Draft Final Report

PROMOTION OF RENEWABLE ENERGY, ENERGY EFFICIENCY AND GREENHOUSE GAS ABATEMENT (PREGA)

Lao PDR

Biogas Production at Vanith Farm

A Pre-feasibility Study Report[1]

July 2006

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List of Abbreviations

AD	Anaerobic Digestion
ADB	Asian Development Bank
BOOT	Build, Operate, Own and Transfer
BOT	Build, operate and transfer
BTF	Build, transfer and finance
CCEAP	Climate Change Enabling Activity Project
CDM	Clean Development Mechanism
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
CPC	Committee for Planning and Cooperation
CTTE:	Canada-Thailand Tri-bilateral on Environment
DNA	Designated National Agency
DOE / DoE	Department of Electricity
EDL/EdL	Electricité du Laos
EE	Energy Efficiency
EIAs	Environmental Impact Assessments
EM	Extensive Microorganish
EMP	Environmental Management Plan
EMMUs	Environmental Management and Monitoring Units
ESCOs	Energy Service Companies
FAO	Food and Agricultural Organization (of United Nations)
GDP	Gross Domestic Product
GEF	Global Environment Facility
GIS	Geographical Information System
GHG	Greenhouse Gas
GMS	Greater Mekong Sub-region
GNP	Gross National Product
GOL/GoL	Government of Lao PDR
HDR	Global Human Development Report
Lao PDR	Lao People's Democratic Republic
LDC	Least-Developed Country
LPG	Liquefied Petroleum Gas
LRMC	Long Run Marginal Cost
MAF	Ministry of Agriculture and Forestry
MDG	Millennium Development Goals
MHP	Micro-Hydropower
MIH	Ministry of Industry and Handicrafts
MOC	Ministry of Commerce
MRC	Mekong River Commission
MSW	Municipal Solid Wastes
MUB	Multi-nutrient Urea Block
N_2O	Nitrous Oxide
NGO	Non-governmental Organization
NO_x	Nitrogen Oxide
NPEP	National Poverty Eradication Programme
NREL	US National Renewable Energy Laboratory
PDIH	Provincial Department(s) of Industry and Handicrafts

PEA	Provincial Electricity Authority of Thailand
PPA	Power Purchase Agreement
PPAg	Power Purchase Agreement
PPP	Purchasing Power Parity
PREGA	Promotion of Renewable Energy, Energy Efficiency and Greenhouse Gas Abatement
PRC	People's Republic of China
PV	Photovoltaic
R&D	Research and Development
RE	Renewable Energy
REGA	Renewable Energy, Energy Efficiency and Greenhouse Gas Abatement
RESDALAO	The Renewable Energy for Sustainable Development Association
RET(s)	Renewable Energy Technology (ies)
RETC	Renewable Energy Technology Centre
SHP	Small Scale Hydropower Potential
SHS	Solar Home System
SIDA:	Swedish International Development Agency
SPRE	Southern Provinces Rural Electrification Project
STEA	Science, Technology and Environment Agency
SNV	The Netherlands Development Organization
SWH	Solar Water Heater
TCD	Tons of Crushing per Day
TRI	Technology Research Institute
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
Vientiane Cpt.	Vientiane Capital
WB	The World Bank

Currency Unit

Unless otherwise specified, the term "dollar" refers to US$

Currency	=	Kip (KN)
$1	=	KN10,820
KN1	=	$0.000092

Units

km	Kilometers
ha	Hectares
GJ	Giga Joule
GWh	Gigawatt hour
ktoe	Kiloton of Oil Equivalent
kW	Kilowatt
kWh	Kilowatt hour
kWhe/kW	Kilowatt-hour per Kilowatt
m^2	Square meter
m^3	Cubic Meter

MW	Megawatt
toe	Ton of Oil Equivalent
kWh/m^2	kilowatt-hours per square meter
kWp	kilowatt-peak
m/s	Metre per second

1. EXECUTIVE SUMMARY

1. Lao People's Democratic Republic (Lao PDR) is a landlocked country in the heart of Southeast Asia at the centre of the Indochinese peninsula between latitude 13-23 degrees north and 100-108 degrees east. Lao PDR has eastern border of 1,957 kilometres (km) with the Socialist Republic of Vietnam, a western border of 1,730 km with the Kingdom of Thailand, a southern border of 492 km with the Kingdom of Cambodia, a northern border of 416 km with the People's Republic of China and a north-western border of 230 km with the Union of Myanmar.

2. The climate is monsoonal, bringing rain from May to September and a dry season from November to February. In 2004, Lao PDR had a population of approximately 5.6 million people with a population growth rate of 2.7% per year. Buddhism is the dominant religion with more than 85% of the population as believers. The official language of the Lao PDR is Lao. The population density is 23 persons per square kilometre (km^2) and roughly 85% of the population lives in rural areas.

3. Lao PDR is one of the 13 least developed countries (LDC) in the Asia-Pacific region; it is ranked 135 out of 175 countries in the Global Human Development Report (HDR) 2004. The narrowly based economy is one of the least developed in Asia with an approximate per capita Gross National Product (GNP) of around US$ 370 annum. Real GDP growth over the last few years has been in the range of 5.5 – 6.5 % / year. Lao PDR is the recipient of about US$ 200 million annually in international grant support, which is largely targeted at social and environmental projects designed to alleviate poverty in the country.

4. The National Poverty Eradication Programme (NPEP) is central to the national development agenda. The NPEP encapsulates the essence of the Lao PDR's approach towards achieving the goal set in 1996 by the 6th Party Congress, namely, exiting the group of LDCs by 2020. The Lao PDR's long-term national development goal is to be achieved through sustained equitable economic growth and social development, while safeguarding the country's social, cultural, economic and political identity. The foundations for reaching this goal have been laid during the past 28 years of peace and development in the country by:

- Moving consistently towards a market-oriented economy;
- Building-up the needed infrastructure throughout the country; and
- Improving the well being of the people through greater food security, extension of social services and environment conservation, while enhancing the spiritual and cultural life of the Lao multi-ethnic population.

5. Lao PDR is endowed with significant indigenous energy resources, in particular for electricity generation. Hydropower is the most abundant and cost-effective resource for electricity generation. The energy resources range from traditional energy sources such as fuel-wood to coal and hydropower. The forest areas, which cover over 47 % of the total land area as potential source for substantial traditional energy supplies. The total exploitable hydropower potential of Lao PDR is around 23,000 MW with major Mekong tributaries estimated at around 56%, followed by 35% of mainstream Mekong and 9% of the rest of the country. The Lao PDR's hydropower potential is very considerable and its development offers extensive benefits for the country. Hydropower is a major contributor both direct and indirect to economic output, government revenues and export earnings. However, only 623 Megawatts (MW) has so far been developed.

6. The Government of Lao PDR's goal is to increase the electrification ratio for the whole country from 41% to 90% by 2020, with intermediate targets of 45% in 2005 and 70% in 2010. This goal will be achieved through:

- On-grid household electrification – involving main transmission / distribution grid extensions to meet the 90% target, after deduction of off-grid installations.
- Off-grid household electrification – an embryonic but successful program of electrification of off-grid households employing state, donor and private resources is underway in Lao PDR and targets electrification of 150,000 households by 2020. However this program will need to be substantially scaled-up, if this target is to be achieved by 2020. Current projections of village and household electrification are as follows:

Year	2004	2005	2010	2013	2015	2020
No. of Villages Electrified	3,464	3,574	5,584	6,433	7,024	8,906
% of Villages Electrified	31%	32%	50%	58%	63%	80%
No. of Households Electrified	395,598	423,122	733,926	858,794	914,894	1,140,396
% of Households Electrified	41%	45%	70%	76%	79%	90%

7. Lao PDR ratified the United Nations Framework Convention on Climate Change (UNFCCC) on 4 April 1995. Awareness on climate change however, has been stirred in Lao PDR since it participated in the 1992 Rio Earth Summit. The first major climate change activity in the country was the Lao National Greenhouse Gas (GHG) Inventory Project (GEF Climate Change Enabling Activity (CCEAP) project and the capacity building project of GEF implemented through UNDP. The GOL has ratified the Kyoto Protocol on Clean Development Mechanism on February 6, 2003 and the Designated National Agency (DNA) has been established as the Science Technology and Environment Agency. The GOL has ratified the Kyoto Protocol on Clean Development Mechanism by February 6, 2003 and the DNA has been established as the Science Technology and Environment Agency.

8. Renewable energy resources will most likely be developed under the direction of the Ministry of Industry and Handicrafts (MIH) and/or Electricité du Laos (EDL), coordination with renewable energy sector organizations is recommended so that their data, experience and expertise can be accessed for the future projects. As well, staff of these organizations may be able to contribute practical experience on appropriate technologies, implementation approaches and pilot projects. The Science, Technology and Environment Agency (STEA) and/or the Technology Research Institute (TRI) of STEA is an important institution for any renewable energy related work, and their staff should be consulted particularly in respect of the biomass energy assessment, but also in respect of mini / micro hydropower, wind power assessments and solar PV energy technologies.

9. It can be said that the financial aspect is one of the most important issues that will contribute towards the success of the planning and implementation process in Lao PDR, but the Government has constraints in finance. Based on previous developments, it is indicated that most of the funding sources for energy/renewable energy sectors will come from the loans and

grants of multilateral financial organizations and international and local participants into this sector, although these are still limited.

10. There is a lack of energy efficiency/renewable energy (EE/RE) Promotion Funds, Lending conditions and procedures are complicated and often changed, Bank/financial organizations lack the necessary capacity to evaluate EE&RE projects, Banks also face high transaction costs due to the smallness of potential EE/RE projects, Credit institutions are hesitant to lend to EE/RE projects due to perceived high risks and long time to recover the investment cost. Renewable energy/efficiency energy financing is feasible but there are risks and barriers that need to be resolved. It requires detailed analyses to be carried out by both the electric service company (ESCO) and the financier. Performance contracts, insurance, owners' commitments & other safety measures are key elements that enhance its attractiveness over other investment opportunities.

11. There is limitation of manpower with the know-how, experience and skills in strategic planning and those of implementing the plans. On the contrary, distributing manpower from ministerial to provincial workplaces is not balanced. In addition, responsibilities among agencies, which are in charge of the energy sector are not clearly defined and coordinated. The separate energy organizations also mean reduction of efficiency in planning, implementing and managing energy resources. At present, there is only the hydropower sub-sector becoming the main priority for the energy sector; however other energy type sub-sectors are not well determined and not a single responsibility of any one organization.

12. Policy options and strategies for increasing the scale and application of energy/ efficiency energy sources must take account of the diversity of national circumstances, as well as of technology options. It requires reliable support from the government in the form of incentives. The creation of an enabling policy environment, with appropriate institutional arrangements at the national level, would accelerate the development and wider scale application of new and renewable sources of energy. Available policies in Lao PDR include the following:

- (i) Linking new and renewable energy policies to sustainable development policies and to actions consistent with international agreements;
- (ii) Legal and regulatory policies and frameworks for attracting investment;
- (iii) Providing a clear policy message to mobilize all key actors and catalyze them into action.

13. As for the Lao PDR, the socio-economic development must be implemented with efficiency, continuation and stability so as to guarantee the balance between the economic growth and the social and cultural development as well as the eternally sustainable environmental protection. Consequently, the utilization of advanced technology is considered, which needs to be developed and resolved to suit the real situation of each field of work.

14. In order to achieve the above-mentioned issues for supporting the additional technical know-how, capacity and expertise of the technocrats, the staff must be supported and promoted. For example, it is essential to make use of all-existing technocrats' competency so as to systematically train them in the environmental field as well as carefully set plans of human resource development within this field of work. It is urgently necessary to guarantee providing the fund for environmental protection. Thus, one of the most important things is to raise money for the contribution for the National Environmental Fund simultaneously in an attempt to not only

search for the financial assistance from the friendly international agencies, but also to better promote the bilateral and multilateral cooperation.

15. The purpose of this study is to evaluate the feasibility of implementing biogas production from pig farm for generating electricity, particularly in the Vanith Pig Farm Company, in particular Farm No. F3, which is polluting the air and affecting the neighbours surrounding this farm. Primarily, this study is going to review the literature of anaerobic digestion (AD) technology and the process of the AD fermentation for producing biogas, after consideration of seven examples of AD plant from various locations in estimating biogas production through the size of co-generator or gas turbine. Installed system costs of AD + co-generator are also included.

16. Based on the actual data survey and literature review:

For currently available data, it is found that the gas production per day, at farm no F1+F2 is about 1099 m^3/day with size of gas turbine 120 kW, with cost of investment from 368,880 US**$** up to 443,040 US**$** and at farm No F3 is 298 m^3/day, 35 kW, with cost of investment from 107,590 US**$** up to 129,220 US**$**.

For future estimation plan, it is found that the gas production per day, at farm no F1+F2 is about 1651 m^3/day with size of gas turbine 195 kW of and the investment cost is 599,430 US$ and at farm No F3 is 447 m^3/day, 50 kW with investment cost from 153,700 US$ up to 184,600 US$ (2 Units $\times$25 kW).

2. MAP SHOWING THE LOCATION OF THE PROJECT

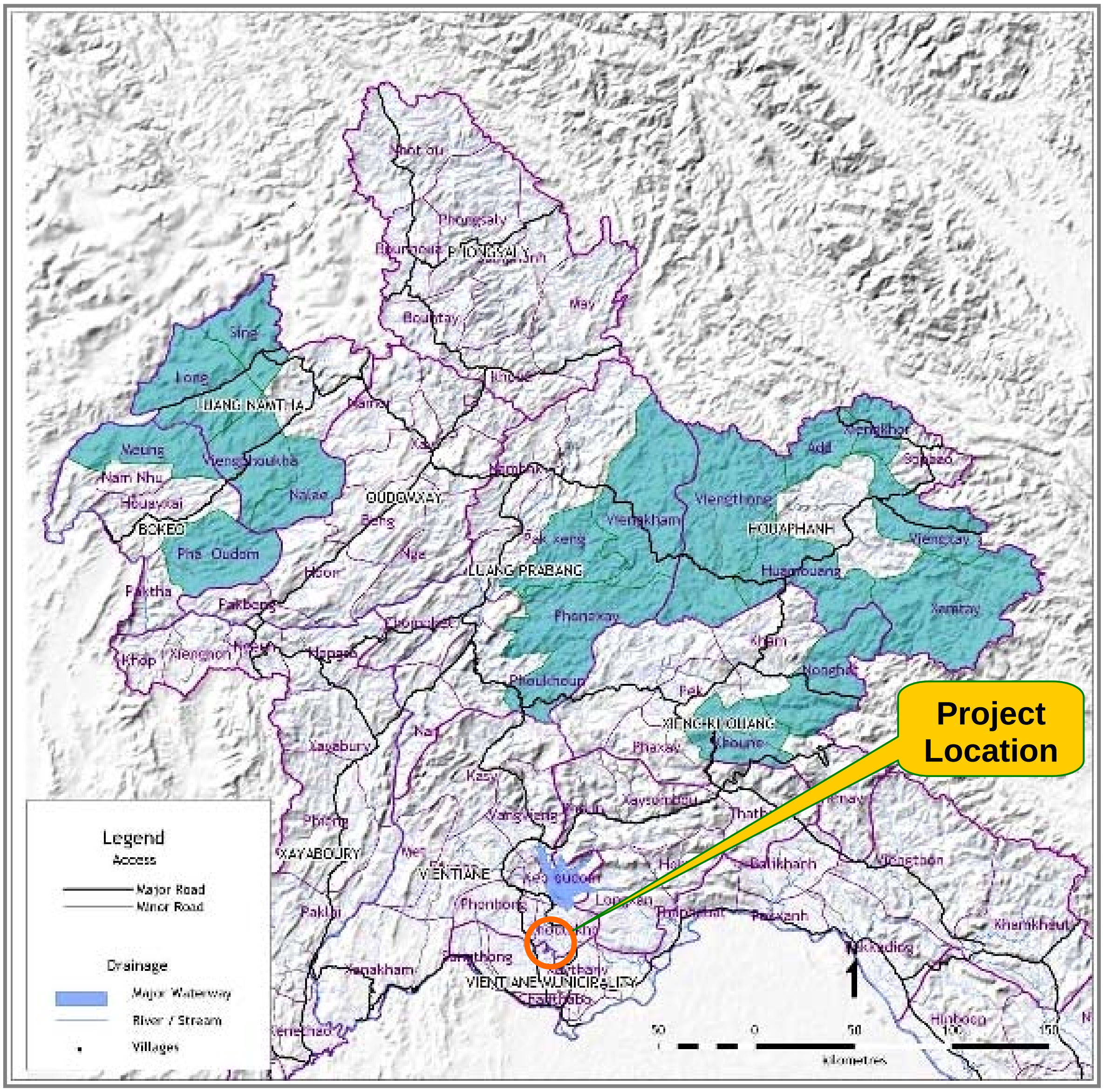


Figure 1: Map Showing the Location of the Project

3. INTRODUCTION

The Lao PDR economy has reported steady growth since 2000 with average GDP growth (in real terms) of over 5% per annum, the most recent figure being 5.8% in 2003 over the previous year. Annual inflation continues to rise from 7.7% in 2001 to 10.7% in 2002 and 15.5% in 2003 (mainly in response to a decline in the value of the Kip) although there were signs towards the end of 2003 that inflation was decreasing. The structure of the economy is changing gradually as dependence on the agricultural sector decreases and industry and services become increasingly important. While agricultural GDP (in current terms) continues to increase, its annual growth rate (in real terms) has declined from a peak in 1999 of 8.2% to 2.2% in 2003 in spite of a relatively strong performance of the forestry sector. As a consequence, the agricultural contribution to overall GDP has declined from 53.7% in 1999 to 48.6% in 2003, a trend that is expected to continue under the influence of growing industrial and services sectors that reported annual growth rates of 11.5% and 5.8% respectively in 2003.

