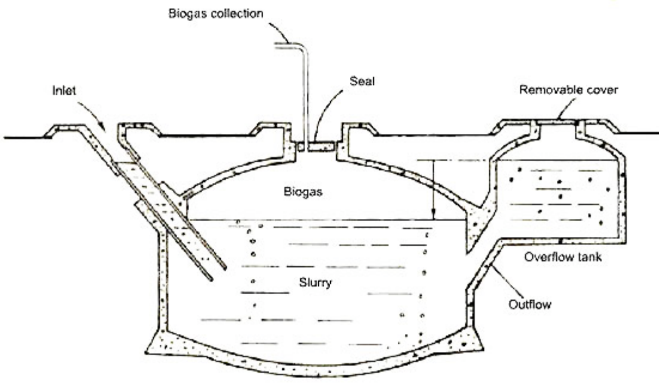
Biogas production in climates with long cold winters



Authors

Urmila Balasubramaniyam

Llionel S. Zisengwe

Niccoló Meriggi

Eric Buysman

Supervisor: Dr. Ir. Grietje Zeeman

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Prepared by: Wageningen University, the Netherlands
Urmila Balasubramaniyam
Eric Buysman
Niccoló Meriggi
Llionel S. Zisengwe
Supervisor: Dr. Ir. Grietje Zeeman

For further information:

Urmila Balasubramaniyam	Urmila.balasubramaniyam@wur.nl
Llionel S. Zisengwe	llionelsimbarashe.zisengwe@wur.nl
Niccoló Meriggi	niccol.meriggi@wur.nl
Eric Buysman	eric.buysman@wur.nl

For Women in Europe for a Common Future, WECF
The Netherlands
Email: wecf@wecf.eu
Webpage: www.wecf.eu

Abstract
The need to provide affordable energy for poor communities is of great importance world wide. This is just the same for poor communities in European countries. This study analyses the feasibility and potential production of biogas in these countries with emphasis on Romania, Kyrgyzstan, Georgia, Kazakhstan and Armenia. Comparison of the use of the biogas plants is done from India, China, Nepal and Bolivia and literature review is done as well before suggesting the same technology for the colder target communities. Suggestions are made on whether to use the plants on household or community level afterwards.

Acknowledgements

First of all, we owe many thanks to Grietje Zeeman. Her insight helped us a lot, not to mention her readiness to meet at 6 in the evening! Furthermore, the meeting with the staff of WECF was very interesting, especially the stories they told us about their work to alleviate poverty. We would like to thank Anna Samwel, Fedde Jorritsma and Margriet Samwel for their help and assistance during writing this report, which took much more time than anticipated.

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1. Introduction

Anaerobic digestion is a natural process whereby bacteria existing in oxygen-free environments decompose organic matter. Anaerobic digesters are designed and managed to accomplish this decomposition. As a result of this digestion, organic material is stabilized and gaseous byproducts, primarily methane (CH4) and carbon dioxide (CO2) are released. Typically anaerobic digesters are designed to operate in either the mesophilic (20-45°C) or thermophilic (45-60°C) temperature ranges. However, methanogenesis is also possible under low temperature (< 20°C), this referred to as psychrophilic digestion. Anaerobic digestion at psychrophilic temperatures has not been as extensively explored as either mesophilic or thermophilic digestion, probably due to little anticipation of the development of economically attractive systems using this technology. The present study, therefore, deals with the investigation of biogas production under long winter climate countries like Romania, Kazakhstan, Armenia and Georgia.

Methane, a greenhouse gas, plays an important role in global warming. Current atmospheric concentration of CH4 is around 1.72 ppmV and is increasing at the rate of 0.8–1% per year, which has a significant effect in global warming (Crutzen, 1991; Milich, 1999). The production of methane from anaerobic digestion depends on the kind of material added to the digester, the solids loading, the temperature, and the hydraulic retention time (HRT)[1] (Santosh, 2004). By controlled anaerobic digestion of animal manure, methane emissions from manure can be reduced

Anaerobic digestion of animal wastes for production of biogas is a widely studied subject. Properly functioning biogas systems can yield a whole range of benefits for their users, including production of heat, light, and electricity, transformation of organic waste into high-quality fertilizer, improvement of hygienic conditions through reduction of pathogens, reduction of work for firewood collection and cooking, and environmental protection. However, in general, studies have been confined to biogas production at mesophilic and thermophilic temperatures. Low temperature has a deleterious effect on methanogenesis and can cause decreased gas yields and digester failure, when digester are not properly designed.

