MW get 0.30 Baht/kWh (~0.7 Euro cents) (Palang Thai, 2006).

The introduction of the adder led to a sharp increase in RE project development and the number of VSPP applications.

1. Facilities with electricity demand of more than 1 MW or energy consumption of more than 20 TJ per year (excluding onsite RE-based energy use)

2. Initially interest to the banks was 0 %, later on set at 0.5 % to cover administrative costs

By the end of 2011, there were 1,110 MW of renewable energy connected to the grid through the VSPP program with 6,252 MW under development and review. All biogas-based power supplied to the grid falls under the VSPP program, and accounts for 17 % of VSPP's contracted capacity.

The government has been somewhat overwhelmed by the number of applications, particularly from solar PV projects, and in recent years has responded with fairly ad-hoc measures, affecting the entire RE industry. Since 2010, the number of new applications and approvals has reduced considerably, and few new PPAs have been signed (Tongsopit and Greacen, 2012). At the end of 2011, the government stopped accepting new VSPP applications and is currently in the process of preparing a Feed-In-Tariff (FIT) mechanism to replace the adder subsidy. Existing projects will continue to receive the adder until the end of the 7-year period.

Alternative Energy Development Plan (AEDP 2012–2021)

To stimulate the development of EE and RE, the Thai government has developed a number of successive energy development plans. In 2011, it announced the 10-Year Alternative Energy Development Plan (AEDP 2011–2021), which replaced the earlier Renewable Energy Development Plan (REDP 2008–2022). The new plan has set the target to increase RE consumption to 25 % of the total energy consumption by 2021, with specific targets for different technologies. In 2010, renewable energy accounted for 19.1 % of total energy consumption (DEDE, 2011). Under the REDP, the target for biogas was set at 120 MW in 2022. Since this was already exceeded in 2011, the new plan set the biogas target at 600 MW by 2021, a five-fold increase from the earlier plan (DEDE, 2012).

It should be noted that the REDP's short-term targets for 2011 were easily surpassed for solar and biogas, but other technologies such as wind and biomass fell rather short. Partly, this could be attributed to the fact that these technologies are more resource constrained. For example, compared to biomass resources such as rice husk and corn cobs, industrial waste water has no alternative use or economic value, and is unsuitable for transport over larger distances.

Apart from AEDP, Thailand has four other long-term energy development plans, focusing on specific sectors and resources. These are prepared by different government agencies with little coordination among these, and there is no unified energy plan. Therefore, elements of some of these plans are conflicting. The Power Development Plan (PDP 2010–2030) projects future electricity demand and the required additional capacity, focusing on large-scale power plants to be built by EGAT and IPPs. As a result, the PDP and AEDP have diverging targets for RE (Tongsopit and Greacen, 2012).

Historical Development of Industrial Biogas

The development of biogas in Thailand can be understood to have had a number of phases, discussed below.

BIOGAS FROM LIVESTOCK (1950–2000)

Biogas technology was first introduced to Thailand in the 1950s, through efforts of Kasetsart University, Thailand's main agricultural university. During the 1960s, the Ministry of Health promoted household-size demonstration plants in ru-

ral areas, aimed at the hygienic disposal of animal manure and the production of cooking gas. After the oil crises of the 1970s and 1980s, the National Energy Administration (NEA) and the Department of Agricultural Extension (DAE) initiated biogas programs for rural energy on small farms. By 1988, about 5,500 biogas plants of 4–6 m³ digester size were constructed. However, 60 % of these plants never operated, or were quickly abandoned, mostly due to technical problems.

In 1988, GTZ launched the Thai-German Biogas Program, jointly implemented by DAE and Chiang Mai University. Under this program, which ran until 1996, several systems of various sizes were constructed in the northern and western regions of Thailand, partly supported through loans from the Bank of Agriculture and Agricultural Cooperatives (BAAC). Subsequently, in 1995, the National Energy Policy Office (currently EPPO), launched the National Biogas Dissemination Program for medium and large-scale livestock farms. The program installed 150 plants in medium-to-large swine farms using UASB technology, with the government subsidizing a portion of the instalment costs (BAU, 1999).