ADB has significantly providing financial assistance in the development of Lao PDR, particularly in (i) industry and power sector, (ii) agriculture and natural resources, (iii) education and primary health care, (iii) infrastructure including energy, transport and communications, water supply, sanitation and waste management, and (iv) law reform and public sector management. ADB chairs the infrastructure-working group for the coordination of external funding in the sector and is the co-chair of the industry, agriculture, environment and natural resources working group.

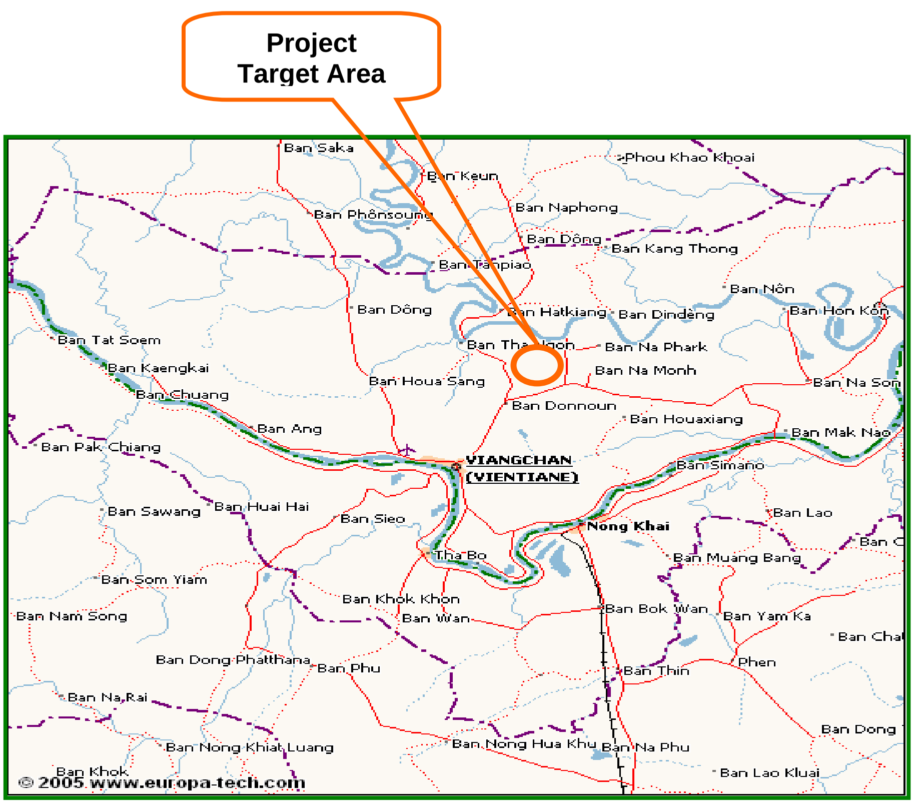


Figure 2: Map Showing the Project Target Area

Biogas technology was introduced in Lao PDR in 1983 through the assistance of the Food and Agricultural Organization (FAO). The implementation of biogas technologies is expected in Lao

PDR in reducing environmental problems and in helping reduce importation of gas. In the energy sector, biogas could enable the farmers to supply themselves with heat and electricity and to supply the excess electricity to the national grid. It could significantly increase the income of a farm. All animal waste products contain organic and inorganic nutrients with potential to decompose in the environment with high Chemical Oxygen Demand (COD), methane and ammonia emissions and the release of excess nutrients and pathogens. Concerns have been expressed in recent years on the effects of pollution of the air and water from municipal, industrial and agricultural operations and such concerns continue to grow around the world. The emission of CO_2 and other greenhouse gases (GHG) has become an important issue, particularly since the governments of most Asian countries are signatories to the Kyoto Protocol.

Vanith Pig Farm Company is the biggest farm in Vientiane Capital with a total herd of about 9,705 heads of pig. This farm was established in 1992 under the cooperation investment between Mr. Vanith, a Lao private enterprise and a French Investor, and upgraded the company to become a Joint Venture Company. This project is sustainable under the policy of Lao government intended to reduce and eradicate poverty of Lao population. The Vanith Pig Farm Company separates into two locations, including Farm 1 and Farm 2 (F1+F2) are located at the first site, and Farm 3 (F3) is located at the second site. The first location of the farm is in Latkhouay village, Xaythany district, which is about 23 km from Vientiane Capital; it has a total area about 34 ha. The second location of Pig Farm is about 19 kilometres from Vientiane Capital, along the Road No. 10, with an area of 27 ha.

The initial investment registered cost is US$ 200,000. At that time, there were only 100 sows growing at the farms # F1+F2; two years later the breeding sow population has increased to 600 heads. The Capital Agriculture and Forestry Department of Vientiane Capital, Lao Development Bank and Agricultural Promotion Bank have recognized the importance and the need of the pig farm. They provided a loan of US$ 155,000 with an interest rate of 5% to enable the Vanith Pig Farm Company to increase the capacity to produce piglets to respond to the farmer demand in Vientiane Capital.

It appears that this proposed project would be possible if there would be a grant from NGO or other international organization as a pilot or demonstrative project for Lao PDR. One of the possible approaches for financing this proposed project is by a private investment.

The Vanith Pig Farm Company perceives the advantages and benefits in the long term from using AD technology. However when the PREGA team of Lao P.D.R tried to explain to the owner the process of ‘‘biogas production from their farm for electricity generation’’, the owner of the company remains concerned that the investment cost is very high, and this is compounded because the company has financial problems related to their competitiveness in the Lao pork market, and the company is still reliant on the government grant assistance to stay in business.

4. BACKGROUND

4.1 Description

Renewable energy is power that comes from renewable resources such as the sun, wind and organic matter. These resources are constantly replenished by nature and are a cleaner source of energy.

Large municipal or industrial landfills produce gas that can be tapped to generate electricity. Microorganisms that live in organic materials such as food wastes, paper or yard clippings cause these materials to decompose. This produces landfill gas, typically comprised of roughly 60 percent methane (CH_4) and 40 percent carbon dioxide (or "CO_2").

Landfills are the largest human related source of methane. Methane is a powerful GHG, more than 21 times more potent than carbon dioxide emissions. Landfill gas is collected by drilling "wells" into the landfills, and collecting the gases through pipes. Once the landfill gas is processed, it can be combined with natural gas to supplement the natural gas supply or can be burned in an internal combustion engine or micro turbine coupled to a generator to create electricity.

There is a wealth of energy to harness because of the abundance of plants and animals around us. Power generated using organic matter is called biomass energy or bioenergy. One form of bioenergy is a gas called methane. It's a naturally occurring byproduct of decaying plant and animal material. It is often found in bogs, wetlands and even landfills. The process can be duplicated in biogas generators using bacteria to break down organic material such as agricultural waste. The resulting methane gas is burned to produce electricity. It's a remarkable process that turns waste into energy.

For Lao PDR, livestock plays an important role in an agriculture-dependent country, where there has been little experience in biogas systems. Animal and human excreta is generally available within rural areas, and there is a potential for larger biogas digester program for cooking, lighting and other purposes within the country (RETC has set up five demonstrative units, and completed a feasibility study of a support program for domestic biogas plants in rural households in Lao PDR). There are 1.1 million cattle, 1.2 million buffaloes and 1.5 million pigs in Laos, though widely dispersed. Experience in other countries has shown that families

Figure 3: Vanith Pig Farm Company

with enough animals to run a biogas digester are probably rich enough to use kerosene or LPG anyway, but recent increases in fuel costs may begin to negate this point. Pig excreta are a good energy resource, and if housed in pens, this makes dung collection easy, again reducing barriers to household scale development.

Large-scale biogas digesters using pig farm wastes could be established and be used to generate electricity. It is understood that there are no cultural inhibitions towards using biomass digesters based on human and animal excreta.

Biogas obtained by anaerobic fermentation of cow/pig dung and other organic matters can be used as energy source for cooking, lighting and other purposes. Biogas technology was introduced in Lao PDR in 1983 through the assistance of the Food and Agricultural Organization (FAO). Initially, three family-size biogas units were set up by the Ministry of Agriculture and Forestry with the cooperation of FAO. Since 1983, STEA has been involved in the development of pilot biogas plants. At present 14 biogas plants with capacity ranging from 12 to 16 m^3 each have been installed in the country.

Pig waste in large pig farms is a potential source of methane gas and most pig farms (35 in total) are concentrated around Vientiane Capital City. The data on large pig farms within Vientiane Capital City are shown in Annex 1.

4.2 Opportunities, Constraints and Issues Related

Lao PDR does not have its own fossil fuel resources with the exception of some small amounts of lignite. All of the needed fuel and gas is imported from abroad. From this point of view , it may motivate the Lao community to develop biogas from animal dung in the future. The current issue is whether the development of biogas could contribute to reduce costs of imported fuel and gas. The overall expansion of renewable energy technologies (RETs) so far has relied upon government and donor agency assistance in the form of subsidies and grants. This does not mean that these technologies are financially unattractive. Beyond doubt, RETs can compete with other conventional alternatives. The proper design and implementation of these technologies can boost socio-economic development and address environmental concerns. Based on their implementation in the past, these technologies have not always been successful in rural electrification. For RETs to reach the goal, more attention must be paid not only to technical issues but also to social, cultural and management issues. Otherwise, even though, there are good RET applications, they are likely to be unsuccessfully implemented. To date, the contribution of RETs in meeting overall energy needs has been very small in Lao PDR, and the success of these technologies varies widely. Biogas is a well-established fuel for cooking and lighting in a number of developing countries, and it is also an environmentally friendly source of energy because biogas typically contains small (around 0.2%) hydrogen sulphide, which needs to be removed before combustion in most small generators. It produces electricity and heat but still keeps carbon dioxide emissions neutral and emits no sulphur. Biogas plant technology for generating energy from manure is an ancient method, but it is still useful for developing countries, especially for Lao PDR, a country where fossil fuel resources are scarce.

4.3 Sustainable Development Objectives

The main objective of this study is to utilize renewable energy in a sustainable manner, to reduce electricity expense and encourage the owner of the pig farm that could run his business smoothly, without any objections from the people, who live surrounding the pig farm.

Even though the electric power produced from the pig farm is small scale, the implementation of this project may contribute in addressing environmental impacts such as unpleasant nuisance odour, proliferation of flies and the contamination of wastewater and land. The pig farm owner can generate additional revenue by selling the by-product that could be used as fertilizer.

Recently, the demand of pork is increasing; pig farms seem to be a good sustainable business. Bird flu scares may be contributing to the growing demand for pork. Consequently, this proposed project could have a high degree of sustainability. This project may also enable pig farm to be more competitive. The electricity required in the farm can be completely covered and the surplus could also be sold directly to the EDL. There is a great potential for efficient energy production for both individual producers and large-scale livestock operations.

4.4 Government Policies and Strategies Relevant to the Project Sector

4.4.1 Electricity Law of Lao PDR

The Electricity Law which became effective on 29 August 1997, sets out the regime for the administration, production, transmission and distribution of electricity, including export and import, through the use of productive natural resources, and potentially contributes to the implementation of the national socio-economic development plan and to upgrade the living standards of the people (Article 1). Amongst other things, it provides a suitable framework for the promotion and implementation of rural electrification.

With respect to concessions for electricity activities, it is stipulated that investment is solely by the State or with foreign partners. Cooperative investments are allowed. Modalities may be:

- Build, operate, own and transfer (BOOT),
- Build, operate and transfer (BOT),
- Build, transfer and finance (BTF),
- Operation by the State Electricity Company,
- Some other form.

However, in the section relating to concessions, the law stipulates that small-scale hydro generators under 2 MW, and thermal electricity generators under 500 kW, are exceptions to concession applications. As the majority of rural electrification projects will be under 2 MW (or under 500 kW in the case of diesel generators), concessions for such projects will not generally be required.

The law stipulates that MIH, the provincial and district authorities and the village administrative authorities have coordinating and supervisory duties and rights. Electrification projects between capacities of 100 kW and 2 MW are handled by the respective PDIH (Provincial Department(s) of Industry and Handicrafts, with approval from MIH), and projects under 100 kW are handled at the district authority level (with approval from PDIH / MIH).

In village schemes (generally less than about 10 kW), the village chief has the right and duty to facilitate parties who are undertaking electricity enterprises. This represents current practice, in that small entrepreneurs use solar PV, thermal and micro hydro generators for very small commercial distribution networks, operated as private investments, presumably with district authorization through the village chief. These systems assign operational control and ownership to customers and to village scheme managers.

The law stipulates that an off-grid fund may be established by the State, financed from various sources, including the State, entrepreneurs, consumer, and foreign or domestic assistance. The State may have a policy of reducing or exempting equipment, operation, and vehicles, from taxes and duties in order to facilitate off-grid development.

4.4.2 Power Sector Policy

Power sector policy is outlined in the Government's Power Sector Policy Statement, September 2000 (revision 4). The main power sector priorities are to:

(i) Maintain and expand an affordable, reliable and sustainable electricity supply in Lao PDR to promote economic and social development.
(ii) Promote power generation for export to provide revenues to meet the Government's development objectives.
(iii) Develop and enhance the legal and regulatory framework to effectively direct and facilitate power sector development.
(iv) Reform institutions and institutional structures to clarify responsibilities, strengthen commercial functions and streamline administration.

4.4.3 Other Relevant Laws, Policies and Regulations

A program of legislative reform has been in progress in Lao PDR for more than a decade, aimed at creating amongst other things a legal environment that encourages investment in the country. In addition to the Electricity Law (1997) already discussed, relevant legislation includes the:

- Law on Foreign Investment (1988)
- Contract Law (1990)
- Commercial Bank and Financial Institutions Act (1992)
- Customs Law (1994)
- Labor Law (1994)
- Business Law (1994)
- Law on the Promotion and Management of Foreign Investment (1994)
- Secured Transaction Law (1994)
- Water & Water Resources Law (1996)
- Environmental Protection Law (1999) and the
- Rules for Consideration and Approval of Foreign Investment Projects in Lao PDR (2002).

Institutional Arrangement for Energy Planning-the energy sub-sector in Lao PDR managed by relevant line ministries and organizations are:

- The petroleum and gas under Ministry of Commerce (MOC),
- Electric Power including New and Renewable Energy and Coal under Ministry of Industry and Handicrafts,
- Fuel-wood under Ministry of Agriculture and Forestry (MAF),

At the energy sub-sector:

- The Ministry of Commerce is responsible for entire petroleum and gas sector planning for commercial aspects.
- The Department of Electricity, Ministry of Industry and Handicrafts is in charge of the power sector strategic planning which includes hydropower, and the Ministry's Department of Geology and Mining is responsible for coal.
- The Department of Forestry, Ministry of Agriculture and forestry is responsible for overall supervision of the fuel-wood sector planning, in addition to its main forest sector planning.
- The Science, Technology and Environment Agency, Technology Research Institute is responsible for research on sustainable utilization of natural resources (New and Renewable Energy).

4.5 Overlap of Government and ADB objectives

ADB supported the government projects in terms of grant or soft long-term loan with low interests. It assists the government in achieving its policies (Poverty reduction and eradication, clean water, community health, reduce child mortality, AIDS /HIV prevention etc).

5. DESCRIPTION OF THE PROPOSED PROJECT

5.1 Project Goal and Objective

The main goal of this proposed project is to produce electricity utilizing AD biogas from a pig farm. It also aims to reduce net environmental impacts, disseminate the use of renewable energy in the country and compensate the consumption of energy at the farm. To achieve the goal and objectives the following activities were undertaken: literature review, study of the existing AD technology of different sizes, estimation of the possible production of biogas based on the actual pig farms and animal diets, and consideration of the existing plants in foreign countries as examples for the selection of AD plant.

The project will reduce the odour problem and flies from the pig farm, which could affect areas of more than one and half kilometres surrounding the farm. The project will also reduce the problem of the wastewater and land contaminants in the area and will encourage the farm owner to reduce his expense on energy consumption especially in Vanith Pig Farm F1+F2 and Farm F3, located at Latkhouay Village, Xaythany district, Vientiane Capital, Lao PDR.

5.2 Poverty Reduction and other MDG (Millennium Development Goal) Impacts

The National Poverty Eradication Program of Lao PDR is central to the national development agenda. The NPEP encapsulates the essence of the Lao PDR's approach towards achieving the goal set in 1996 by the 6th Party Congress: that is, exiting from the group of Least-developed countries (LDCs) by 2020. Lao PDR's long-term national development goal is to be achieved through sustained equitable economic growth and social development, while safeguarding the country's social, cultural, economic and political identity. The foundations for reaching this goal have been laid during the past 28 years of peace and development in the country by:

1. Moving consistently towards a market - oriented economy;
2. Building-up the needed infrastructure throughout the country, and;

iii. Improving the well being of the people through greater food security, extension of social services and environment conservation, while enhancing the spiritual and cultural life of the multi-ethnic population.

The 7th Party Congress (March 2001) defined the following guidelines for poverty eradication and sustainable economic growth:

- The socio-economic development of the country must be balanced between the three pillars of economic growth, socio-cultural development and environmental preservation.
- Socio-economic development must be based on sound macro-economic management and institutional strengthening and must be harmoniously distributed between sector and regional development, and between urban and rural development, so as to fully and efficiently utilize human and natural resources.
- The national development potential and strengths must be combined with regional and global opportunities to enable Lao PDR's participation in regional and international economic integration.
- Socio-economic development must be closely linked with national security and stability.

Within these guidelines, the main objectives of the long-term development strategy include:

a) Sustaining economic growth at an average rate of about 7 per cent (to triple the per-capita income of the multi-ethnic Lao population by 2020);
b) Halving poverty levels by 2005 and eradicating mass poverty by 2010, and;
c) Eliminating opium production by 2005 and phasing-out shifting cultivation by 2010.

5.3 Potential of the Vanith Pig Farm Company

Vanith Pig Farm Company is the biggest pig farm in Vientiane Capital with a total herd numbering about 9,705 heads. This farm was established in 1992 under the cooperation investment between Lao private enterprise and a French Investor. This project is sustainable under the policy of Lao government intended to reduce and eradicate poverty of Lao population. The Vanith Pig Farm Company separates into two locations, including Farm 1 and Farm 2 (F1+F2) are located at the first site, and Farm 3 (F3) is located at the second site. The first location of the farm is in Latkhouay village, Xaythany district, which is about 23 km from Vientiane Capital; it has a total area about 34 ha. The second location of Pig Farm is about 19 kilometres from Vientiane Capital, along the Road No. 10, with an area of 27 ha.