In this report we mention about the background of biogas production, that includes steps of anaerobic digestion, some experiences of biogas plant under cold climates, temperature analysis of the target countries and substrates in relation to biogas production.

[1] The Hydraulic retention time (HRT) is a measure of the average length of time that a soluble compound remains in a constructed bioreactor. The volume of the aeration tank divided by the influent flow rate is the hydraulic retention time. (source: Metcalf and Eddy page 592)

The concept behind the community based plants is the designing of a plant that can serve more households than those which are suggested for a household plant. This is based on empirical analysis of research work that has been done in other countries with temperatures close to or as low as those from the study areas that we have ear marked for our biogas project. The theory that has been used in the work on community biogas plants has largely come from India, Denmark, Egypt China and Japan. As pointed out the temperatures found in the study areas have variations at times with those anticipated in (say) Romania, but the basic theory behind it all is that we should be able to find similarities that will stand out to relate the places and give us an opportunity to suggest the projects to WECF.

We have done some thinking as well into the idea of an inoculum circulating plant that has a heating system to help keep viable temperatures in the plant. This report will offer some suggestions into this community based plant and try to offer some suggestions for our beneficiary communities targeted by WECF.

1.1 Objectives

The main objective of this study is to investigate biogas production in rural areas with cold climates.

- Investigation on the conditions and exploitation of a biogas energy system on low scale, low tech, during winter time in such a way that the needed gas for heating and cooking is during the whole year available
- Investigation on costs of investment, operation and maintenance of a possible low-tech digester system on low scale or community scale
- How to manage the digester system during wintertime, if the temperatures are several weeks far below zero; How to assure enough energy for the families during wintertime?
- Investigation whether a low-tech biogas plant can also be a viable solution if it works only in summer, spring, autumn.
- Investigation on the cost – benefits of a digester system in poor rural areas in countries like Armenia and Romania
- Investigation on experiences and the use of human excreta (mixed or separated fractions) in digester systems, including the hygiene aspects of the residues.

2. Background on biogas production

2.1 Anaerobic digestion

Anaerobic Digestion (AD) is a biological process that happens naturally when bacteria breaks down organic matter in environments with little or no oxygen. AD produces a biogas made up of around 60 per cent methane and 40 per cent carbon dioxide (CO2). This can be burnt to generate heat or electricity or can be used as a vehicle fuel. As well as biogas, AD produces a residue called digestate which can be used as a soil conditioner to fertilize land.

This conversion of complex organic compounds into methane and carbon dioxide requires different groups of micro organisms and is carried out in sequence of four stages: Hydrolysis, Acidogenesis, Acetogenesis and Methanogenesis. During hydrolysis organic substrate is converted into smaller components , then acidogenic bacteria use these smaller compounds and produce volatile fatty acid, ethanol, CO_2 and H_2. Acetogenic bacteria convert these fermentation products in to acetic acid, CO_2 and H_2. Finally methanogenic bacteria use hydrogen and acetate (most important substrate) and produce methane and carbon dioxide. The following scheme clearly shows sequence of anaerobic digestion;