The livestock biogas programs were helpful to develop the technical capacity among agriculture, academic and government sectors and set the stage for later developments in industries. At a later stage, several university spin-off companies were established to benefit from the biogas opportunities at industries.

FIRST SYSTEMS AT STARCH MILLS (2000–2003)

Among the first industries to take up biogas were tapioca starch mills, one of the most important agro-industries in Thailand. The country is one of the world's biggest producers of tapioca starch, made from the cassava root. In 2011, the industry exported 2.7 million tons of tapioca starch worth €1.2 billion (TTSA, 2012).

As with most food processing facilities in Asia, starch mills use Heavy Fuel Oil (HFO) to operate their boilers and electricity from the grid for the balance of their operations. In addition, their waste stream is high in organics which makes it suitable for biogas generation. Starch production generates about 23 m³ of waste water per ton of starch, with a high organic concentration in the form of Chemical Oxygen Demand (COD)³ as high as 13,000–20,000 mg/l (EPPO, 2007).

Typically, the waste water is treated in a series of open lagoons. There is no legal requirement that the mills install more effective treatment systems. Nevertheless, the combination of high energy costs and large amounts of organic waste made the starch industry a suitable target for biogas development.

Government Supported Projects

The first starch biogas plants were partly funded by government subsidies. In 2000, the King Mongkut's University of Technology Thonburi (KMUTT) constructed a biogas system at Bangkok Interfood, which experienced severe odour issues from its open pond wastewater treatment, drawing complaints from neighbours. EPPO funded 25 % of the investment costs (APFED, undated).

3. COD is a measure of pollution for waste water and represents the amount of oxygen required to chemically oxidize the organic matter in a waste stream.

In 2003, EPPO launched a pilot demonstration of biogas in the starch industry with four different technologies in nine factories. The factories received grant support from the ENCON Fund through 4 agencies, including DEDE and Chiang Mai University. Biogas production from waste water at these 9 cassava starch plants was estimated at 36 million m³ per year, displacing 22 million litres of heavy fuel oil (EPPO, 2007). According to staff of DEDE's biogas division, the program had some difficulties in finding factories willing to join. The subsidy amounted to about 30 % of total project costs, with the remainder to be invested by the factories. Because of limited experience at industries, many factories were still hesitant to make such a large investment at the time.

First Commercial Project

The first fully commercially financed industrial biogas project was the Khorat Waste To Energy (KWTE) project, located at Sanguan Wongse Industries (SWI) in the north-eastern province of Nakhon Ratchasima. SWI is one of the largest cassava starch mills in Thailand, producing 1,000 ton of starch per day. Before the project the factory used more than 7.5 million litres of heavy fuel oil (HFO) and 35 GWh of grid electricity per year.

The biogas facility was developed by the company Clean THAI and designed by Waste Solutions Limited from New Zealand. It was setup on a Build-Own-Operate-Transfer (BOOT) basis, providing SWI savings of 20 % on its energy expenses, at no risk. KWTE is a separate legal entity that runs the plant for 10 years, after which SWI will assume ownership and responsibility for all operations. SWI provided the land for the facility and all of its wastewater.

Under the BOOT agreement, SWI committed to purchase all gas and electricity supplied by the biogas plant. KWTE bills SWI monthly, depending on its off-take of gas and electricity. The tariffs are set at 80 % of current prices of HFO and grid electricity, adjusted on a monthly basis. In case KWTE is unable to supply sufficient energy, SWI can revert to the grid and fuel oil for the balance of its needs. The boilers were upgraded with dual-fuel burners that can use either biogas or fuel oil. Since the start of commercial operation in 2003, SWI is nearly energy self-sufficient (Plevin et al., 2004).

Since banks were hardly willing to provide debt financing, the project was established with equity financing only, provided by E+Co, REEF, and Al Tayyar Energy, all international clean energy investors. Only the gensets were refinanced by the Industrial Finance Corporation of Thailand (IFCT), the leading Thai lender in EE and RE at the time.