The initial investment registered cost is US$ 200,000. At that time there were only 100 sows growing at the farms # F1+F2; two years later the breeding sow population has increased to 600 heads. The Agriculture and Forestry Department of Vientiane Capital, Lao Development Bank and Agricultural Promotion Bank have recognised the importance and the need of the pig farm. They provided a loan of US$ 155,000 with the interest rate of 5% to enable the Vanith Pig Farm Company to increase the capacity to produce piglets to respond to the farmer demand in Vientiane Capital.

In the year 1999 to 2000, Vanith Pig Farm Company increased the breeding sow population up to 1200 heads and at the end of the year Vanith Pig Farm Company achieved a capacity of 1800 piglets/month. Finally, Vanith Pig Farm Company had faced a significant problem with the smuggling of piglets into Vientiane Capital from neighbouring countries with the objective of breaking the local market, due to all the raw materials, which are used in the pig farms being imported. Consequently, the Vanith Farm could not distribute their piglets and then the farm owner has to spread into three farms as Farm 3 (F3) by conceding the Pig Farm No 3 from the government farm which is constructed by the grant of Czechoslovakia to Laos Government. This farm produces the slaughter pigs (flattening pigs) only for distribution and sale to the local market. To date, the Vanith Pig Farm Company has a capital cost up to US$ 3,500,000 and the total of the pig population is 9705 heads on late October 2005.

5.4 Description of the Subsystems in the Farm

Pig Production Subsystem. Recently, Vanith Pig Farm Company has a total number of 31 pens: 10 pens in Farm F1, 12 pens in Farm F2 and 9 pens in Farm F3. Pig dung slurry is disposed of in pond; there are 3 ponds at F1+F2 and 5 ponds at F3 (2 ponds at F3 are utilized for fish culture).

Pig Farms F1+F2 have a total of 7636 heads while Pig Farm F3 has 2069 heads of pigs for slaughter. This subsystem has a total of 9705 pigs that is grouped as follows: 63 father pigs (120 - 300 kg), 1138 breeding sows (100-180 kg), 1143 lactating pigs (less than 30 kg), 3433 piglet (30 to 45 kg) and 3928 fattening (slaughter) pigs (50 to 80 kg). These animals are distributed to five groups: father pigs, breeding (lactating) sows, suckling piglets (baby pigs), growing pigs and fattening pigs (slaughter pigs), the data of the population of pigs in Vanith pig farm is shown in the table below (showing data to the end of October, 2005).

Animals are mainly fed with a ration based on maize and soybean meal prepared at the farm, 75% of the meal is locally sourced and 25% of the meal is imported from Thailand such as: soybean 15 %, powder fish 7%, powder milk and vitamin complex 3%. Base on the 2004 Annual Report, Vanith Pig Farm has produced 19,000 piglets/year, distributed 13,939 heads/year of slaughter pigs, and sold 1,500 heads/year of young pigs to the farmer for growing.

Table 1: Data of the Pig Population at Vanith Pig Farm Company

Description	Farm: F1 (Pigs)	Farm: F2 (Pigs)	Farm: F1+F2 (Pigs)	Farm: F3 (Pigs)	Total (Pigs)
Father pigs	34	29	63		63
Breeding sows	594	544	1138		1138
Lactating pigs	473	670	1143		1143
Piglet pigs	1831	1602	3433		3433
Slaughter pigs (Hog)	1100	759	1859	2069	3928
Total	**4032**	**3604**	**7636**	**2069**	**9705**

The amount of food for feeding the pigs in these three farms is 4,000 tons per year and the total population of pig supplied by the company at the end of 2004 was 8811 heads. Based on the actual available data, the average amount of food given to a pig per day is about 1.25 kg.

Based on our interview with an employee who is responsible for the pigpen and the actual data collected from the Vanith Pig Farm, it was noted that the water consumption for drinking and washing away the pig manure is approximately 14 litres/pig/day. The chemical for reducing the odour (EM=Extensive Microorganish) is about 444 ml/day/pen mixed with 200 litres water. The total needed EM per day is approximately 14 litres (1 litre cost 14,500 Kips) mixed with 6400 litres of water. This solution is sprayed onto the floor for eliminating odour in those pens.

The data of electrical energy consumption in Vanith Farm has been collected from EDL for two years and ten months back, from January 2003 to October 2005. It could be seen that the average consumption in Farm F1&F2 was about 44,789 kWh/month with average load of 62.21 kW, Farm F3 is 7,752 kWh/month with average load of 10.77 kW. The details are illustrated in the table below.

Table 2: Summary of Electric Energy Consumption and Water Used

Farm	Average Load Connected	Average Electric Energy Consumption	Electric Energy Payment per Month		Water Used	EM Used	
	kW	kWh/month	Kips/month	US$/month	m^3/day	litre/day	Kips/day
F1&F2	62.21	44,789	12,474,266	1,211.094	3.818	9.768	141,636
F3	10.77	7,752	2,207,800	214.350	1.035	3.996	43,442
Total	**72.98**	**52,541**	**14,682,066**	**1,425.444**	**4.852**	**13.764**	**185,078**

5.5 Current Main Problem

Nowadays, Vanith Pig Farm Company is faced with the big problem from people who live around these farms. They wish that the owner would stop the business of pig farming because the odour from pig farm is a significant nuisance to the neighbours. The worst problem is occurring at Farm F3, where the people living around the farm want the owner to find solutions for restricting the bad odour from this farm. The situation is worse at this farm as the farm is located at a slightly higher elevation than the village.

Based on the collected data from Vanith Pig Farm, the daily average pig dung production rate is as follows: father pigs and breeding sows is about 2 kg per head, slaughter pig is 1.5 kg per head, piglets are about 0,5 kg per head and for the suckling pigs is about 0,25 kg per head. It may be estimated that the total daily quantity of pig dung in Vanith Farm is approximately 10.3 tons.

Table 3: Estimation of the Pig Dung in the Farms

Description	Farm: F1 & F2	Dung	Farm: F3	Dung	Total	Dung
	Pigs	kg/day	Pigs	kg/day	Pigs	kg/day
Father pigs	63	126			63	126
Breeding sows	1138	2276			1138	2276
Lactating pigs	1143	285,75			1143	285,75
Piglet pigs	3433	1716,5			3433	1716,5
Slaughter pigs (Hog)	1859	2788,5	2069	3103.5	3928	5892
Total	**7636**	**7192,75**	**2069**	**3103.5**	**9705**	**10296.25**

5.6 Future Plan of the Vanith Pig Farm Company

Table 4: Estimation of the Pig Dung in Vanith Farm including Future Plans

Description	Farm: F1&F2	Dung kg/day	Farm: F3	Dung kg/day	Total Pigs	Dung kg/day
Father pigs	106	212			106	212
Breeding sows	1,707	3,414			1,707	3,414
Lactating pigs	1,715	428.75			1,715	428.75
Piglet pigs	5,150	2,575			5,150	2,575
Slaughter pigs (Hog)	2,789	4,183.5	3,104	4,656	5,893	8,839.5
Total	**11,467**	**10,813.25**	**3,104**	**4,656**	**14,571**	**15,469.25**

Based on our interview with the Vanith Company owner, there is a need for expansion in order to respond to the government's policy of eradicating poverty and prevent the export of money out of the country, and to respond to the local demand for flattened pigs. Vanith Company has to expand by more than 15 pens in three farms (it is needed to build an additional 5 pens, 6 pens and 4 pens at Farms F1, F2 and F3 respectively). Farm F3 is for slaughter pig. This future plan can only be realized if the impact to the environment can be completely solved. The estimate of pig production in the future after expansion of the farm is shown in the table above.

5.7 Benefits Resulting from the Use of Anaerobic Digestion Technology

The benefits resulting from this proposed project might be categorized as follows:

Waste Treatment Benefits:

- Natural waste treatment process,
- Requires less land than aerobic composting,
- Reduces disposed waste volume and weight to be land filled applications,
- Reduces concentrations of leachates.

Energy Benefits:

- Net energy producing process,
- Generates high quality renewable fuel,
- Biogas proven in numerous end-uses,
- Reduce monthly energy purchases from electricity and gas suppliers.

Environmental Benefits:

- Significantly reduces greenhouse gas (CO_2, CH_4),
- Reduction of hydrogen sulphide, which is partly responsible for bad odour. It can be reduced with a simple iron oxide filter prior to combustion
- Produces a sanitised compost and nutrient-rich liquid fertiliser,
- Maximises recycling benefits,

Economic Benefits:

- Is more cost-effective than other treatment options from a life-cycle perspective.
- Bringing the community into the project will assist them to share in the economic benefits, particularly at Farm #3. Villagers can possibly act as fertilizer sales reps, or can be offered employment at the new facility.
- The liquid fertilizer can be used to the advantage of the local villagers, since it is difficult to transport and sell compared with the solid fertilizer.

6 BIOGAS TECHNOLOGY

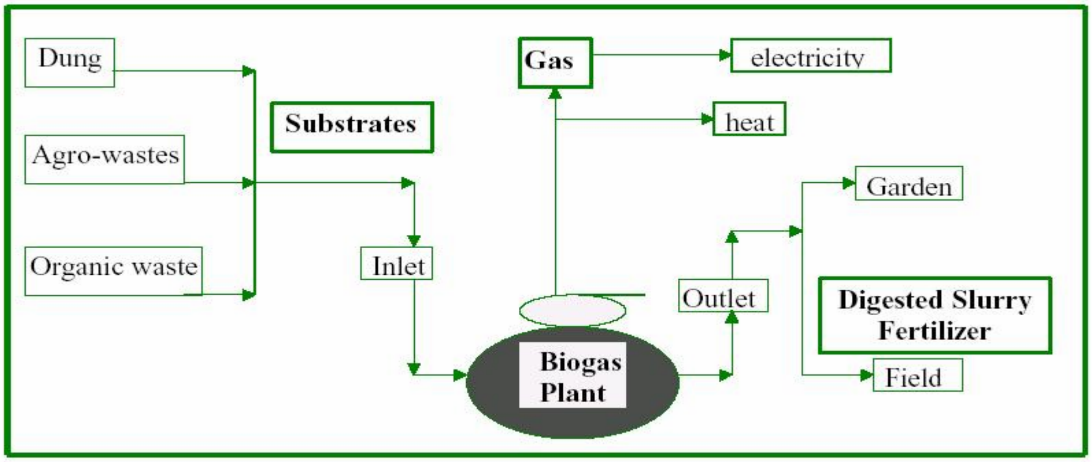
6.1 Role of Renewable Energy Technology

The overall expansion of renewable energy technologies (RETs) so far has relied upon government and donor agency assistance in the form of subsidies and grants. This does not imply that these technologies are financially unattractive. Beyond doubt, RETs can compete with other conventional alternatives. The proper design and implementation of these technologies can boost socio-economic development and address environmental concerns. Wherever implemented, these technologies have been successful in rural electrification in developing many countries. However, its contribution to meeting overall energy needs has been very small, and the success of these technologies varies widely. Biogas is a well-established fuel for cooking and lighting in a number of developing countries, and it is also an environmentally friendly source of energy because it produces electricity and heat but still keeps carbon dioxide emissions neutral and emits no sulphur (Hydrogen Sulphide (H_2S) is emitted but can be removed via a filter). Biogas plant technology for generating energy from manure is widely used as a renewable energy technology around the world.

6.2 Biogas Technology

The implementation of biogas technologies in Lao PDR could reduce environmental problems and help reduce gas imports. In the energy sector, biogas could enable the farmers to supply themselves with heat and electricity and to supply the excess electricity to the national grid. It could significantly increase the income of a farm. All animal waste products contain organic and inorganic nutrients with potential to decompose in the environment with high Chemical Oxygen Demand (COD), methane and ammonia emissions and the release of excess nutrients and pathogens. Concerns have been expressed in recent years on the effects of air and water pollution from municipal, industrial and agricultural operations and such concerns continue to grow around the world. CO_2 and other GHG emission has become an important concern, particularly since the governments of most Asian countries are signatories to the Kyoto Protocol. The implementation of biogas technologies would be profitable for commercial pig producers in terms of sale of carbon credits. Likewise, fertilizer can have a monetary value as well as the energy produced, with the present system of waste disposal. The concept of the 'four R's', which stands for Reduce, Reuse, Recycle, and Renewable energy, has generally been accepted as a useful principle for waste handling.

Figure 4: Basics of Biogas Digesters



Source: http://gate.gtz.de/biogas/basics/basics.html

One of the most generally available sources of renewable energy is biogas. Biogas digesters have been used extensively (But not always successfully on a small scale) in developing countries as sources of pollution-free heat and electricity, enriched fertilizer, and waste-management, but the success of digesters in colder climates in the past has been mixed. Biogas digesters have been proven to control odour, stabilize waste volatility, and convert methane emissions to usable energy. There is a great potential for efficient energy production for both individual producers and large-scale livestock operations. Not only would biogas digesters provide these operators with a waste-management system and emissions reduction tool, but also a source of pollution-free heat and electricity. The surplus energy produced by biogas digestion could also be sold for public consumption. As the technology involved in biogas digestion has improved since its inception thirty years ago, so has the need for such measures. How the basics of biogas digester for hog operations is illustrated in Saskatchewan. With the conditions of Saskatchewan including winter temperatures of -20 to -40 degrees Celsius, it would require all piping to be insulated and a heat exchange system for the digester. A biogas hot water boiler is an effective means of maintaining the digester's ambient temperature requirements through a coil heat exchanger. Heated water can be pumped through pipes within the digester; at the most 20% of the biogas will be expended to maintain the required reactor temperature. The saving accrued through building a smaller digestion tank can mitigate this loss. Through this system, it is possible to maintain a stable temperature with a variance of only 2-8 degrees Celsius in a northern climate[2].

6.3 Technical Review of of Biogas Production

Biogas is a technology, which turns biological wastes into renewable energy and more stable organic matter and even enhances the value of the manure as a fertilizer by mineralization of organic bound nitrogen. Biogas is produced through an anaerobic fermentation process by a complex bacteria culture. In order to optimise the production, the process must be stable with only gradual changes in the supply of organic material and temperature to ensure an optimal adaptation of the bacteria culture. In fact, the bacteria should be regarded as domestic animals and treated with the same care as cows, pigs, and fish in fish farms.

[2] Source: *"The Economics of Biogas in the Hog Industry"*, by the Canadian Agricultural Energy End Use Data and Analysis Centre (CAEEDAC), 1999, http://www.usask.ca/agriculture/caedac/PDF/HOGS.pdf

Biogas is produced by means of a process known as anaerobic digestion (AD). It is a process whereby organic matter is broken down by microbiological activity and, as the name suggests, it is a process, which takes place in the absence of air. It is a phenomenon that occurs naturally at the bottom of ponds and marshes and gives rise to marsh gas or methane, which is a combustible gas. Biogas or methane is produced when organic matter is made to decay under anaerobic (without oxygen) conditions. This is usually done in a digester, which can be a fairly simple and relatively small apparatus. Almost any kind of organic matter including kitchen garbage, animal and chicken manure, vegetable crops, and paper may be used. The methane gas (CH_4) is produced along with about 30% carbon dioxide (CO_2) by the biological processes involved in anaerobic digestion. The waste material from a biogas digester makes a useful fertilizer.

In most literature on the subject, the term "biogas" refers to the raw gas produced, which includes CO_2 and other gases. The term "methane" is used for the pure CH_4 gas. Each 10 m^3 of biogas is equal in calorific value to about 6.2 m^3 of methane, 5.5 m^3 of natural gas, 7.0 litres of gasoline (petrol) and 6.2 litres of diesel.

Several precautions should be taken if one attempts to produce methane for the first time. Operators must learn how to use a starter brew to generate the biological activity, how to dilute and agitate the mixture, and how to control the pH level. The first batch of gas produced must not be used as the original air in the tank can form an explosive mixture. Otherwise the generation of biogas involves few technical or safety problems[3]

Most questions on biogas by possible users relate to the amount of fuel that they can expect from a given amount of organic material. The following table might provide some indication. The figures are based on the production rates of efficient digesters.

Depending on the raw material and the digester efficiency, we can obtain 300-to 600-m3 biogas for each ton of organic matter. Grass and foliage can be used and some groups are experimenting with large plantations of water hyacinth, kelp and algae.

Table 5: Biogas Production: Volumes Obtainable from Waste Matter

Type of Waste	Water Dilution	Volume of Gas per Wt. Material	Gas Produced per Animal per Day
Pigs	× 3	0.4 – 0.5 m^3 /kg	0.24 m^3
Cattle	× 2	0.1 – 0.3 m^3 /kg	0.22 m^3
Poultry	× 4	0.3 – 0.6 m^3 /kg	0.014 m^3
Human & kitchen wastes	variable	0.3 – 0.7 m^3 /kg	0.028 m^3

Source: http://www.fao.org/docrep/fiel/003/AB742E/AB742E02.htm

Comparing it to other fuels, Cheshire[4] states that a continuous gas production rate of 14 m^3 per day will generate 1.0 kW of electricity continuously given an engine efficiency of 25 per cent. Remember that the digesters require some heat for operation in cooler climates and this may be taken from the gas produced. Biogas has a variety of applications. The Table below shows some typical applications and outputs for one cubic metre of biogas. Small-scale biogas digesters usually provide fuel for domestic lighting and cooking.

[3] Clarke, R. Technological Self-Sufficiency. Faber, London, 1976.

[4] Chesshire, M. Methane on the Farm in How to Use Natural Energy. NEC, London, 1978.