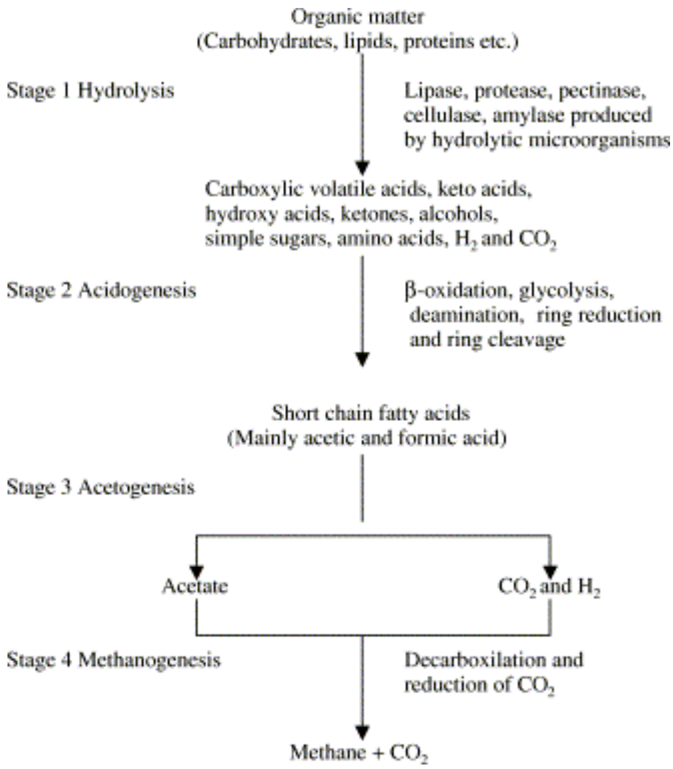


Figure 1: Scheme of anaerobic digestion

A variety of factors affect the rate of digestion and biogas production. The most important is temperature. Biogas production is carried out at different temperatures: temperature range 45–60 °C is referred to as 'thermophilic,' whereas that carried out at temperature range 20–45 °C is known as 'mesophilic' and at low temperatures (<20 °C) is referred to as 'psychrophilic' digestion (Safley and Westerman 1992). The temperature below their optimum for growth, microorganisms are unable to attach substrates from their environment because of lowered affinity (Nedwell, 1999).

2.2 Biogas production with substrate

Many substrates are generally used as feedstock in biogas plants and the potential for biogas production varies with feedstock. Generally animal waste, human waste, kitchen waste and some crop residues are used in small scale biogas plants.

Gas production rate varies with the type of substrate used in the biogas plant. Normally 1 m3 of biogas is enough to cook three meals for a family of 5-6 members (Practical Action Org, 2006). Here we present a possible combination of substrate to produce 1m3 of biogas.

Table 1: Biogas production with different substrate.

Substrate	Gas production rate(l/kg waste)(1)	Manure availability (Kg/animal/day) (2)	No. of animal required
Cattle dung	40	10	2-3
Buffalo dung	30	15	2-3
Pig dung	60	2.25	7-8
Chicken droppings	70	0.18	80
Human excreta	28	0.4	90

(1-FAO,1997 and 2-Nagamani &Ramasamy, no date)