RAPID BIOGAS DEPLOYMENT (2004–2011)

The success of KWTE was a significant turnaround for the industrial biogas sector. In comparison with earlier projects, the plant was established entirely on commercial terms. The project exceeded all expectations, even among its investors, and proved to be highly profitable, with a yearly IRR of 15–17 %. This prompted the development of similar BOOT projects and a general increased interest among starch mills, as well as technology suppliers and investors.

Thailand has 77 medium to large scale starch plants that operate almost year round. As of the end of 2011, around 50 out of these have a biogas system installed. The remaining plants are mostly smaller size factories, which have limited means to at-

tract capital or operate only seasonally so a biogas system might not be economical.

The BOOT projects provide significant costs savings to the host factories without requiring them to make an investment. Nevertheless, once the technology was shown to be successful, many factories opted to invest their own capital in a self-owned system, either through a self-built or turn-key solution. They considered this to be more economical in the long term, especially with the potential revenue from CERs, which would mostly go to the biogas plant investors. In addition, factories were generally able to obtain debt financing from local banks, mostly as part of overall corporate financing, while BOOT projects mostly relied on international private equity financing, further restricting their widespread development.

Palm Oil Mills

Following the rapid installation of biogas at cassava-based starch mills, other agro-industries became the target of developers and investors, in particular palm oil mills. There are around 60 medium to large palm oil mills in Thailand, mostly in the south of the country. By early 2012, most of these had a biogas systems installed, all since 2005. A total of 29 palm oil mills sell electricity to the grid under the VSPP program.

In contrast to starch mills, palm oil mills do not use biogas for their operations. Traditionally, the mills rely on palm fibre and shell as fuels to generate steam and electricity for their operations. Therefore, biogas development at palm oil mills was driven by factors other than energy savings. The potential revenue from the sales of electricity and CERs was an important driver for biogas in the palm industry. In addition, the mills' open pond wastewater treatment systems created serious odour problems. For example, one company was considering relocating one of its palm oil mills because of the odour affecting the community around the mill. The installation of a biogas system has, at least for now, postponed the need for relocation. Subsequently, the company installed biogas plants at two other mills.

It should be noted that the development of biogas at palm oil mills was initially faced with a number of technical challenges compared to starch mills. Palm Oil Mill Effluent (POME) has a considerable oil content, which affects the generation of methane. Furthermore, since palm oil mills generate their own power, they are often located in remote rural locations, where the electricity grid is relatively unstable, so the electricity generated cannot always be fed into the grid, leading to a loss in revenue.

Electricity Sales from Biogas

During the second half of the decade, numerous industrial biogas systems were connected to the grid to sell electricity under the VSPP program. Between 2005 and 2010, the amount of biogas-based grid electricity went from 2 to 214 GWh, representing an average annual increase of 161 %. This does not include electricity for own use by the factories, which could be in the same order of magnitude. For 2012–2016, an additional 90 MW of installed capacity from biogas is projected (DEDE, 2010).

By December 2011, a total of 71 biogas projects were supplying electricity to the grid, with a total capacity of 113 MW. An additional 111 projects with an installed capacity of 216 MW were in the approval process (EPPO, 2012).

Table 1. Grid Electricity from Biogas.

	Biogas Production (million m ³)	Electricity sold to grid (GWh)	Installed Capacity (MW)	Number of Projects
2005	2	2	7	8
2006	8	10	10	11
2007	12	14	8	17
2008	32	38	23	24
2009	73	83	60	42
2010	125	214	90	53

Source: DEDE (2010), EPPO (2012)

Table 2. Status of biogas projects under VSPP (Dec 2011).

Status	# Projects	Capacity (MW)
Applied	33	75
Approved	36	59
PPA Signed	42	83
Generating	71	113
Total	182	329

Source: EPPO (2012)

As mentioned above, since the end of 2011, no more new VSPP applications are accepted and the government is developing an alternative mechanism. It is unknown what the replacement program will look like and what its impacts will be on the RE sector. Most large scale industrial facilities already have a biogas system and have applied for VSPP, so changes in the tariff structure are expected to have limited impacts on the industrial biogas sector. Nevertheless, for the smaller facilities VSPP revenue would help to make a biogas system more economical.