Table 6: The application of biogas in several forms

No	Application	1 m^3 biogas equivalent
1	Lighting	Equal to 60-100 Watt bulb for 6 hours
2	Cooking	Can cook 3 meals for a family of 5-6
3	Fuel replacement	0.7 kg of petrol
4	Shaft power	Can run a one horse power motor for 2 hours
5	Electricity generation	Can generate 1.25 kilowatt hours of electricity

Source: http://www.itdg.org/docs/technical_information_service/biogas_liguid_fuels.pdf

There are two common man-made technologies for obtaining biogas: the first (which is more widespread) is the fermentation of human and/or animal waste in specially designed digesters. The second is a more recently developed technology for capturing methane from municipal waste landfill sites. The scale of simple biogas plants can vary from a small household system to large commercial plants of several thousand cubic metres. In the preliminary, two popular simple designs of digester have been developed, the first is fixed dome digester developed by China in 1936, and the second is floating cover biogas digester developed by India in 1937, both digesters are the same digestion process but the gas collection method is different in each. In the floating cover type, the water sealed cover of the digester is capable of rising as gas is produced and acts as a storage chamber, whereas the fixed dome type has a lower gas storage capacity and requires good sealing if gas leakage is to be prevented. Both have been designed for use with animal waste or dung.

7. OVERVIEW of ANAEROBIC DIGESTION TECHNOLOGY

Anaerobic Digestion equipment consists, in simple terms, of a heated or well-insulated digester tank, a gasholder to store the biogas, and a gas-burning engine/generator set, if electricity is to be produced. The organic waste is broken down in the tank and up to 60% of this waste is converted into biogas; the rate of breakdown depends on the nature of the waste and the operating temperature. The biogas has a calorific value typically between 50% and 70% that of natural gas and can be combusted directly, but the hydrogen sulphide should be scrubbed out first to reduce corrosion in modified natural gas boilers or when used to run internal combustion engines. Apart from biogas, the process also produces a digestate, which may be separated into liquid and solid components. The liquid element can be used as a fertilizer and the solid element may be used as a soil conditioner or further processed to produce higher value organic compost.[5]

7.1 Anaerobic Digestion Process

Anaerobic digestion is a biological process in which bacteria break down organic matter in an airless environment, with biogas as the end product. Biogas derived from dairy manure comprises approximately 60% methane (CH_4), 40% carbon dioxide (CO_2), and trace amounts of other gases, including hydrogen sulphide (H_2S). Due to its high methane content, biogas can be used as a fuel for energy conversion devices. Alternatively, it can simply be flared, as the resulting carbon dioxide makes a lesser impact on global climate than the methane. Depending on the system design, biogas can be combusted to run a generator producing electricity and heat, or it can be burned as a fuel in a boiler or other burner. Several different types of bacteria work together to break down complex organic wastes in stages, resulting in the production of "biogas".

[5] Source: http://europa.eu.int/comm/energy_transport/atlas/htmlu/adotech.html

Symbiotic groups of bacteria perform different functions at different stages of the digestion process. There are four basic types of micro organisms involved. Hydrolytic bacteria break down complex organic wastes into sugars and amino acids. Fermentative bacteria then convert those products into organic acids. Acidogenic micro organisms convert the acids into hydrogen, carbon dioxide and acetate. Finally, the methanogenic bacteria produce biogas from acetic acid, hydrogen and carbon dioxide.

Digester temperature is an important factor in maintaining the bacteria necessary for digestion. Gas production is dependent upon controlling anaerobic digester temperature, fermentation or retention time and the feedstock material. The gas production from the manure is dependent on the feeding of the animals, and the age of the manure when it is fed into the digester. The produced biogas is by co-generation converted into electricity and heat, and the solid residue is by the anaerobic digestion converted into a "more ready to use" fertiliser.

7.2 Potential Operating Digester

The potential output of an operating digester is dependent on the control of the anaerobic digestion conditions. To promote bacterial activity, the digester must be maintained at a temperature of at least 15°C up to 60°C depending on the type of anaerobic bacteria. There are more species of anaerobic bacteria that thrive in the temperature range of a standard design such as Psychrophilic bacteria, mesophilic bacteria and thermophilic bacteria. Thermophilic is a specie bacteria of three that thrive at higher temperatures. The potential operating digester can occur within three different temperature ranges:

- Psychrophilic range is between 15°C–25°C and is usually associated with systems that operate at ground temperature. These systems are very stable and easy to manage but it has the lowest biogas production rate and pathogen removal than for other systems of the three temperature ranges.

- The mesophilic range is between 30°C–38°C, these systems need a longer storage time (retention times of 15–20 days or more) in order for the lower temperature micro-organisms to break down organic matter. In general, these systems are reported to be more robust when considering temperature upsets. Smaller agricultural systems will operate in this temperature range. Digesters operating in the mesophilic range require constant heating in order to maintain a temperature of 38°C.

- The thermophylic range is between 50°C–60°C. It operates at a high temperature that allows for the highest rate of biogas production and the lowest hydraulic retention time (HRT), average retention times in the range of 3–5 days. Greater insulation is necessary to maintain the optimum temperature range and more energy needs to be consumed in heating the system. These systems may be more sensitive to upsets due to temperature variations. However, these systems are more effective in pathogen removal. To avoid operating errors, they require closer monitoring and maintenance. Another drawback is that their effluent is not odour free.

7.3 Types of Anaerobic Digesters

This study will present only three basic digester designs, namely covered lagoon, complete mix and plug-flow digester. All of them can trap methane and reduce faecal coliform bacteria, but they differ in cost, climate suitability and the concentration of manure solids they can digest. In less developed countries, direct AD is the only treatment of wastewater. If the digester is adequately designed and the retention time of the water is long enough, the quality of the treated water can be excellent.

7.3.1 Cover Lagoon Digester

A covered lagoon digester, as the name suggests, consists of a manure storage lagoon with a cover. The cover traps gas produced during decomposition of the manure. This type of digester is the least expensive of the three. Covering a manure storage lagoon is a simple form of digester technology suitable for liquid manure with less than 3-percent solids. For this type of digester, an impermeable floating cover of industrial fabric covers all or part of the lagoon. A concrete footing along the edge of the lagoon holds the cover in place with an airtight seal. Methane produced in the lagoon collects under the cover. A suction pipe extracts the gas for use. Covered lagoon digesters require large lagoon volumes and a warm climate. Covered lagoons have low capital cost, but these systems are not suitable for locations in cooler climates or locations where a high water table exists. Regarding AD systems used on U.S. dairy farms with a covered lagoons design, it is found that they operate at approximately ground temperature in the psychrophilic range, and have the lowest biogas production rate.

7.3.2 Complete Mix Digester

A complete mix digester converts organic waste to biogas in a heated tank above or below ground. A mechanical or gas mixer keeps the solids in suspension. Complete mix digesters are expensive to construct and cost more than plug-flow digesters to operate and maintain. Complete mix digesters are suitable for larger manure volumes having solids concentration of 3 percent to 10 percent. The reactor is a circular steel or poured concrete container. During the digestion process, the manure slurry is continuously mixed to keep the solids in suspension. Biogas accumulates at the top of the digester. The biogas can be used as fuel for an engine-generator to produce electricity or as boiler fuel to produce steam. Using waste heat from the engine or boiler to warm the slurry in the digester reduces retention time to less than 20 days. It is often operated in the thermophylic range, thereby generating biogas at a high rate, it consist of a large tank where fresh material is mixed with partially digested material. These systems are suitable for manure with lower dry matter content (4%–12%).

7.3.3 Plug-Flow Digesters

Plug-flow digesters are suitable for ruminant animal manure that has a solids concentration of 11 percent to 13 percent. A typical design for a plug-flow system includes a manure collection system, a mixing pit and the digester itself. In the mixing pit, the addition of water adjusts the proportion of solids in the manure slurry to the optimal consistency. The digester is a long, rectangular container or tubular tank, usually built below ground, with an airtight, expandable cover. New material added to the tank at one end pushes older material to the opposite end. Coarse solids in ruminant manure form a viscous material as they are digested, limiting solids separation in the digester tank. As a result, the material flows through the tank in a "plug" For optimal digestion, the average retention time (the time a manure "plug" remains in the digester), should take about 15 to 20 days for a plug to pass completely through the digester. Anaerobic digestion of the manure slurry releases biogas as the material flows through the digester. A flexible, impermeable cover on the digester traps the gas. Pipes beneath the cover carry the biogas from the digester to an engine-generator set.

A plug-flow digester requires minimal maintenance and it is more suitable for manure with lower solids concentrations, such as swine manure. Waste heat from the engine-generator can be used to heat the digester. Inside the digester, suspended heating pipes allow hot water to circulate. The hot water heats the digester to keep the slurry at 25°C to 40°C (77°F to 104°F), a temperature range suitable for methane-producing bacteria. The hot water can come from recovered waste heat from an engine generator fuelled with digester gas or from burning digester gas directly in a boiler. Plug flow systems rely on external recycling of a proportion of the outgoing digestate to inoculate the incoming raw feedstock. There are systems with vertical plug-flow and horizontal plug-flow.

Table 7: Summary Characteristics of Digester Technology

Characteristics	Covered Lagoon	Complet Mix Digester	Plug-Flow Digester
Digestion Vessel	Deep lagoon	Round/Square In/Above-Ground	Tubular/Rectangular In/Above-Ground Tank
Level of Technology	Low	Medium	In the past low, nowadays uncertain
Supplemental Heat	No	Yes	Yes
Total Solids	0,5-3%	3-10%	11-13%
Solids Characteristics	Fine	Coarse	Coarse
HTR *(days)	40-60		
Farm Type	Dairy, Hog	Dairy, Hog	Dairy, Hog
Optimum Location	Temperature and Warm climate	All climate	All climate

Source: http://www.epa.gov/agstar/pdf/handbook/chapter1.pdf

7.4 Other Digester Types

Besides the three digester types discussed above, there are many other anaerobic digester designs that have been used for processing municipal sewage as well as industrial waste[6]. Most of them treat waste streams with a low solids content, and thus have found various ways to speed up the digestion process or increase the solids content in order to reduce the volume required for digesting, thereby reducing costs. Without providing details of how they work, other digester designs include:

1. Batch-fed reactor, such as the anaerobic sequential batch reactor (ASBR);
2. Temperature-phased anaerobic digester (TPAD);
3. Suspended particle reactor;
4. Anaerobic filter reactor;
5. Upflow solids reactor;
6. Continuously stirred tank reactor with solids recycle;
7. Up flow anaerobic sludge blanket reactor;
8. Anaerobic pump digester;

[6] Industries that use anaerobic digestion to treat their wastes include: food processing (milk and milk products, starch products and sugar confectionery, brewing, and distilling and fermentation are some of the largest), and the paper industry. The treatment of the industrial waste, as well as municipal sewage, is often driven by regulations.

9. Fluidized- and expanded-bed reactors,[7] and
10. Fixed-film anaerobic digester.[8]

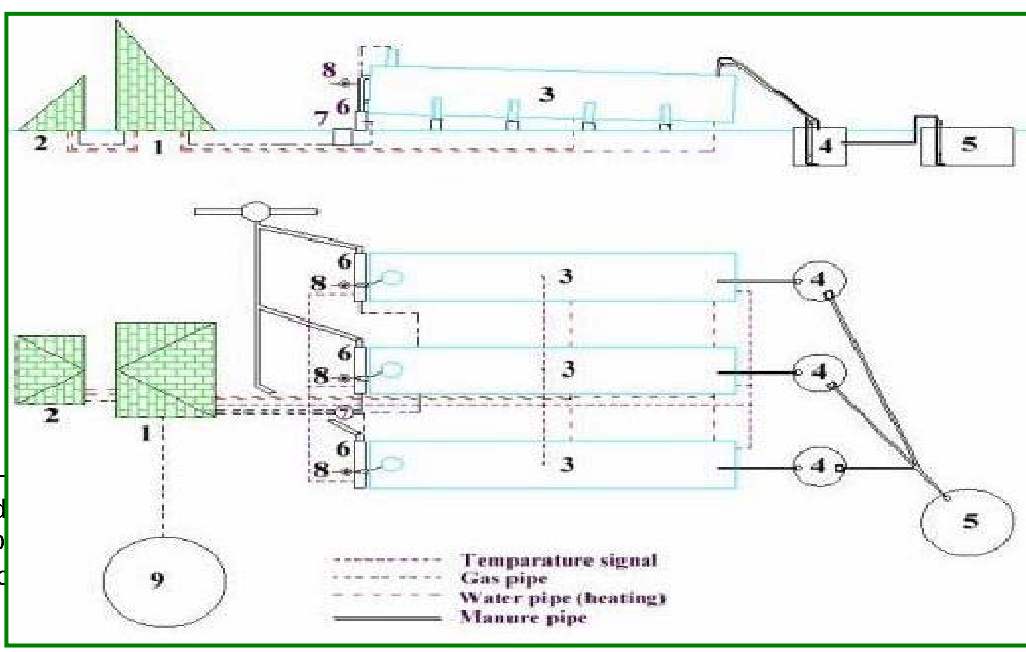
8. REVIEW OF BIOGAS PLANT TECHNOLOGY

The gas production from manure is dependent on the diet of the animals, and the age of the manure when it is fed into the digester. The produced biogas is by co-generation converted into electricity and heat, is by the anaerobic digestion converted into a "more ready to use" fertiliser.

8.1 First Case Overview (Lithuania)

An example of biogas technology exists in Lithuania – at the Rokai Pig Farm Demonstration Biogas Plant Kaunas using Danish Folkecenter's Renewable Energy Technology. The Anaerobic Digestion design is an inclined tubular digester (a modified form of the horizontal displacement digester). The digestion vessel is tubular, but inclined at an acute angle to the horizontal. Thus, the main advantages of a horizontal displacement digester are retained, while the exposed surface area of the digester contents, where scum and crusts can form, is minimized. It is also mechanically simpler to remove any scum and crust. The main applications of this design are likely to be for treating particulate waste of 8% total solids concentration, where some settling will occur. The biogas plant is designed based on the daily 60 m^3 of manure from the 11,000 pigs, is by the anaerobic digestion process where waste is converted into a "more ready to use" fertiliser. The produced biogas is converted into electricity and heat by co-generation, which will reduce the farms expenses for energy significantly. The technology gives possibility for much higher production with surplus of electric energy, which will be sold to the public grid. There are two gas turbine units, 1×75 kW + 1×110 kW, and electricity production is 2400 kWhe/day. Installation system cost is equivalent to 3,692.31 USD per 1 kW. Electricity production or cogeneration can be run with a biogas boiler followed by a vapour turbine. The following figures show the layout and schematics drawing of the biogas plant of the Rokai plant.

Figure 5: Schematic Drawing of the Biogas Plant (Decline Plug-flow Digester Type)



[7] For a d… cson, "Anaerob…
[8] "Reduc… 00.

Source: http://www.folkecenter.dk/en/rokai/rokai.html

1) Technical building, control room, shows room, laboratory, and boilers.
2) Technical building, co-generation. **3)** Digesters. **4)** 30 m^3 mixing tank. **5)** 60 m^3 Pre-tank.
6) Sulphur cleaning system. **7)** Condensate separation. **8)** Air pump. **9)** Gas holder

Note: The sulphur cleaning system is needed to study for installation at Vanith Farm.

The biogas plant consists of 3 horizontal digesters in a parallel configuration - fed by the same raw material - the manure. Each $300m^3$ digester receives daily $20m^3$ manure in the $30m^3$ individual mixing tanks. Waste additives are added and mixed in the same tank. The manure is pumped into the digester in intervals every 2 hours through a 24- hour period. An equivalent volume of manure is displaced at the outlet end of the digester. The process mix is heated to a temperature between 35°C and 50°C. Heating is obtained by an integrated heat exchanger, and heat loses are minimised by a 200 mm insulation covered by weatherproof steel plate coating. To keep the manure homogeneous and to avoid scum layer, the manure is mixed at intervals by a slowly rotating axial agitating system.

The agitator also transports the sediments to the sand outlet, where it can be removed. The biogas leaves from the top of the digester at a low pressure, sufficient to overcome the losses in pipes and the counter pressure from the floating gasholder.

The gasholder delivers pressure enough to operate gas burner and co-generation motor without any compressor to raise pressure. If the system pressure exceeds 45 mbar, the gas is released from the digester by a siphon trap.

8.2 Second Case Overview (Korea)

In the case of biogas production from slurry for generating electricity in Korea, an Integrated Biogas Energy System (IBES) was developed in 1999. The biogas plants have been designed to process pigs' slurry of 10 m^3/day, and the anaerobic digester tank is 200 m^3 used for 2000 pigs with the rate of biogas production 138 m^3/day. The installed electricity generator is rated at continuous 33 kW, 380/220 V, 3-Phase, 0.8 power factor, and 60 hertz. This system showed that renewable energy production was 216 000 kWh/yr. The biogas produced by the digester was collected, and sent to a spark ignition engine or a dual-fuel engine-generator (this method was developed a few years ago). The electricity generator was rated at a continuous 33 kW (kilowatt), 380/220 volt, 3-phase, 0.8 power factor, and 60 hertz. This system consists of three parts: an anaerobic digester for reduction of organic matter and the production of biogas; an electricity generator for generating energy; and electrochemical oxidation process for waste water treatment containing bio refractory pollutants. Digestion takes place in a semi-continuous, single-stage, continuously stirring anaerobic digester, under 35°C of mesospheric temperature.

8.3 Third Case Overview (Zebulon)

In the case of Barham Farm of Zebulon[9] (this project is located on the Julian Barham Farm near Zebulon, North Carolina), 4000 sows to weaner pig farm with pit recharge are studied. This farm applied the covered lagoon type of digester. The construction process began in July 1996. The lagoon cover, a 400,000 Btu boiler and a 120 kW generator were installed in December 1996. Biogas use for heating water began in January 1997. Lagoon cover manufacturing problems limited biogas recovery and the production of electricity, however the boiler has operated almost continuously, providing hot water for pig mats under farrowed pigs. The owner recovered his money and has since purchased a new 40-mil HDPE cover. Preliminary results from July 1998 showed a recovery of 792 m^3/d. of biogas while operating 12 hours of 90 kW daytime generator operations and 12 hours of nighttime boiler operation. Odour is virtually non-existent, the effluent is stable and nutrient content of the second lagoon has been reduced substantially.