2.3 Temperature analysis of target countries

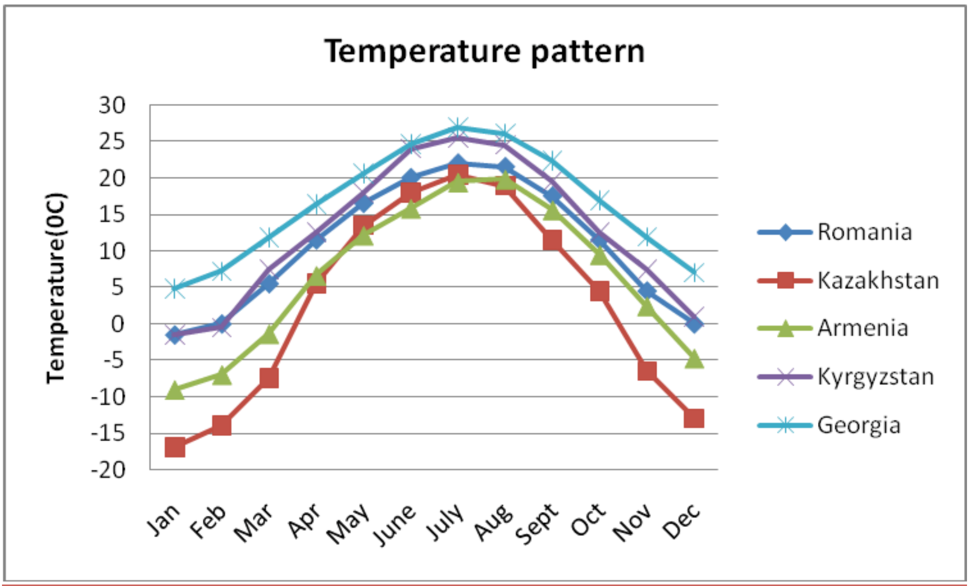


Figure 2: Average monthly temperature of targeted countries

The above figure shows average monthly temperature variation of the countries targeted for the biogas project *(data presented in annex 1).* These countries' temperatures change significantly over time. Most of these countries have very low temperatures for nearly three months of the year and psychrophilic temperature (<20 ^{o}C) condition more than six months, except Kazakhstan and Armenia which have longer periods of low temperature.

2.4 Experiences in other developing countries with low temperature

Biogas technology poses many challenges. Biogas production of mesophilic and thermophilic range is well understood, conditions which can be applied in most developing countries (Kashyap et al. 2003; Alvarez et al. 2006). The development of technology in making available biogas as energy for cooking and heating in the colder areas of any country in the winter season is a matter of great concern. The major reason for their failure seems to be the climatic conditions (temperature) in these areas.

A number of researchers are engaged in studies on biomethanation, but very little work has been done regarding the production of biogas at psychrophilic temperatures. Singh et al.(1995) have studied the effect of HRT on production of biogas from night soil under psychrophilic temperature. At 20 day HRT, propionate concentration has been reported to be about three times higher than that of acetate, whereas at higher HRT acetate and propionate maintained at almost equal concentrations. From the above study it is concluded that anaerobic digestion of night soil can be carried out at 10°C using adapted inoculums. Meher et al., (1994) indicate the night soil under psychrophilic condition, he mention below 20^{0}C methane production observed with the addition of temperature adopted inoculums. Results of Zeeman (1991) showed a stable digestion process at digesting cow manure at a process temperature of 15 ^{0}C and an HRT of 100 and 150 days. The COD reductions were 14 and 18 percent respectively. Even at 150 days HRT the gas production was lower as compare to that at 30 ^{0}C and 20 days HRT.

Safely and Westerman(1994) evaluated the performance of lagoon anaerobic digesters under low temperature ,that shows digestion is feasible at a minimum digester temperature of 10^{0}C with minimum hydraulic retention time of 50 days at the maximum loading rate of 0.12 kg VS/m^{3}/day and this could be adjusted upward for higher temperatures. Sutter and Wellinger (1988) indicate that the gross biogas production by a digester operating at 20^{0}C and retention time of 40-50 days is comparable to a digester operating at mesophilic temperature but at half the retention time.

The case of Tongliang in China is a success in biogas production at different temperature. The daily production rate of biogas during winter (6-10^{0}C) is 0.05m^{3}/m^{3}; spring (16-22^{0}C) is 0.1-0.2 m^{3}/m^{3}and summer (22-23^{0}C) is 0.2-0.33 m^{3}/m^{3} (Daxiong et al, 1990). The biodigester can therefore function all through the year, but winter gas production is insufficient.

The Janata biogas plant in India is located in hilly conditions; the digester slurry temperature followed the same pattern as the ambient temperature. The fall in the mean ambient temperature from 25-26°C in summer to 9-10°C in winter month resulted in the lowering of the digester temperature from 22-23^{0}C to 13-14^{0}C. The digester temperature remains in lower mesophilic ranges of (16-24°C) for nearly eight months and the rest of the year in the psychrophilic range (l3-14°C). This results in lowering of the gas production by 23-37% in winter (Kalia and Kanwar, 1998).