CURRENT STATUS AND PROSPECTS

After the rapid development over the last few years, the biogas market for the starch and palm industry is currently rather saturated. All major facilities have a system installed or under development, and a biogas system is more or less seen as a must in terms of competitiveness and efficiency. There is still a market for new systems at smaller facilities, but due to their size and lower operating hours an investment in a biogas system is not always economically feasible, and these factories own limited financial assets restricting their access to bank loans.

Nevertheless, while the market for new systems is limited, there is a large scope for improving the performance of existing plants at starch and palm oil mills. Many biogas plants are underperforming, mostly due to operational procedures and limited technical skills. Since biogas is not part of the core business for the factories, limited priority is given to its proper operation. Operators and technicians are often inadequately trained and frequently replaced, and there is limited understanding

among factories of the impact of changes in the waste water stream coming from the factory on the biogas production.

Some biogas technology companies are now exploring opportunities in biogas from other types of feedstock, such as food processing waste, but these typically have higher costs per m³ of biogas and are less standardized than the waste from starch and palm oil mills. With support from the government, efforts are also underway to develop compressed biogas (CBG) for transportation.

Financing for Biogas

Following the review of the developments of industrial biogas over the last few years, this section discusses the role of different sources of financing. The main ones discussed are public funding, local banks, private equity and carbon finance.

PUBLIC FUNDING

The government has been providing funding for biogas through several mechanisms, originating mostly from the EN-CON Fund.

Direct subsidies

In the early 2000s, EPPO provided grant funding to some of the early starch biogas projects, covering around 30 % of the investment costs. Most of these projects were designed by universities adopting European technologies, such as UASB, to the local situation. Reportedly, many of these projects were not very successful in terms of performance, but nevertheless

helped to set the stage for later developments. To stimulate biogas development in other sectors, EPPO is currently running a biogas program providing partial grant funding for vegetable oil, ethanol, rubber and food processing facilities, ranging from 20–50 % depending on the type of industry.

Energy Efficiency Revolving Fund (EERF)

To stimulate fuel substitution, the EERF also provided loan funds to RE projects, including biogas. It is estimated that 30–40 biogas plants have been partially financed by the EERF. Since maximum funding was €1.25 million, many projects required additional funding, typically supplied by the banks' own loan funds.

The level of interest and motivation to co-fund projects with EERF varied from bank to bank. Some banks joined to keep their existing customers, fearing that some of their corporate customers would switch to other banks promoting EE and RE loans. For small banks, the EERF provided a slight competitive advantage, because by blending EERF funds with their own funding they could offer a slightly lower interest rate. Banks, however, reported that the fund had a long approval process, and clients didn't always want to wait, preferring to proceed with 100 % bank funding, even though that meant paying a marginally higher interest rate (0.25–0.5 %).

At the end of 2011 the EERF stopped providing new loans. DEDE felt that by that time, the banks should have been sufficiently familiar with EE and RE to continue lending to these projects without government support. This may be the case for banks that have been most actively using the EERF, but for most banks, this is probably not the case, as they don't see clean energy as a key market for their business. Therefore, people contacted for this study expect the fund to be revived at some point, both to stimulate lending from banks that have so far been reluctantly involved and to help the government meet its RE targets of 25 % by the year 2021.

While the EERF has been instrumental in familiarizing banks with EE and RE, it has not led to a change in lending practices. Apart from the maximum interest rate and loan term, banks set their own terms for lending, and applications, mostly from existing industrial clients, were evaluated based largely on their balance sheets without considering project specifics. This meant that loans were provided as corporate finance rather than project finance, and many factories probably would have been able to obtain bank financing without EERF funds.

ESCO Venture Capital Fund

Since its launch in 2008, the fund has made investments in 5 biogas projects totalling around 60 million Baht, including two leases for biogas engines and three equity investments. So far, the fund's impact on industrial biogas is limited. Equity capital is often not interesting for factories that use a self-owned approach, since it would complicate the investment structure. Initially, the limit for equipment leasing was set at 10 million Baht (€0.25 million), too small for most industries. Recently, the leasing limit was raised to 50 million Baht.