8.4 Seven Farms Case Overview

This study is overview merely seven pig farms which has different scale, location and also AD type for being sample of pilot project study for Vanith Pig Farm, its have been part of a research project over the last ten-years. From the sample calculation of gas production samples per day per pig head in the table 9 are very different. If we observe biogas production per day per pig head, it can be seen that the data reported for Colorado Pork LLC is very high compared to the others; one pig gives biogas production about 0.3139 m^3 per day. For this reason, it might be dependent on the content of the stock feed used. And the other hand, when we are considering energy electric production per day for different types of AD, we supposed that, the Go-generator (Gas turbine) operates 12 hour & 24 hour per day, and we have noticed that Arex Pork Farm is one of seven farm, is highly productive when compared to the big scale farm at Hang Zhou which has a larger population of swine (nearly 30 times), more than, Shynyi (nearly 7 times), and Rokai biogas plant of Lithuania (more than 1.2 times). At the Arex farm for the Ratio 1 equivalent to 4.891 and, for the Ratio 2 equivalent to 2.446 the power electric of gas turbine of 1 kW can be produced electric energy of 4.891 kWh.

[9] *"Development of Environmentally Superior Technologies"*, Waste Management Programs, College of Agriculture and life sciences, http://www.cals.ncsu.edu/waste_mgt.
http://www.epa.gov/agstar/resources/ben.html

Table 8: Comparisons of 7 Different Manure Digestion Systems, and Capacity of Gas Production and Size of Gas Turbine. (Estimated the Quality of Gas turbine Operate 12 hour/day)

Example: Determination of the quality of gas turbine, the sample 1 total of energy production is 1448 kWh/day.

We estimated that the system is operated 24 h/day, therefore:

Ratio = (Total Energy Production per day) / (Hour Used per day X Gas Turbine Capacity)
= 1448 kWh.day/(24 h/day*85 kW) = 0.710

Average Ratio = (Sum of Total Ratio of Gas Turbine) / (Number of Gas Turbine)

Total of Energy Production per day = Average Ratio X Hour Used per day X Gas Turbine Capacity

Sample size study	**Farm Name And Type of AD**	**Head of Pigs**	**Gas Production per day**	**Size of Gas Turbine**	**1m3 of gas produce electric** (3/2)	**One pig produce gas per day (2/1)**	**Energy Production per day**	**Quality of AD (6/1)**	**Quality of Gas Turbine**
			M^3	kW	kW	m^3	kWh	kWh/pig	Ratio
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	Colorado Pork LLC Complete Mix	5,500	1,726	85	0,0493	0.3139	1448	0.2633	0.710
2	Barham Hog, Cover Lagoon	4,000	792.4	90	0,1136	0.1981	1080	0.2700	0.500
3	Hang Zhou, Zgehang Province[a]	200,000	8,500	230	0,0271	0.0425	13,500	1.5168	2.446
4	Shynyi, Beijing Municipality[b]	60,000	2,500	100	0,04	0.0417	4000	0.0666	1.667
5	Arex Pork Complete Mix	8,900	1,018.8	230	0,2258	0.1145	13,500	1.5168	2.446
6	Rokai, Lithuania, Plug-flow	11,000	1,200	185	0.1542	0.1091	2400	0.2182	0.541
7	Pig Slurry in Korea, Plug-flow	2,000	138	33	0,2391	0.0690	592	0.3000	0.747

[a] Project Activity Brief No.4: Biogas (didn't mention AD type)
[b] Project Activity Brief No.4: Biogas (didn't mention AD type)

It is noticed that in the seventh sample size study, one pig produced 0.069 m^3/day of biogas per day; this result is very close to the value of 0.07 m^3/day, which is mentioned in the RAP BULLETIN, 1995

8.5 Installed System Costs of Digester + Generator Review

In order to calculate the installation system cost of Digester + Generator of Vanith Pig Farm Company, information is taken the installation system cost of Rokai Pig Farm (Lithuania) which is mentioned in the previous page, and Colorado Pork LLC (USA) for sample study as is shown in table below

Table 9: Anaerobic Digester System Costs of Colorado Pork LLC (USA)

System Type	**Installation cost** US$	**O & M costs** US$/year	**Installation system cost** US$/kW
Digester + Generator (5 systems)			
Low[6]	15,300	500	N/A
High[6]	32,200	2,500	N/A
Digester + Generator (7 systems)			
Low[10] *(System size: 25 kW)*	96,000	5,000	3,840
High[11] *(System size: 120 kW)*	368,880	10,000	3,074

Source: http://www.westbioenergy.org/swine/six.html

9. ESTIMATION OF VOLUME BIOGAS PRODUCTION AND CO-GENERATOR CAPACITY

9.1 Estimation of the Feasibility of Biogas Volume Production from Pig Farm

This study refers to the production rate of efficient digesters that includes pig effluent with a gas production of about 0.24 m^3/day. Referring to Chesshire[1] that states that a gas production rate of 14 m^3/day can generate 1 kW of electricity. Seven examples of different farm sizes from Asia, Europe and America have been studied, based on the actual pig population in the pig farm throughout Vientiane Capital City. The calculation of the gas production from pig farms in this study involved a statistical analysis to assist decision-making in the selection of the capacity of the co-generator. This study offers a current estimation of the amount of gas production per day through the selected co-generator capacity for eight pig farms. Beside these farms, it is noticed that the daily capacity of gas production is not enough for generating electricity. More details are given in Attachment 3.

Based on the study of the statistical analysis, the range of gas production measured is from 318 m^3/day to 2,397 m^3/day of the typical amounts from seven example farm sizes, but is noted to be only 87.9 m^3/day to 298 m^3/day have found at Vanith Farms F1+F2 and F3 respectively. It can be seen that the difference in gas production is quite large, and it is influenced by the different nutrient concentration in the food, and possibly the genetic quality of the pigs themselves. From this point, in order to improve the average value of gas production for the

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[10] Lusk, Phil. (September 1998). Methane Recovery from Animal Manures: the Current Opportunities Casebook. NREL/SR-25145. NREL. Golden, CO. pp. 4-5: 4-69.

[11] Roos, Kurt. (May 2000). Colorado Pork LLC.

farm, F1+F2 should have an output from 969 m^3/day to 1,229 m^3/day and farm F3 from 263 m^3/day to 333 m^3/day. To achieve this target the specialist of Vanith Farm should consider the quality of pig food. The assessment of gas production per day in Vanith Farm will reach the medium standard value if the quality of food could be at standard level. It means that Vanith Farm is able to gain the average value of gas production as shown in the column thirteen which is the average value of column eleventh and twelve, the estimation of biogas production for farm F1+F2 is 1,099 m^3/day and farm F3 is 332.9 m^3/day.

Table 10: The Current Estimation Plan of the Volume of Biogas and Methane Production by Comparing Within Different Sample Sizes of Study

No.	Name of Pig Farm	No. of Pig	Theory 0.24 m3/day/pig	S1: 0.31389m3/day/pig	S2: 0.1981 m3/day/pig	S3: 0.0425 m3/day/pig	S4: 0.041667m3/day/day	S5: 0.1145 m3/day/pig	S6: 0.1091 m3/day/pig	S7: 0.069 m3/day/pig	Average of seven sample size	Average of five sample size (ignore S3 & S4)	Estimation of gas production
1	2	3	4	5	6	7	8	9	10	11	12	13	14
			m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	M^3/d	m^3/d	m^3/d	m^3/d
1	Vanith Farm F1+F2	7,636	1,833	2,397	1,513	325	318	874	833	527	969	1,229	1,099
2	Vanith Farm F3	2,069	497	649	410	87.9	86.2	237	226	143	263	332.9	298
3	Total	9,705	2,330	3,046	1,913	413	404	1,111	1,059	670	1,232	1,562	1,397
	The Volume of Methane Production by Comparing within Different Sample Sizes of Study												
			kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh
1	Vanith Farm F1+F2	7,636	1,178	1,539	973	209	204	562	535	339	623	790	706
2	Vanith Farm F3	2,069	319	417	264	565	554	152	145	92	169	2140	191
3	Total	9,705	1,498	1,956	1,237	774	758	714	680	431	792	2,930	897

Where: Biogas production = 7,636 heads X 0.24 m^3/day/head = 1,833 m^3/day
Methane production = (1,833 X 9)/14

9.2 Estimation of the Feasibility for Selecting the Capacity of Co-generator

Based on the table 10, the estimation of biogas production per day among several sample size studies, it can be calculated that the average size of co-generator for selecting the size of co-generator, and this is shown in the table below, in column 14.

Table 11: The Current Estimation Plan of the Capacity of Co-generator by Comparing within Different Sample Sizes of Study

No.	Name of Pig Farm	14 m^3 of biogas equivalent 1 kW	1 m^3 = 0.0493 kW	1 m^3 = 0.114 kW	1 m^3 = 0.027 kW	1 m^3 = 0.040 kW	1 m^3 = 0.226 kW	1 m^3 = 0.154 kW	1 m^3 = 0.239 kW	Average of seven sample	Average of five sample size (ignore S3 & S4)	Average of (11+12)/2	Select Capacity of co-generator
1	2	3	4	5	6	7	8	9	10	11	12	13	14
		kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW
1	Vanith Farm F1+F2	131	118	172	8,8	12.7	197	128	126	109	148	129	120
2	Vanith Farm F3	35.5	32	47	2.4	3.4	53	35	34	29.5	40	35	35
3	Total	166.5	150	219	11.2	16.4	250	163	157	139	188	164	155
The Conversion from Calorific value of Methane to kWh													
		kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	
1	Vanith Farm F1+F2	12,041	15,732	9,482	2,135	2,089	5,743	5,474	3,463	6,367	8,076	7,222	
2	Vanith Farm F3	3,266.	4,264	2,698	5,785	5,663	1,553	1,482	940	1,727	21,875	1,962	
3	Total	15,307	19,996	12,181	7,921	7,752	7,297	6,956	4,403	8,095	29,951	9,184	

Where, example:

a. Size of co-generator = 1,833 $m^3 \times 1$ kW/14 m^3 = 131 kW
b. Size of co-generator = 2,397 $m^3 \times 0.0493$kW/m^3 = 118.17 kW

Note: 14 cubic meters of biogas to contain around 9 cubic meters of methane, which has a calorific value of 315,000 BTU's, or 332 mega joules.

Based on the table 4, showing an estimation of the future pig population, the potential biogas production and the capacity of the co-generator can be calculated. This is shown in table 12 and 13.

Table 12: The Future Plan Estimation of the Volume of Biogas Production

No.	Name of Pig Farm	No. of Pig	Theory 0.24 m3/day/pig	S1: 0.31387m3/day/pig	S2: 0.1981 m3/day/pig	S3: 0.0425 m3/day/pig	S4: 0.041667m3/day/day	S5: 0,1145 m3/day/pig	S6: 0.1091 m3/day/pig	S7: 0.069 m3/day/pig	Average of seven sample size	Average of five sample size (ignore S3 & S4)	Estimation of gas production
1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Heads	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d
1	Vanith Farm F1+F2	11467	2752	3599	2272	487	478	1313	1251	791	1456	1845	1651
2	Vanith Farm F3	3104	745	974	615	132	129	355	339	214	394	499,5	447
5	Total	14571	3497	4573	2887	619	607	1668	1590	1005	1850	2345	2098
The Conversion from Calorific value of Methane to kWh													
		Heads	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d
1	Vanith Farm F1+F2	11,467	1,769	2,314	1,461	313	307	844	804	509	936	1,186	1,061
2	Vanith Farm F3	3,104	479	626	395	85	83	228	218	138	253	321	287
3	Total	14,571	2,248	2,940	1,856	398	390	1,072	1022	646	1,189	1,507	1,349

Table 13: The Future Estimation Plan for the Capacity of the Co-generator

No.	Name of Pig Farm	14 m^3 of biogas equivalent 1 kW	1 m^3 = 0.0493 kW	1 m^3 = 0.114 kW	1 m^3 = 0.027 kW	1 m^3 = 0.040 kW	1 m^3 = 0.226 kW	1 m^3 = 0.154 kW	1 m^3 = 0.239 kW	Average of seven examples	Average of five sample size (ignore S3 & S4)	Average of (11+12)/2	Select Capacity of co-generator
1	2	3	4	5	6	7	8	9	10	11	12	13	14
		kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW
1	Vanith Farm F1+F2	197	177	258	13,2	19	296	193	189	164	223	193	195
2	Vanith Farm F3	53.2	48	69.8	3.57	5.2	80.2	52.2	51.2	44.3	60.3	52	50
3	Total	250	4573	2887	16.8	24	377	245	240	208	283	246	245
The Conversion from Calorific value of Methane to kWh													
		kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh
1	Vanith Farm F1+F2	18,083	23,654	14,935	3,200	3,138	8,628	8,219	5,203	9,568	12,124	10,846	
2	Vanith Farm F3	4,896	6,399	4,038	869	848	2,331	2,228	1,411	2,586	3,281	2,934	
3	Total	22,980	30,053	18,972	4,068	3,986	10,958	10,447	6,613	12,154	15,405	13,779	

9.3 Conversion to Other Chemical Forms

Regarding Tables 10 and 12 under column 13, the energy can be converted to another form such as methane, natural gas, petrol and diesel, for present and in future as shown in table 14. Also in addition an estimation of biogas production from pig farms shown in table 5. See also the Annex 4 & 5 whole pig farm through Vientiane Capital City.

Table 14: Shows the Amount of Conversion Value of Gas to Methane, Natural Gas, Petrol and Diesel for Present Plan and for Future Plan

No.	Name of Pig Farm	Gas Production	1 m3 of gas equivalent to 0.62 m3 of methane	1 m3 of gas equivalent to 0.55 m3 of natural gas	1 m3 of gas equivalent to 0.7 litre of petrol	1 m3 of gas equivalent to 0.62 litre of diesel
1	2	4	5	6	7	8
		M^3/d	m^3/d	m^3/d	Litres/d	Litres/d
Present plan						
1	Vanith Farm F1+F2	1099	681.45	604.51	769.38	681.45
2	Vanith Farm F3	298	184.641	163.79	208.47	184.641
3	**Total**	**1397**	**866.091**	**786.31**	**977.84**	**866.091**
Future plan						
1	Vanith Farm F1+F2	1651	1023.62	908,05	1155.7	1023.62
2	Vanith Farm F3	447	277.14	245.85	312.9	277.14
3	**Total**	**2098**	**1300.76**	**1153.9**	**1468.6**	**1300.76**

This project is intended to produce biogas by utilizing a by-product from the existing pig farm (pig dung) as raw material to feed an anaerobic digester. The biogas produced will be utilized as fuel to run a co-generator for generating electricity. The produced electrical energy will be utilized to cover the energy consumption of the farm and any surplus may be sold to the national grid. This is one inexpensive alternative form for the production of electrical energy. In addition biogas may be utilized for heating and cooking.

9.4 Estimation of Daily Energy Production

The principal objective of this study after selecting the capacity of the co-generator is the need to evaluate the possibility of electrical energy production per day, which takes into account the capacity of co-generator. From this point of view, it is necessary to consider table 3, in column 8, which shows the quality of the co-generator from the various scale pig farms. Some pig farms are very large scale such as Hang Zhou and Shynyi pig. This study is considering only small-scale farms and uses the average value of five small-scale farms to estimate the efficiency of co-generator at 1.977 kWhe/kW. This results in a daily production of electrical energy equivalent to 2610 kWhe/day. Considering the size of farm and taking the average value, our finding is in the margin. Finally, the average efficiency of the co-generator is equivalent to 1.254 kWhe/kW, with the electrical energy production per day equivalent to 1650 kWhe/day.

<u>Example:</u>

Cases 1 is studied from a study of five similar sized examples from which the average is calculated:

For Farm F1+F2:
Co-generator size of 110 kW, suppose the co-generator operates 12 h per day
Quality of Co-generator = (1.00+1.42 + 4.891 + 1.081 + 1.494) kWhe/kW = 1.977 kWhe/kW
Electrical Energy Production per day = 110 kW × 1.977 kWhe/kW × 12 h/day = 2610 kWhe/day

For farm F3:
Co-generator size 35 kW, suppose the co-generator operate 12 h per day
Electrical Energy Production per day = 35kW × 1.977 kWhe/kW × 12 h/day = 830 kWhe/day

Cases 2 is studied from four samples size study and calculates an average:

For farm F1+F2:
Co-generator size 110 kW, suppose the co-generator operate 12 h per day
Quality of Co-generator = (1.00+1.42 +1.081 + 1.494) kWhe/kW = 1.25 kWhe/kW
Electrical Energy Production per day = 110 kW × 1.25 kWhe/kW × 12 h/day = 1650 kWhe/day

For farm F3:
Co-generator size 35 kW, suppose the co-generator operate 12 h per day
Electrical Energy Production per day = 35kW × 1.25 kWhe/kW × 12 h/day = 527 kWhe/day

Table 15: Summary of the Evaluation for Daily Potential Electrical Energy Production

No.	Name of Pig Farm	No. of Pigs	Size of Co-generator	Quality of Co-generator		Electric Production Per day	
				min	max	min	max
		Heads	kW	kWhe/kW	kWhe/kW	kWhe/kW	kWhe/kW
Present plan							
1	Vanith Farm F1+F2	7636	120	1.25	1.977	1800	2847
			110	1.25	1.977	1650	2610
2	Vanith Farm F3	2069	35	1.25	1.977	525	830
3	**Total**	**9705**	**155**			**2175 - 2325**	**3440 - 3677**
Future Plan							
1	Vanith Farm F1+F2	11467	195	1.25	1.977	2925	4626
2	Vanith Farm F3	3104	50	1.25	1.977	750	1186
3	**Total**	**14571**	**245**			**3675**	**5812**

Estimation of the current electrical energy production per day for Vanith Pig Farm and for future plans could be summarized in the table above.

9.5 Adopted Technology

This study learns from the experience of the Rokai Pig Farm concept using combined heat and power (CHP) and will mean that the plant is scaled according to the amount of resource available on the Vanith Farm. Presently, for F1+F2, the daily estimate of manure from the 7636 pigs is 40 m^3 and for F3 is 11 m^3 of manure from the 2069 pigs. By utilizing an anaerobic digestion process this can be converted from raw manure into biogas and "more ready to use" fertiliser. Biogas is utilized by co-generation and converted into electricity and heat, which will significantly reduce the farms expenditure on energy.

The technology provides the possibility for much higher production of electricity with the surplus being sold to the public grid. The technical estimation of the manure tank, the digester tank, the gas storage tank, pressure of the system and the capacity of co-generator will influence the expected output. The details of using a slurry heater in AD on different conditions are as follows:

1a. Technical estimation data for Vanith Digester Plant for Farm F1 and F2 for currently data

Manure	: 40 m^3 pig manure / day
Waste concentrated:	~ 7.19 t / day
Digester	: 2 x 300 m^3 horizontal steel digesters
Gas production	: 318 - 2397 m3/day (compare with the proportion of Rokai 850-2500 m^3/day)
System pressure	: 25 Mbar, (max. 45 Mbar by safety siphon trap)
Gas storage	: 40 m^3
Co-generation	: 110 kW or 120 kW
Boiler/burner	: 1 x 200 kW gas burner
Sulphur cleaning	: Aerobic external biological process
Control system	: PC based control -and data acquisition system

1b. Estimation technical data for Vanith Digester Plant for Farm F3 for currently data

Manure	: 11 m^3 pig manure / day
Waste concentrated	: ~ 3.1 t / day
Digester	: 1 x 300 m^3 horizontal steel digesters
Gas production	: 86.02 - 649 m3/day (compare with the proportion of Rokai 250-700 m^3/day)
System pressure	: 25 Mbar, (max. 45 Mbar by safety siphon trap)
Gas storage	: 20 m^3
Co-generation	: 25 kW or 35 kW
Boiler/burner	: 1 x 50 kW gas burner
Sulphur cleaning	: Aerobic external biological process
Control system	: PC based control - and data acquisition system

2a. Estimation technical data for Vanith Digester Plant for Farm F1 and F2 for future plan

Manure	: 63 m^3 pig manure / day

Waste concentrated : ~ 10.8 t / day
Digester : 3 x 300 m^3 horizontal steel digesters
Gas production : 478 – 3599 m3/day (compare with the proportion of Rokai 1200 - 3600 m^3/day)
System pressure : 25 Mbar, (max. 45 Mbar by safety siphon trap)
Gas storage : 40 m^3
Co-generation : 1 x 75 kW + 1 x 120 kW
Boiler/burner : 1 x 300 kW gas burner
Sulphur cleaning : Aerobic external biological process
Control system : PC based control- and data acquisition system

2b. Estimation technical data for Vanith Digester Plant for F3 for future plan

Manure : 17 m^3 pig manure / day
Waste concentrated : ~ 4.66 t / day
Digester : 1 x 300 m^3 horizontal steel digesters
Gas production : 129- 974 m3/day (compare with the proportion of Rokai 250 – 700 m^3/day)
System pressure : 25 Mbar, (max. 45 Mbar by safety siphon trap)
Gas storage : 20 m^3
Co-generation : 2 x 25 kW
Boiler/burner : 1 x 85 kW gas burner
Sulphur cleaning : Aerobic external biological process
Control system : PC based control and data acquisition system

9.6 Core Business of Vanith Farm is to Row and Supply of Pork to the Local Market.

The Vanith Pig Farm Company is a joint venture between Mr. Vanith and a private investor from France. The core business of this proposed project is to produce electricity by utilizing AD biogas produced at Vanith Pig farm to fuel a co-generator. Referring to the survey, financially Vanith Farm is not able to fund this proposed project. This is partly due to the farm not being the property of Vanith Company (This Pig Farm is the property of Ministry of Agriculture and Forestry, and now is become a concession project and run as a joint venture company). In addition, this proposed project may not be profitable for them. It seems that Vanith Company relies only on the Government authority to solve their problems.

It appears that this proposed project would be possible if there would be a grant from NGO or other international organization as a pilot or demonstrative project for Lao PDR. One of the possible approaches for financing this proposed project is by a private investment.

9.7 The product(s) or Service(s) Generated by the Project:

Electricity from biogas

- characteristics of energy produced (electricity, steam or hot water at specified temperature/pressure and daily, weekly and monthly quantities to match current and projected energy loads and profiles);

  The installed capacity of the system is 35 kW under 0.4 kV will produce electrical energy of about 525 kWh per day.

- realistic expected annual production (GWh, GJ, TOE replaced, etc) to tie in with seasonal fuel supply/energy/production demand, using realistic annual hours of use - including provision for scheduled maintenance and major plant/generator overhauls;

  The expected annual production is 191.6 MWh, the amount of 93.0 MWh will be utilized to run the farm; a surplus of 99.8 MWh will be sold to the grid.

- how any electricity/fuel/steam/hot water produced will be utilized in an efficient production process including specified current and future process temperature/pressures for steam/hot water/direct drying and so forth;

  The amount of 93 MWh will be utilized to run the farm

- Why the stated annual production/activity level is reasonable for the plant concerned compared with other comparable plants/activities in the country and in relation to international practice

- Customer/process ability to pay for full cost of providing energy service (particularly relevant for small grid electricity to replace explicitly and more commonly implicitly subsidized/unrealistically low electricity prices where source of necessary ongoing subsidies is not identified, or source and likelihood of ongoing explicit or implicit subsidies continuing for project duration)

  The electricity company will purchase the surplus at a lower rate. One of the alternatives to be more beneficial is to operate the plant during peak hours.

9.8 Assessment Installation Cost of the Gas Turbine for Vanith Pig Farm Company

This study refers to technology installed at the Rokai Pig farm and Colorado pig farm with the cost of digester system shown on table 3. This is then applied to the Vanith pig farm and, based on its present proportions for determining the construction size and design for present and future planning. It is then possible to assess the installation cost of a digester system as shown in the table below:

Table 16: Estimation of Installation Cost of Anaerobic Digester System Costs

Type of Technology	Installation Cost (US$)	Operation and Maintenance Costs (O&M Costs) (US$)	Installation System Cost (US$)
Estimation of Installation cost for currently data			
Transfer Rokai Technology			
• F1&F2 (110 kW)	406,120		3,692
• F1&F2 (120 kW)	443,040		3,692
• F3 (35 kW)	129,220		3,692
• F3 (25 kW)	92,300		3,692
Transfer USA Technology			
• F1&F2 (120 kW)	368,880	10,000	3,074
• F3 (35 kW)	107590	10,000	3,840
• F3 (25 kW)	96,000	5,000	3,840
Estimation of Installation cost for future plan			
Transfer Rokai Technology			

F1&F2 (75 kW + 110 kW)	683,020		3,692
F3 (50 kW)	184,600		3,692
Transfer USA Technology			
F1&F2 (75 kW + 120 kW)	599,430	10,000	3,074
F3 (50 kW)	153,700	5,000	3,074

9.9 Assessment of the Reduction of Environmental Impact

The reduction in methane emissions obtained by processing, based on the Rokai pig farm∗, the manure (or raw dung) is about 1000 kg/m^3, the methane is 0.717 kg per m^3, and the equivalent amount of CO_2 is 19-21 times greater, 68 kg CO_2 or 0.068 tCO_2/m^3. The estimation of reduction in methane emission for this study is separated in two conditions for present and future plan for two location of pig farm F1+F2 & F3.

Present plan:

- In case of pig farm F1+F2, with 40 m^3 of manure per day:
  40 m^3 of dung is estimated to produce between 318 and 2397 m^3 of biogas, which is only 65% methane, so worst case this would yield (say) 200 m3 of methane per day, which will weight 200 x 0.717 = 143 kg per day, or 52 tons CO2 eq per annum. Then the 35% CO2 must be subtracted too.
- In case of pig farm F3, with 20 m^3 of manure per day:
  20 m^3 of dung is estimated to produce between 159 and 1198.5 m^3 of biogas, which is only 65% methane, so worst case this would yield (say) 100 m3 of methane per day, which will weight 100 x 0.717 = 717 kg per day, or 26 tons CO2 equiv. per annum. Then the 35% CO2 must be subtracted too.

Future plan:

- In case of pig farm F1+F2, with 40 m^3 of manure per day:
  40 m^3 of dung is estimated to produce between 318 and 2397 m^3 of biogas, which is only 65% methane, so in better case this would yield (say) 300 m3 of methane per day, which will weight 300 x 0.717 = 215.1kg per day, or 78 tons CO2 equiv. per annum. Then the 35% CO2 must be subtracted too.
- In case of pig farm F3, with 20 m^3 of manure per day:
  20 m^3 of dung is estimated to produce between 159 and 1198.5 m^3 of biogas, which is only 65% methane, so in better case this would yield (say) 150 m3 of methane per day, which will weight 150 x 0.717 = 107.55 kg per day, or 39 tons CO2 equiv. per annum. Then the 35% CO2 must be subtracted too.

10. FINANCIAL ANALYSIS OF THE PROJECT

10.1 Financial Analysis and Commercial Viability

Effective financial models are powerful tools to most corporate finance transactions. Developers have to provide the lender a clear, comprehensive and accurate project model that shows project/shareholder's return and lender coverage ratio. The models should focus on the management of the continuing business and on project cash flow. The assumptions should be conservative and a sensitivity analysis should demonstrate the viability of the project and the financing structure under different scenarios. Financial advisers are often employed by the developers to produce financial models. These models monitor the success of long-term project finance arrangement. Financial advisers provide monitoring services and model custody services that allow project finance to meet the requirements of their loan agreements. In particular, lenders will require periodic reports about lending ratios, sensitivity analysis and debt coverage ratios to allow them to monitor the risk of the developer's loan. Monitoring models are used at regular intervals during the life of the project financing to mitigate risks. Financial models are refined through the different stages of project development. As the project moves through the advance stage of development, a more precise model is possible to predict the viability and profitability of the project. The model does not only serve as a tool for analysis for the developer but more importantly it gives an overview of the project economics to potential participants such as investors and lenders. In the case of the Vanith Pig Farm proposed project, ADB has standard models available from their website to use

10.2 Structuring the Financial Model: Building and Securing the Project Cash Flow

The financial model should be designed to be an integrated spreadsheet-based program with several sheets linked to each other. The main features of the model should include:

- Separate but linked worksheets to allow the user to easily understand the different functions of the model and to navigate it with ease.
- Inclusion of technical analysis to determine the potential power and heat generation capacity of the chosen technology.
- Data entry is done on designated worksheets only, and changes in data can be accordingly done.
- An operation worksheet is included which captures the demand of the households served as well as the seasonality of the primary energy sources chosen.
- Sensitivity analyses on different parameters are included.
- The model should be customized to the specific project and to the technologies chosen, which increases the accuracy of the analysis

Once the technical option is determined, the most appropriate business model should be used for the financial modeling exercise. At this stage, the practical aspects of the business will be structured which will reflect matters related to the company's shareholding structure, financial plan, capital investment, and operational details. The financial model normally consists of different worksheets. Each worksheet has a different function and theme. Below are the descriptions of these worksheets and their functions in the model:

- **Results and summary:** This worksheet gives a summary of the assumptions used in the analysis and the corresponding results. The results presented include life-cycle performance such as the Internal Rate of Return (IRR) for the project and the equity, the Net Present Value (NPV) and payback period. The sheet can be printed in one page and is designed to give an overview of the business/project analyzed.
- **Inputs and assumptions:** In this worksheet, inputs on both technological and financial parameters are entered. Basic technical calculations and assumptions are included for each technology considered. Information on the electricity tariff and revenue structures is also included.
- **Costs data:** Information on the costing includes capital investment costs, operation and maintenance costs and financial costs. The major costs are further broken down into detailed items as far as possible.
- **Operation:** The Operation worksheet calculates, on a monthly basis, the electricity generation coming from the installed power generation plant, the losses incurred, the

consumption of the end-users or off-takers to be served considering their peak and off-peak electricity consumption, and the net electricity export to the grid, where appropriate.

- **Income statement:** The Income Statement shows the performance of the project. Data from the previous worksheets are captured to calculate the projected yearly income and expenses of the project analyzed. The Income Statement shows whether the project is generating net earnings, in which case giving wealth to the company, or net losses, which reduces the wealth of the company.
- **Cash flow:** The projected cash flow of the project is the main basis for the analysis of the life-cycle performance of the project. If financing is made on a project finance basis, the banks will look into the cash flow as the main source of debt service (i.e. repayment of principal and interests) for the loans extended to the project. The performance of the project for both operational and financing cash flows is determined. Its debt service performance is also determined.
- **Balance sheet:** The Balance Sheet gives a picture of what the company has – its wealth and how this wealth is financed. The model should provide the yearly projected values and shows key items such as cash and other current assets, fixed assets, as well as equity, loans and current liabilities that are required for the smooth operation of the company.
- **Sensitivity analysis:** As most of the figures considered in the analysis of a base case come from assumptions and estimates, the actual figures such as costs and revenues may vary. Thus, it is important to anticipate any uncertainty by considering the effect of different scenarios in the performance of the project. Sensitivity analyses on some parameters are conducted to determine which parameters, when changed affect the performance of the project significantly. The sensitivity analyses are carried out in the Cost Data worksheet.

The result of the financial modeling will show the viability of the project. Typically, a project that results in an IRR higher than the cost of capital of the company is a viable option. This cost of capital is reflected in the discount rate determined for the company and is used in the financial analysis. The financial model will also reveal the debt service coverage for the borrowing of the business. To be attractive for the financial institutions to provide financing to the project, the debt service coverage ratio should typically be equal to or over 1.2x in any given year during the tenor of the debt. Other information such as required subsidy levels in order for the business to be viable, whenever necessary, will also be determined as an output of the financial analysis.

When preparing a set of cash flow projections for a prospective project, it is important to give all the critical details. Prospective lenders and equity investors are particularly interested in the assumptions because the projections are meaningful only to the extent the assumptions have a sound basis. The projected operating cash flows form the basis for measuring the expected rates of return to the equity investors.

The Internal Rate of Return (IRR) is the expected rate of return of the investment into the project or business. The IRR is the discount rate when the net of the present values of all items in the cash flow is zero. The IRR is calculated from the net cash flow in the cash flow table using the following formula:

$$0 = CF_0 + \frac{CF_1}{(1+IRR)} + \frac{CF_2}{(1+IRR)^2} + \ldots + \frac{CF_n}{(1+IRR)^n}$$

Where: CF = net cash flow at different periods n = end of any period

The decision rule to apply when using the IRR method is to undertake the investment if the IRR exceeds the company's cost of capital.

Another measure of the viability of the investment that will be calculated is the Net Present Value (NPV). The NPV of a project is the difference between what the project costs and the value it has created (or destroyed) due to the investment made. It is determined by computing the present value of all relevant cash flows using the formula:

$$NPV = CF_0 + \frac{CF_1}{(1+r)} + \frac{CF_2}{(1+r)^2} + \ldots + \frac{CF_n}{(1+r)^n}$$

Where: CF = net cash flow at different periods
n = end of any period
r = cost of capital or discount rate

According to Gupta and Bhandari (2000, p. 92-93), a country first needs to prioritize the type of projects it perceives as potential projects under the Clean Development Mechanism (CDM). These projects should meet the financial additionality criterion and should make a contribution to sustainable development. The concern of developing country governments that PREGA/CDM projects will trade away less expensive abatement options should be addressed at this stage. Several projects could qualify in meeting the environmental and financial additionality criteria. The Nepalese government and other developing countries can identify additional criteria other than carbon abatement depending upon the local needs and priority to evaluate the project. The following table lists four hypothetical projects and additional parameters that the project must address.

Table 18: Hypothetical Projects and Additional Parameters

Project	CO_2 abatement Cost US$/t$CO_2$	Positive Environment Impacts	Employment Generation	Access to the New Technology
A	3	Low	Low	Low
B	5	Medium	High	Low
C	8	Low	Low	High
D	21	High	Medium	High

The additional parameters of the project are cost per ton of CO_2 abated (financial aspects), employment generation (social and developmental aspects), local environmental impacts (economic and environmental aspects) and access to technology (technological aspects). The host country may decide to exclude projects of type A as it fears that it is trading "low-hanging fruit" and the resultant additional benefits are not significant. On the other extreme, type D projects, for instance, with high CO_2 abatement costs but with favorable benefits could clearly be included in the list of desirable CDM/PREGA projects. It is for the government to decide whether to include projects of type B and C. The government should clearly prioritize identified projects and define rules of exclusion for potential CDM/PREGA projects.

Economic cost calculation is the ideal cost concept for use in GHG abatement assessment. Given the limitations in data and time for this country study review report, it will not be possible to employ full economic costs in the analysis. Life cycle cost (LCC) analysis has been carried out for all six potential REGA technologies in order to find out the abatement cost which has been used as the basis for prioritization. LCC is the total discounted cash flow for an investment during its economic life. In other words, it is the present value of all the costs associated with an investment which generally includes the initial cost, the sum of discounted annual maintenance and operating cost, and a credit for any residual value for the investment at the end of the project period.

The formula for LCC is:

$$\text{Lifecycle cost (LCC)} = Cc + \sum_{n=1}^{t} \frac{Cn}{(1+r)^t} - \frac{RV}{(1+r)^t}$$

Where:
Cc = Initial capital cost (capital, labor, administration cost)
Cn = Operating cost (operation, and maintenance cost, fuel, tax and interest) in year n
n = time period (year)
r = discount rate
t = total life of project
RV = Residual Value

If the annual operating costs are constant, the simplified formula will be:

$$LCC = Cc + \frac{Cn}{CRF} - \frac{RV}{(1+r)^t}$$

$$\text{where: CRF (capital recovery factor)} = \frac{r}{1-(1+r)^{-t}}$$

(Source: Spalding - Fecher, Clark, James, 1999, P. 23, 24)

The incremental cost thus obtained through the LCC analysis assuming constant O&M costs for REGA technologies and the conventional system is divided by the CO_2 abatement potential to get the incremental cost per ton of CO_2 abatement. An initial attempt has been made to calculate the incremental cost based on various assumptions. There is ample room to make the calculations more explicit once all the required empirical data are available

11. BARRIERS AND CONCLUSION

11.1 Barriers for Development of Energy from Biogas

A number of barriers, which impair the development of the energy from biogas, include: psychological, social, institutional, legal and economical factors.