LOCAL BANKS

Several local banks have provided financing for industrial biogas projects. As mentioned above, this was mostly collateral-based and to existing clients. Nevertheless, some, like Kasikorn

Bank, are actively seeking to invest in RE and have set up special facilities for RE financing.

The first bank to invest in biogas was the Industrial Finance Corporation of Thailand (IFCT), which was a state financial institute to support the industrial sector. The bank was well equipped to review applications from RE projects, with a dedicated team of engineers. In 2003, IFCT had approved loans worth around €5 million to eight biogas projects, including KWTE. In 2004, IFCT was merged with TMB, which had no specific interest in RE financing.

Subsequently, the banks that have become substantially involved were Kasikorn, Khrung Thai and CIMB. Kasikorn financed more than 10 biogas projects, lending directly to factories as corporate finance. More recently, the bank also started looking into BOOT projects but has not financed any yet. CIMB, as a relatively small bank, uses RE financing to expand its customer base. So far, the bank has provided financing to 3–5 biogas projects, mostly to palm oil mills. In 2011, the bank launched a clean energy loan facility to finance EE and RE projects.

By now, many banks are fairly familiar with biogas. They consider the technology proven but are concerned about performance issues at individual projects. They also require technical expertise to evaluate project proposals. However, despite the higher familiarity and confidence in RE, bank lending to RE is still mostly asset-based.

PRIVATE CAPITAL

As mentioned above, apart from the genset financing by IFCT, the KWTE project was funded by equity capital, since local banks were unwilling to finance project construction. All equity funding came from foreign RE investors. Subsequent BOOT projects were mostly financed with equity capital. There are about 20 BOOT projects at the moment.

Other projects were either self-built or turn-key, for which factories invested their own resources, supplemented with bank loans. Since bank financing was often provided as part of wider corporate financing, it is difficult to estimate the amount of capital invested directly by the industries.

CARBON FINANCE

KWTE's success stimulated significant interest and involvement of local and international brokers and traders of Certified Emission Reductions (CERs) under the Clean Development Mechanism (CDM). The project was expected to generate about 300,000 tons of CERs annually. This opened the market to numerous carbon consultants eager to benefit from the potential carbon revenue. Carbon brokers such as EcoSecurities and Trading Emissions PLC established dedicated biogas development units, with the objective to develop BOOT projects that would generate large amounts of CERs, with project development partially financed by the forward sales of CERs. In practice, it proved much harder than expected to realize the full potential, for a variety of reasons.

First of all, registering a project under the Clean Development Mechanism (CDM) is complicated, lengthy and expensive. Several projects didn't have adequate resources or the technical capacity to go through this process. Furthermore, not all of the numerous carbon consultants who entered the Thai market were able to satisfy the strict standards set by the CDM

system. Hence, final results were often less than expected and several projects failed to generate carbon revenue. In addition, adjustments in approved CDM methodologies reduced the actual amount of CERs that could be issued for a specific project, and CER prices have been falling over the years.

Second, while initially it was expected that there was a large potential for replicating the BOOT model applied at KWTE, in practice, most factory owners preferred to follow a self-owned approach using local bank financing. In addition, Thailand was somewhat slow to establish the Designated National Authority that needs to approve local CDM projects, significantly delaying the development of CDM projects and the issuance of CERs.

Carbon revenues have been significantly lower than projected in 2004 and often were obtained several years after the start of commercial operation, meaning that they had to be financially viable without carbon revenues. Out of the more than 100 biogas projects in place, only 8 have managed to have CERs issued and generate carbon revenue, for a total of 964,539 tons of CERs since 2003. KWTE is by far the largest, accounting for 74 % of the total. In comparison, revenue from VSPP sales has been much higher, estimated at around €25 million since 2005, roughly 4–5 times as high as total CER revenue. Considering that most CER revenue goes to one project, the difference is even more skewed. VSPP revenue has also been much more predictable and consistent, providing more confidence to industries, developers, investors and banks.