Legal and Financial Barriers:

- lack of proper legal standards determining explicitly the programme and policy;
- insufficient economic mechanisms, in particular fiscal, to facilitate achieving the desirable profits related to the investment costs, installations and equipments;
- relatively high costs of technologies, labour (e.g. geological investigations).

Information Barriers:

- lack of easily available information on projects feasible for technical applications;
- lack of easy accessible information on procedures for projects implementation and realisation, standard costs, economic, social and ecological benefits;
- lack of information on installations producers, suppliers and contractors
- lack of information the certain of the design and construction of scale anaerobic digestion systems
- limited application of knowledge gained from the operation of existing plants in the design of plants
- lack of familiarity with biogas investments amongst the financial community

11.2 Conclusion

The volume of daily biogas production from pig farm, generally, is dependent upon the type of anaerobic digester design that is concerned with the system of controlling anaerobic digester temperature, fermentation or retention time and the feedstock material.

The preferred type of digester is the complete mix digester, thereby generating biogas at a high rate and the lowest hydraulic retention time (HRT), It is often operated in the thermophylic range, at a high temperature (between 50°C–60°C), but the construction cost is very expensive, and the operation cost and the maintenance cost are also higher than the plug-flow type.

There are some difficulties in finding an accurate prediction for biogas production per head of pig (it is variable and depends on the design of the digester) and also the AD technology through the capacity of gas turbine.

It is noted that the selection of the capacity of a co-generator or gas turbine for the Vanith Pig Farm Company (which is shown in table 12), is reasonable when compared to the samples 6 and 7 (selected at 120 kW for F1+F2 and 35 kW or 33 kW for F3). And also, for the future estimated plan of the capacity of co-generator or gas turbine (in table 14), in it may be considered more viable to use a standard size of production turbine. Considering the Rokai case, it is possible to select two gas turbines (1×75 kW + 1×120 kW) instead of 1 x 195 kW for Farm F1+F2 and one unit 50 kW for farm F3 (if this size is available).

Investment Cost of AD plant:

It is found that the investment cost of AD plant is very high.
For current data

- Farm No F1+F2 is about 368,880 US**$** (transfer Colorado Pork LLC Complete Mix technology, case study of sample 1) up to 443,040 US$ (transfer Rokai technology, case study of sample 6)
- Farm No F3 is about 107,590 US**$** (transfer USA technology, case study of sample 1) up to 129,220 US**$** (transfer Rokai technology, case study of sample 6).

For future estimation plan

- Farm No F1+F2 is about 599,430 US$ (transfer USA technology, case study of sample 1)
- Farm No F3 is about 153,700 US**$** (transfer USA technology, case study of sample 1) up to 184,600 US**$** (transfer Rokai technology, case study of sample 6).

Based on the actual potential and background and the need of Vanith Pig Farm Company, if the gas production estimates based on the comparison farms are accurate, it can be perceived that there is high feasibility of implementation the pig farm waste to produce biogas for generating electricity:

Depending on the technology deployed and the level of gas filtering done, biogas systems can help the owner's of the Vanith pig farm on several fronts, such as:

- reducing their expense of electricity and energy consumption,
- resolving the problem of objection to the business of pig farm by neighbours,
- solving the problems of odours from the pig farm,
- continuously expanding the pigs pens as needed,
- reducing water pollution and ground contamination step by step,
- obtaining the extra benefit from selling the fertilizer from the pig manure,

The Vanith Pig Farm Company perceives the advantages and benefits in the long term from using AD technology. However when the PREGA team of Lao P.D.R tried to explain to the owner the process of ''biogas production from their farm for electricity generation'', the owner of the company remains concerned that the investment cost is very high, and this is compounded because the company has financial problems related to their competitiveness in the Lao pork market, and the company is still reliant on the government grant assistance to stay in business.

Recommendation

This study has only considered the generation of electrical energy by utilizing biogas produced from pig dung at the Vanith pig farm. Once the basic profitability of the Vanith Pig Farm Company is resolved, it may be worth studying further the alternative option of the direct sale of biogas, which consists of digester and biogas station. It may be expected that the investment cost of the former is higher than the latter. As Lao PDR does not have any known gas resources; consequently all of the gas needed is imported from neighbouring countries. This would add to the value of biogas, as it would be competing with expensive imported LPG and diesel, and not with lower cost reticulated natural gas.

REFERENCES

- **CADDET Renewable Energy,** (Web site: www.caddet-re.org)

- Electricité du Laos: ***"Annual Report 2003"***, Electricité du Laos, Ministry of Industry and Handicrafts, Lao PDR, 2003.

- Electricité du Laos: ***"30 Years Report 1975-2005"***, Electricité du Laos, Ministry of Industry and Handicrafts, Lao PDR, 2005.

- (http://www.efe.or.th/index.php?option=content&task=view&id=11&Itemid=35)

- International Development Association (IDA), Final Report: ***"Evaluation of Rural Electrification Socio-Economic Survey Establishment of Database for Rural Electrification Planning in Lao PDR"***, Department of Electricity, Ministry of Industry and Handicrafts and IDA, Vientiane, Lao PDR, August 2004.

- Lao PDR: ***"National Poverty Eradication Programme (NPEP)"***, Eight Round Table Meeting, Vientiane, September 4-5, 2003.

- Ministry of Industry and Handicrafts, Department of Electricity: ***"Environmental Management Standard for Electricity Projects"***, Ministry of Industry and Handicrafts and UNDP, Vientiane, Lao PDR, 2003.

- Ministry of Industry and Handicrafts, Department of Electricity, Final Report: ***"Rural Electrification Frameworks Study"***, Ministry of Industry and Handicrafts, Lao PDR, Prepared by Maunsell Ltd, New Zealand, November 2004.

- National Statistical Centre: **"*The Report of the Population Count 2003*"**, carried out by the National Statistical Centre, Lao PDR, July 2003).

- Nepal Country Report, Draft Report: ***"Promotion of Renewable Energy, Energy Efficiency and Greenhouse Gas Abatement (PREGA)"***, March 2004.

- Renewable Energy Technologies in Asia - A Regional Research and Dissemination, ***Phase I**: **"A Summary of Activities and Achievements in Lao People's Democratic Republic"***, Development Technology Department; Science, Technology and Environment Organization (STENO), Lao PDR; and Energy Program, Asian Institute of Technology, Thailand.

- Renewable Energy Technologies in Asia - A Regional Research and Dissemination, ***Phase II**: **"A Summary of Activities and Achievements in Lao People's Democratic Republic"***, Development Technology Department; Science, Technology and Environment Organization (STENO), Lao PDR; and Energy Program, Asian Institute of Technology, Thailand.

- World Bank: ***"Global Human Development Report (HDR) 2004"***, World Bank, 2004.

- Otto Rentz, Dominik Möst, Anke Eßer: ***"Current Development of Green IPPs: Experiences, Challenges, and Strategies"***, Workshop of the EC-ASEAN Green Independent Power Producers Network, in Universitätsverlag Karlsruhe, Germany, 15th of September, 2005

- Science Technology and Environment Agency: ***"Assessment Report on Technology Needs and Priorities for Mitigating Greenhouse Gas Emissions"***, Science Technology and Environment Agency, Lao PDR, April, 2004.
- Science Technology and Environment Agency: ***"Lao PDR, The First National Communication on Climate Change"***, Science Technology and Environment Agency, Lao PDR, October, 2000.

- The Lao's People Revolutionary Party, Central Committee Executive Board: ***"The Resolution of the 5th Session of the Central Committee Meeting"***, Vientiane, Lao PDR, April, 2004.

- ***United Nations Framework Convention on Climate Change (UNFCCC)***: (http://cdm.unfccc.int/Reference/Documents)

- United Nations Framework Convention on Climate Change (UNFCCC): ***"Guidelines for Completing CDM-PDD, CDM-NMB and CDM-NMM"***, Version 04, 2005.

- Energy Efficiency and Renewable Energy Clearing House (EREC), Department of Energy: ***"Renewable Energy: An Over View"***, March 2001.

- The Canadian Agricultural Energy End Use Data and Analysis Centre (CAEEDAC): ***"The Economics of Biogas in the Hog Industry"***, by the Canadian Agricultural Energy End Use Data and Analysis Centre (CAEEDAC), 1999.

- Waste Management Programs, College of Agriculture and life sciences: ***"Development of Environmentally Superior Technologies"***, two-Year Progress Report for Technology Determinations per Agreements between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms, and Frontline Farmers. http://www.cals.ncsu.edu/waste_mgt

Annex 1: The Statistics of Pig Farms in Vientiane Capital City

No.	Name of Pig Farm (*)	No. of Pig	Location	Latitude Degree	Longitude Degree	Remark
	Large scale pig farm					
1	Vanit Farm F1+F2	7636	Vientiane Capital	18.08	102.42	
2	Vanit Farm F3	2069	Vientiane Capital	18.08	102.42	
3	Chanhpheng Douangphachanh	1,234	Vientiane Capital	17.59	102.31	
4	Khenphone Nongteng	1,112	Vientiane Capital	18.01	102.31	
	Medium scale fig farm					
5	Keo Inthiphon	545	Vientiane Capital	18.11	102.38	
6	Phouvong Kolasak	535	Vientiane Capital	18.01	102.31	
7	Nang Vone	486	Vientiane Capital	17.53	102.45	
8	Nang Kham	357	Vientiane Capital	17.51	102.37	
9	Khamsing Sisoutham	224	Vientiane Capital	18.12	102.39	
10	Khamphay	223	Vientiane Capital	18.07	102.45	
11	Sivilay Hungheuang	180	Vientiane Capital	18.02	102.38	
12	Boun Gnanong	156	Vientiane Capital	18.09	102.38	
13	Liangkham	143	Vientiane Capital	17.58	102.52	
14	Champhonh	142	Vientiane Capital	17.56	102.43	
15	Nang Chanh	139	Vientiane Capital	17.55	102.39	
16	Khamsone Keamany	131	Vientiane Capital	18.03	102.37	
17	Phongsamouth	121	Vientiane Capital	18.05	102.43	
18	Nongphagna	111	Vientiane Capital	18.01	102.37	
19	Bounheng	104	Vientiane Capital	17.56	102.31	
	Small scale pig farm					
20	Souay	85	Vientiane Capital	18.06	102.31	
21	Phan Sophapmixay	77	Vientiane Capital	17.53	102.37	
22	Pancha	77	Vientiane Capital	18.07	102.39	
23	Chin	61	Vientiane Capital	17.59	102.41	
24	Bouaket	45	Vientiane Capital	17.59	102.29	
25	Damdouan Nonghai	45	Vientiane Capital	17.59	102.29	
26	Done Naxay	36	Vientiane Capital	17.59	102.39	
27	Loung Dom	35	Vientiane Capital	18.02	102.37	
28	Neuang	35	Vientiane Capital	18.02	102.37	
29	Khamla	33	Vientiane Capital	17.59	102.39	
30	Say	26	Vientiane Capital	18.03	102.32	
31	Phongphanh	21	Vientiane Capital	18.12	103.03	
32	Chanthone	21	Vientiane Capital	18.12	103.03	
33	Chommany	20	Vientiane Capital	18.01	102.38	
34	Sob Souanmone	18	Vientiane Capital	17.55	102.38	
35	That Sisoubath	15	Vientiane Capital	17.56	102.45	
36	Bounsou	15	Vientiane Capital	17.56	102.45	
	Total	16313				

Source: Department of Agriculture and Livestock, MAF. (*) Estimate

Annex 2: Assessment of Capacity of Gas Production from Thirty Seven Pig Farms in Vientiane Capital City by Considering Different Case from the Theory and Seven Sample Sizes

No.	Name of Pig Farm (*)	No. of Pig	Gas production per pig 0.24 m3/day	Gas production per pig 0.31387m3/day	Gas production per pig 0.1981 m3/day	Gas production per pig 0.0425 m3/day	Gas production per pig 0.041667m3/day	Gas production per pig 0.1145 m3/day	Gas production per pig 0.1091 m3/day	Gas production per pig 0.069 m3/day	Gas production per pig Average of 7 sample sizes	Gas production per pig Average of 5 simple size	Gas production per pig (12+13)/2
			Theory	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	mean	mean	mean
1	2	3	4	5	6	7	8	9	10	11	12	13	14
		heads	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/day	m^3/day	m^3/day
1	Vanith Farm F1+F2	7,636	1832.6	2396.7	1512.7	324.53	318.17	874.32	833.09	526.88	969.485	1228.7	1099.112
2	Vanith Farm F3	2,069	496.56	649.4	409.87	87.933	86.208	236.9	225.73	142.76	262.685	332.93	297.8081
3	Chanhpheng Douangphachanh	1,234	296.16	387.32	244.46	52.445	51.417	141.29	134.63	85.146	156.672	198.57	177.6197
4	Khenphone Nongteng	1,112	266.88	349.02	220.29	47.26	46.333	127.32	121.32	76.728	141.182	178.94	160.0593
5	Keo Inthiphon	545	130.8	171.06	107.96	23.163	22.708	62.403	59.46	37.605	69.1945	87.698	78.44632
6	Phouvong Kolasak	535	128.4	167.92	105.98	22.738	22.292	61.258	58.369	36.915	67.9249	86.089	77.00693
7	Nang Vone	486	116.64	152.54	96.277	20.655	20.25	55.647	53.023	33.534	61.7037	78.204	69.95396
8	Nang Kham	357	85.68	112.05	70.722	15.173	14.875	40.877	38.949	24.633	45.3256	57.446	51.38593
9	Khamsing Sisoutham	224	53.76	70.307	44.374	9.52	9.3333	25.648	24.438	15.456	28.4396	36.045	32.24216
10	Khamphay	223	53.52	69.993	44.176	9.4775	9.2917	25.534	24.329	15.387	28.3126	35.884	32.09822
11	Sivilay Hungheuang	180	43.2	56.497	35.658	7.65	7.5	20.61	19.638	12.42	22.8532	28.965	25.90887
12	Nang Chanh	139	33.36	43.628	27.536	5.9075	5.7917	15.916	15.165	9.591	17.6478	22.367	20.00741
13	Boun Gnanong	156	37.44	48.964	30.904	6.63	6.5	17.862	17.02	10.764	19.8061	25.103	22.45436

Annex 2 (Con’t): Assessment of Capacity of Gas Production from Thirty Seven Pig Farms in Vientiane Capital City by Considering Different Case from the Theory and Seven Sample Sizes

No.	Name of Pig Farm (*)	No. of Pig	Gas production per pig 0.24 m3/day	Gas production per pig 0.31387m3/day	Gas production per pig 0.1981 m3/day	Gas production per pig 0.0425 m3/day	Gas production per pig 0.041667m3/day	Gas production per pig 0.1145 m3/day	Gas production per pig 0.1091 m3/day	Gas production per pig 0.069 m3/day	Gas production per pig Average of 7 sample sizes	Gas production per pig Average of 5 simple size	Gas production per pig (12+13)/2
			Theory	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	mean	mean	mean
1	2	3	4	5	6	7	8	9	10	11	12	13	14
		heads	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/day	m^3/day	m^3/day
14	Liangkham	143	34.32	44.883	28.328	6.0775	5.9583	16.374	15.601	9.867	18.1556	23.011	20.583
15	Champhonh	142	34.08	44.57	28.13	6035	5.9167	16.259	15.492	9.798	18.0287	22.85	20.43922
16	Khamsone Keamany	131	31.44	41.117	25.951	5.5675	5.4583	15	14.292	9.039	16.6321	21.08	18.8559
17	Phongsamouth	121	29.04	37.978	23.97	5.1425	5.0417	13.855	13.201	8.349	15.3624	19.471	17.41652
18	Nongphagna	111	26.64	34.84	21.989	4.7175	4.625	12.71	12.11	7.659	14.0928	17.861	15.97714
19	Bounheng	104	24.96	32.642	20.602	4.42	4.3333	11.908	11.346	7.176	13.2041	16.735	14.96957
20	Souay	85	20.4	26.679	16.839	3.6125	3.5417	9.7325	9.2735	5.865	10.7918	13.678	12.23475
21	Phan Sophapmixay	77	18.48	24.168	15.254	3.2725	3.2083	8.8165	8.4007	5.313	9.7761	12.39	11.08324
22	Pancha	77	18.48	24.168	15.254	3.2725	3.2083	8.8165	8.4007	5.313	9.7761	12.39	11.08324
23	Chin	61	14.64	19.146	12.084	2.5925	2.5417	6.9845	6.6551	4.209	7.74471	9.8158	8.78023
24	Bouaket	45	10.8	14.124	8.9145	1.9125	1.875	5.1525	4.9095	3.105	5.71331	7.2411	6.477219
25	Damdouan Nonghai	45	10.8	14.124	8.9145	1.9125	1.875	5.1525	4.9095	3.105	5.71331	7.2411	6.477219
26	Done Naxay	36	8.64	11.299	7.1316	1.53	1.5	4.122	3.9276	2.484	4.57065	5.7929	5.181775

Annex 2 (Con't): Assessment of Capacity of Gas Production from Thirty Seven Pig Farms in Vientiane Capital City by Considering Different Case from the Theory and Seven Sample Sizes