Confronted with the difficulties to generate CERs, several projects have opted to sell their carbon offsets as Voluntary Emissions Reductions (VERs, also called Verified Emissions Reductions). Registration and verification of VERs is considerably less complex compared to CERs, but they also fetch much lower prices.

Conclusions

The industrial biogas sector in Thailand provides an interesting case of a rapid take-up of a technology that can provide significant savings and additional sources of revenue for agro-industries. Biogas has increased the competitiveness and efficiency of these industries, with practically all large-scale facilities having a system in place. Biogas has possibly become more commonplace at these industries than other efficiency measures. The pace of biogas development has exceeded expectations of a decade ago, shown o.a. by the quick surpassing of the 15-year target for biogas that was set by the government as recent as 2008.

Initially, most systems were installed at cassava-based starch mills providing in-house energy needs, both in the form of heat and power, generating savings on energy costs of up to 20 %. Later on, biogas systems were installed at most of the palm oil mills in the country, spurred by the opportunity to sell electricity to the grid. It is estimated that total investments in industrial biogas amount to €200–300 million over the last decade, based on the number of projects under the VSPP and average project costs. Probably most of this was financed by local banks, largely as asset-based corporate finance.

Multiple factors have contributed to the rapid deployment of industrial biogas in Thailand, of which the following are considered the main ones:

1. *Long-Term Government Support:* At least since 1992, the Thai government has shown a strong commitment to the promotion and support of EE and RE, through a variety of mechanisms. This commitment is apparent from several strategies, such as the publication of annual RE statistics, direct funding and subsidies and long-term targets for RE. These are to a certain extent driven by limited availability of domestic energy resources and the increasing volume and cost of imports of oil, gas and electricity. The government commitment has also helped to involve the banking sector, e.g., through EERF and the provision of technical support.
2. *Well-Established Industrial Sector:* Compared to many of its neighbours, Thailand has a strong export-oriented agro-industrial sector, with mostly medium to large scale factories that operate efficiently using standardized processes. Once the biogas technology had been proven in technical and financial terms, this allowed for its rapid replication in an economic and straightforward manner. The strength of the industries also meant that factories, as long-term reliable clients, had good access to financing from local banks.
3. *VSPP Program:* Related to point 1., but worth separate mentioning, the ability to sell excess electricity to the grid at attractive rates and under a transparent and efficient system has been a clear driving force and was mentioned, without exception, by the developers, banks and industries interviewed. In the four year period since the announcement of the adder system in late 2006, biogas-based grid electricity has increased more than 10-fold. For the most part, the application and approval process is standardized and straightforward, and revenue from VSPP is fairly secure and predictable. VSPP has also been instrumental in the development of other RE power generation projects, in particular biomass and solar.
4. *Carbon Finance:* Even though carbon revenue has been less than projected, the prospect of the potentially high revenues was a significant driving force in the first half of the decade, leading to the entry into the market of a variety of players, such as technology providers, investors, banks and carbon brokers.
5. *Investment Climate:* In general, Thailand has a favourable investment climate that is supportive of industrial biogas development. This includes many factors, such as the high level of electrification, the local availability of construction materials and engineering companies, political and economic stability, manageable levels of bureaucracy and corruption, and openness to foreign investment. In addition, the country's tropical climate allows for the use of low-cost technologies at ambient temperatures.

In conclusion, the assessment shows that government support measures are instrumental, but not necessarily sufficient for the successful uptake of RE technologies, since the strength of the industrial sector and the suitability of biogas to its needs played an equally important role. Government support measures also need to be consistent and long-term, evidenced by the recent insecurity surrounding the VSPP program.

Furthermore, even when banks become more familiar and more willing to finance RE, this doesn't necessarily lead to a more project-finance approach to their lending practices, since RE financing in Thailand is still largely asset-based. Finally, even though the value of biogas is widely recognised among industries, quality and performance are not always given high priority, limiting the impacts on overall energy savings that have been achieved through the deployment of industrial biogas.

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