No.	Name of Pig Farm (*)	No. of Pig	Gas production per pig 0.24 m3/day	Gas production per pig 0.31387m3/day	Gas production per pig 0.1981 m3/day	Gas production per pig 0.0425 m3/day	Gas production per pig 0.041667m3/day	Gas production per pig 0.1145 m3/day	Gas production per pig 0.1091 m3/day	Gas production per pig 0.069 m3/day	Gas production per pig Average of 7 sample sizes	Gas production per pig Average of 5 simple size	Gas production per pig (12+13)/2
			Theory	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	mean	mean	mean
1	2	3	4	5	6	7	8	9	10	11	12	13	14
		heads	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/day	m^3/day	m^3/day
27	Loung Dom	35	8.4	10,85	6.9335	1.4875	1.4583	4.0075	3.8185	2.415	4.44368	5.632	5.037837
28	Neuang	35	8.4	10.985	6.9335	1.4875	1.4583	4.0075	3.8185	2.415	4.44368	5.632	5.037837
29	Khamla	33	7.92	10.358	6.5373	1.4025	1.375	3.7785	3.6003	2.277	4.18976	5.3102	4.74996
30	Say	26	6.24	8.1606	5.1506	1.105	1.0833	2.977	2.8366	1.794	3.30102	4.1838	3.742393
31	Phongphanh	21	5.04	6.5913	4.1601	0.8925	0.875	2.4045	2.2911	1.449	2.66621	3.3792	3.022702
32	Chanthone	21	5.04	6.5913	4.1601	0.8925	0.875	2.4045	2.2911	1.449	2.66621	3.3792	3.022702
33	Chommany	20	4.8	6.2774	3.962	0.85	0.8333	2.29	2.182	1.38	2.53925	3.2183	2.878764
34	Sob Souanmone	18	4.32	5.6497	3.5658	0.765	0.75	2.061	1.9638	1.242	2.28532	2.8965	2.590887
35	That Sisoubath	15	3.6	4.7081	2.9715	0.6375	0.625	1.7175	1.6365	1.035	1.90444	2.4137	2.159073
36	Bounsou	15	3.6	4.7081	2.9715	0.6375	0.625	1.7175	1.6365	1.035	1.90444	2.4137	2.159073
	Total	1,6319	3923.1	5130.2	3243.6	707.3	695.71	1885.8	1799.7	1147.6	2095.14	2651	2376.064

Annex 3: Capacity of Power Generating from Thirty Seven Pig Farms in Vientiane Capital City by Considering Different Case from Seven Sample Size

No.	Name of Pig Farm (*)	No. of Pigs	Capacity of Power generating based on theory	Capacity of Power generating based on sample 1	Capacity of Power generating based on sample 2	Capacity of Power generating based on sample 3	Capacity of Power generating based on sample 4	Capacity of Power generating based on sample 5	Capacity of Power generating based on sample 6	Capacity of Power generating based on sample 7	Capacity of Power generating Average for 7 case	Capacity of Power generating Average for nectles case 3 & 4	Capacity of Power generating Average (12+13)/2	Select Capacity of Co-Gen
		Heads	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Vanith Farm F1+F2	7,636	130.903	118.03	171.81	8.7814	12.727	197.33	128.424	125.994	109.014	148.319	128.666	120
2	Vanith Farm F3	2,069	35.4686	31.9807	46.5525	2.37935	3.4483	53.469	34.7968	34.1385	29.5378	40.1874	34.8626	35
3	Chanhpheng Douangphachanh	1,234	21.1543	19.0741	27.765	1.4191	2.0567	31.89	20.7536	20.361	17.617	23.9687	20.7929	20
4	Khenphone Nongteng	1,112	19.0629	17.1883	25.02	1.2788	1.8533	28.737	18.7018	18.348	15.8753	21.599	18.7372	20
5	Keo Inthiphon	545	9.34286	8.42412	12.2625	0.62675	0.9083	14.084	9.16591	8.9925	7.78063	10.5859	9.18324	10
6	Phouvong Kolasak	535	9.17143	8.26955	12.0375	0.61525	0.8917	13.826	8.99773	8.8275	7.63786	10.3916	9.01474	10
7	Nang Vone	486	8.33143	7.51215	10.935	0.5589	0.81	12.56	8.17364	8.019	6.93832	9.43987	8.18909	5
8	Nang Kham	357	6.12	5.51818	8.0325	0.41055	0.595	9.2258	6.00409	5.8905	5.09667	6.93422	6.01544	5
9	Khamsing Sisoutham	224	3.84	3.46239	5.04	0.2576	0.3733	5.7888	3.76727	3.696	3.19791	4.35089	3.7744	
10	Khamphay	223	3.82286	3.44693	5.0175	0.25645	0.3717	5.7629	3.75045	3.6795	3.18363	4.33146	3.75755	
11	Sivilay Hungheuang	180	3.08571	2.78228	4.05	0.207	0.3	4.6517	3.02727	2.97	2.56975	3.49625	3.033	
12	Boun Gnanong	156	2.67429	2.41131	3.51	0.1794	0.26	4.0315	2.62364	2.574	2.22711	3.03008	2,6286	
13	Liangkham	143	2.45143	2.21036	3.2175	0.16445	0.2383	3.6955	2.405	2.3595	2.04152	2.77757	2.40955	
14	Champhonh	142	2.43429	2.19491	3.195	0.1633	0.2367	3.6697	2.38818	2.343	2.02725	2.75815	2.3927	
15	Nang Chanh	139	2.38286	2.14854	3.1275	0.15985	0.2317	3.5921	2.33773	2.935	1.98442	2.9988	2.34215	
16	Phongsamouth	121	2.07429	1.87031	2.7225	0.13915	0.2017	3.127	2.035	1.9965	1.72744	2.35025	2.03885	

Annex 3 (Con't): **Capacity of Power Generating from Thirty Seven Pig Farms in Vientiane Capital City by Considering Different Case from Seven Sample Size**

No.	Name of Pig Farm (*)	No. of Pigs	Capacity of Power generating based on theory	Capacity of Power generating based on sample 1	Capacity of Power generating based on sample 2	Capacity of Power generating based on sample 3	Capacity of Power generating based on sample 4	Capacity of Power generating based on sample 5	Capacity of Power generating based on sample 6	Capacity of Power generating based on sample 7	Capacity of Power generating Average for 7 case	Capacity of Power generating Average for nectles case 3 & 4	Capacity of Power generating Average (12+13)/2	Select Capacity of Co-Gen
		Heads	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW
17	Nongphagna	111	1.90286	1.71574	2.4975	0.12765	0.185	2.8685	1.86682	1.8315	1.58468	2.15602	1.87035	
18	Bounheng	104	1.78286	1.60754	2.34	0.1196	0.1733	2.6876	1.74909	1.716	1.48474	2.02005	1.7524	
19	Souay	85	1.45714	1.31385	1.9125	0.09775	0.1417	2.1966	1.42955	1.4025	1.21349	1.65101	1.43225	
20	Phan Sophapmixay	77	1.32	1.1902	1.7325	0.08855	0.1283	1.9899	1.295	1.2705	1.09928	1.49562	1.29745	
21	Pancha	77	1.32	1.1902	1.7325	0.08855	0.1283	1.9899	1.295	1.2705	1.09928	1.49562	1.29745	
22	Chin	61	1.04571	0.94288	1.3725	0.07015	0.1017	1.5764	1.02591	1.0065	087086	1.18484	1.02785	
23	Bouaket	45	0.77143	0.69557	1.0125	0.05175	0.075	1.1629	0.75682	0.7425	0.64244	0.87406	0.75825	
24	Damdouan Nonghai	45	0.77143	0.69557	1.0125	0.05175	0.075	1.1629	0.75682	0.7425	0.64244	0.87406	0.75825	
25	Done Naxay	36	0.61714	0.55646	0.81	0.0414	0.06	0.9303	0.60545	0.594	0.51395	0.69925	0.6066	
26	Loung Dom	35	0.6	0.541	0.7875	0.04025	0.0583	0.9045	0.58864	0.5775	0.49967	0.67983	0.58975	
27	Neuang	35	0.6	0.541	0.7875	0.04025	0.0583	0.9045	0.58864	0.5775	0.49967	0.67983	0.58975	
28	Khamla	33	0.56571	0.51008	0.7425	0.03795	0.055	0.8528	0.555	0.5445	0.47112	0.64098	0.55605	
29	Say	26	0.44571	0.40188	0.585	0.0299	0.0433	0.6719	0.43727	0.429	0.37119	0.50501	0.4381	
30	Phongphanh	21	0.36	0.3246	0.4725	0.02415	0.035	0.5427	0.35318	0.3465	0.2998	0.4079	0.35385	
31	Chanthone	21	0.36	0.3246	0.4725	0.02415	0.035	0.5427	0.35318	0.3465	0.2998	0.4079	0.35385	
32	Chommany	20	0.34286	0.30914	0.45	0.023	0.0333	0.5169	0.33636	0.33	0.28553	0.38847	0.337	
33	Sob Souanmone	18	0.30857	0.27823	0.405	0.0207	0.03	0.4652	0.30273	0.297	0.25697	0.34962	0.3033	
34	That Sisoubath	15	0.25714	0.23186	0.3375	0.01725	0.025	0.3876	0.25227	0.2475	0.21415	0.29135	0.25275	
35	Bounsou	15	0.25714	0.23186	0.3375	0.01725	0.025	0.3876	0.25227	0.2475	0.21415	0.29135	0.25275	
	Total	**16,313**	279.651	252.152	367.043	18.76	27.188	421.57	274.355	269.165	232.891	316.857	274.874	235

Annex 4: Convert Gas Production from Pig Farm to Methane, Natural Gas, Petrol and Diesel

No.	Name of Pig Farm (*)	No. of Pig	Gas Production	1 m^3 of gas equivalent to 0.62 m3 of methane	1 m3 of gas equivalent to 0.55 m3 of natural gas	1 m3 of gas equivalent to 0.7 litre of petrol	1 m3 of gas equivalent to 0.62 litre of diesel
1	2	3	4	5	6	7	8
		heads	m^3/day	m^3/day	m^3/day	Litres/day	Litres/day
1	Vanith Farm F1+F2	7,636	1,099.112	681.44944	604.5116	769.3784	681.44944
2	Vanith Farm F3	2,069	297.8081	184.641			
2	Vanith Farm F3	2,069	297.8081	184.64102	163.794455	208.46567	184.641022
3	Chanhpheng Douangphachanh	1,234	177.6197	110.12421	97.690835	124.33379	110.124214
4	Khenphone Nongteng	1,112	160.0593	99.236766	88.032615	112.04151	99.236766
5	Keo Inthiphon	545	78.4463	48.636706	43.145465	54.91241	48.636706
6	Phouvong Kolasak	535	77.0069	47.744278	42.353795	53.90483	47.744278
7	Nang Vone	486	69.95396	43.371455	38.474678	48.967772	43.3714552
8	Nang Kham	357	51.38593	31.859277	28.2622615	35.970151	31.8592766
9	Khamsing Sisoutham	224	32.242	19.99004	17.7331	22.5694	19.99004
10	Khamphay	223	32.098	19.90076	17.6539	22.4686	19.90076
11	Sivilay Hungheuang	180	25.9088	16.063456	14.24984	18.13616	16.063456
12	Nang Chanh	139	20.007	12.40434	11.00385	14.0049	12.40434
13	Boun Gnanong	156	22.454	13.92148	12.3497	15.7178	13.92148
14	Liangkham	143	20.583	12.76146	11.32065	14.4081	12.76146
15	Champhonh	142	20.439	12.67218	11.24145	14.3073	12.67218
16	Khamsone Keamany	131	18.8559	11.690658	10.370745	13.19913	11.690658
17	Phongsamouth	121	17.165	10.79823	9.579075	12.19155	10.79823
18	Nongphagna	111	15.977	9.90574	8.78735	11.1839	9.90574
19	Bounheng	104	14.9657	9.278734	8.231135	10.47599	9.278734
20	Souay	85	12.2348	7.585576	6.72914	8.56436	7.585576
21	Phan Sophapmixay	77	11.0832	6.871584	6.09576	7.75824	6.871584
22	Pancha	77	11.0832	6.871584	6.09576	7.75824	6.871584
23	Chin	61	8.7802	5.443724	4.82911	6.14614	5.443724
24	Bouaket	45	6.4772	4.015864	3.56246	4.53404	4.015864
24	Bouaket	45	6.4772	4.015864	3.56246	4.53404	4.015864
25	Damdouan Nonghai	45	6.4772	4.015864	3.56246	4.53404	4.015864
26	Done Naxay	36	5.181775	3.2127005	2.84997625	3.6272425	3.2127005
27	Loung Dom	35	5.03784	3.1234608	2.770812	3.526488	3.1234608

Annex 4 (Con't): Convert Gas Production from Pig Farm to Methane, Natural Gas, Petrol and Diesel

No.	Name of Pig Farm (*)	No. of Pig	Gas Production	1 m3 of gas equivalent to 0.62 m3 of methane	1 m3 of gas equivalent to 0.55 m3 of natural gas	1 m3 of gas equivalent to 0.7 litre of petrol	1 m3 of gas equivalent to 0.62 litre of diesel
1	2	3	4	5	6	7	8
		heads	m^3/day	M^3/day	m^3/day	Litres/day	Litres/day
28	Neuang	35	5.03784	3.1234608	2.770812	3.526488	3.1234608
29	Khamla	33	4.74996	2.9449752	2.612478	3.324972	2.9449752
30	Say	26	3.74239	2.3202818	2.0583145	2.619673	2.3202818
31	Phongphanh	21	3.0227	1.874074	1.662485	2.11589	1.874074
32	Chanthone	21	3.0227	1.874074	1.662485	2.11589	1.874074
33	Chommany	20	2.87876	1.7848312	1.583318	2.015132	1.7848312
34	Sob Souanmone	18	2.59089	1.6063518	1.4249895	1.813623	1.6063518
35	That Sisoubath	15	2.15907	1.3386234	1.1874885	1.511349	1.3386234
36	Bounsou	15	2.15907	1.3386234	1.1874885	1.511349	1.3386234
	Total	1,6319	2,348.0579	1,455.7959	1291.431837	1,643.64052	1,455.79589

Annex 5: Convert the Biogas to Energy and the LPG

No.	Name of Pig Farm (*)	No. of Pigs	Gas production one pig gives $0.07 m^3/d$	1 m^3 of gas equivalent to 1.25 kWh	1 m^3 of gas equivalent to 0.43 kg of LPG
		Heads	m^3/day	kWh/day	kg/day
1	Vanith Farm F1+F2	7636	534.52	668.15	229.8436
2	Vanith Farm F3	2069	144.83	181.0375	62.2769
3	Chanhpheng Douangphachanh	1234	86.38	107.975	37.1434
4	Khenphone Nongteng	1112	77.84	97.3	33.4712
5	Keo Inthiphon	545	38.15	47.6875	16.4045
6	Phouvong Kolasak	535	37.45	46.8125	16.1035
7	Nang Vone	486	34.02	42.525	14.6286
8	Nang Kham	357	24.99	31.2375	10.7457
9	Khamsing Sisoutham	224	15.68	19.6	6.7424
10	Khamphay	223	15.61	19.5125	6.7123
11	Sivilay Hungheuang	180	12.6	15.75	5.418
12	Boun Gnanong	156	10.92	13.65	4.6956
13	Liangkham	143	10.01	12.5125	4.3043
14	Champhonh	142	9.94	12.425	4.2742
15	Nang Chanh	139	9.73	12.1625	4.1839
16	Khamsone Keamany	131	9.17	11.4625	3.9431
17	Phongsamouth	121	8.47	10.5875	3.6421
18	Nongphagna	111	7.77	9.7125	3.3411
19	Bounheng	104	7.28	9.1	3.1304
20	Souay	85	5.95	7.4375	2.5585
21	Phan sophapmixa	77	5.39	6.7375	2.3177
22	Pancha	77	5.39	6.7375	2.3177
23	Chin	61	4.27	5.3375	1.8361
24	Bouaket	45	3.15	3.9375	1.3545
25	Damdouan Nonghai	45	3.15	3.9375	1.3545
26	Done Naxay	36	2.52	3.15	1.0836
27	Loung Dom	35	2.45	3.0625	1.0535
28	Neuang	35	2.45	3.0625	1.0535
29	Khamla	33	2.31	2.8875	0.9933
30	Say	26	1.82	2.275	0.7826
31	Phongphanh	21	1.47	1.8375	0.6321
32	Chanthone	21	1.47	1.8375	0.6321
33	Chommany	20	1.4	1.75	0.602
34	Sob Souanmone	18	1.26	1.575	0.5418
35	That Sisoubath	15	1.05	1.3125	0.4515
36	Bounsou	15	1.05	1.3125	0.4515
	Total	**16,313**	**1,141.91**	**1,427.3875**	491.0213

Annex 6: Financial Analysis Calculation

I. METHODOLOGY

- Project life is 30 years.
- Values are expressed in constant 2005 prices so as to exclude inflation.
- The Lao PDR Kip is the unit of account. The exchange rate used is Kip 10,800 per U.S. dollar.

II. FINANCIAL ANALYSIS

- Total Cost Estimated is US $ 92,300.00 or 996.84 Million Kips.

  Operation and maintenance cost is US $ 5,000.00 or 54.0 Million Kips.
- Project Financial Analyses
  - i. Without the benefits of CO_2 credits, the FIRR is 15% and NPV is 16,653.31 US $
  - ii. With the inclusion of CO_2 credits:
    - a. price at 3 US $/t of CO_2 the FIRR is 16% and NPV is 22,519.68 US $
    - b. price at 5 US $/t of CO_2 the FIRR is 16% and NPV is 26,430.60 US $
    - c. price at 10 US $/t of CO_2 the FIRR is 18% and NPV is 36,207.89 US $
- Financing Plan

  Indicate the sources and proportions of finance for all foreign and local costs

III. ECONOMIC ANALYSES

- Statement of poverty reduction impacts,
- Statement of social, gender and environment impacts,
  - Reduction of local pollutants, further findings and recommendations etc,
  - Land use impact: “ Vanith Pig Farm “ has the land allocated in its own (under the concession with the Government), so there is no impact to the others land ownerships around the farm,
  - Migration, resettlement, good governance, community infrastructure, community organization, etc
- **Project Economic Analyses**
  - i. Without the benefits of CO_2 credits, the EIRR is 19% and NPV is 33,135.45 US $
  - ii. With the inclusion of CO_2 credits:
    - a. price at 5 US$/t of CO_2 the EIRR is 20% and NPV is 42,912.74 US$,
    - b. price at 3 US$/t of CO_2 the EIRR is 20% and NPV is 39,001.83 US$,
    - c. price at 10 US$/t of CO_2 the EIRR is 22% and NPV is 52,690.04 US$.