Biogas production can occur over a wide range of temperatures, in nature from 0 - 97 degrees Celsius (Kashyap *et al.,* 2003 and Zeeman *et al.,* 1988). In conclusion, there is a limited knowledge and a lack of experience concerning psychrophilic digestion, but it is clear that lower temperatures need a longer HRT to achieve a similar gas production (Zeeman, 1991).

(Singh and Sooch 2004) mention Deenbandu biogas plant operating in Punjab India at 25^0C with 40 days HRT. The table below shows, the relationship between HRT and the volume with temperature. The calculations are presented in appendix 2.

Calculation of HRT and volume at lower temperature for same methane yield							
Temperature	˚C	2	5	10	15	20	25
Loading rate at actual T	kg/day	2.00	5.00	10.00	15.00	20.00	25.00
HRT at actual temperature	days	80.00	200.00	400.00	600.00	800.00	1000.00
Volume	m3	14.96	11.08	6.72	4.08	2.47	1.50

2.6 biogas plant

In many countries worldwide biogas plants are in operation, producing biogas from the digestion of manure or other biomass (GTZ, 2007). In addition, with success small scale biogas plants are utilized to displace woody fuels and dung in many developing countries. For example, the Dutch Development Organization, SNV, implemented with success in Nepal and Vietnam over 220,000 household on site biogas plants (FMO, 2007). Moreover, in China and Indian millions of plants are in operation. In conclusion, biogas plants have proven to be an effective and attractive technology for many households in developing countries.

Under the right conditions a biogas plant will yield several benefits for the end-users, the main benefits are (GTZ, 2007):

1. Production of energy for lighting, heat, electricity
2. Improved sanitation (reduction of pathogens, worm eggs and flies)
3. Reduction of workload (less firewood collecting) and a biogas stoves has a better cooking performance
4. Environmental benefits (fertilizers substitution, less greenhouse gas emission)
5. Improved indoor air quality (less smoke and harmful particle emission of a biogas stove compared to wood or dung fuels) (Buysman et al, 2006)
6. Economical benefits (substitution of spending on expensive fuels and fertilizer)

Consequently, biogas plants are of great benefit to the end-users and the environment. Note however, that this only happens under the right conditions. What these conditions are is explained in the next section.

History shows however, that biogas plants have not always been introduced with success. The China biogas program has its roots in the pioneering research of Mr. Lou Guorni in the early 1920s (Daxiong, 1990). His experiments were successful, and the idea of substituting biogas for foreign oils (kerosene, gas, oil) was took up by several government campaigns, in 1958 and the early seventies. However, the focus of the government campaigns was on quantity not quality. This resulted in badly functioning digesters and many of them were not in operation some years later. Farmers, who first were enthusiastic and had the right outlook, were not willing anymore to invest in biodigester technology. These lessons should be taken into mind when developing and disseminating biogas plants, the focus should be on plants which are durable, not only determined on low cost. Kristoferson and Bokhalders (1991), quoted by Bui Xuan An classified the problems experienced by the biogas programs in China and in India as the following:

(a) Design faults;

(b) Construction faults

(c) Difficulty of financing;

(d) Operational problems due to incorrect feeding or poor maintenance and

(e) Organizational problems arising from the differences of approaches and lack of coordination.

All these aspects need to be taken into account. In addition, back up services are important, i.e. monitoring of the performance by experts.

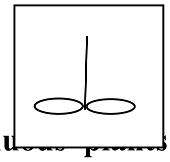
2.6.1 Bioreactor types

The reactor is the place where any substrate is digested. The classification of reactors is based on the mixing of fluid (substrate and sludge) in the reactor (Stalin, 2007). We will discuss here only the completely stirred, non stirred and batch reactor. In addition to these reactors many combinations of these reactors and additions are available; however these reactors are not feasible in the targeted countries, because of its complexity and high financial and human capital input

There are various types of systems. Concerning the feed method, mainly two different forms can be distinguished:

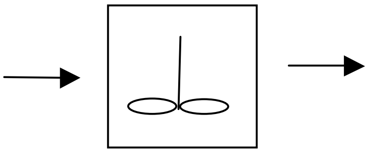
- Batch plants
- Continuous plants
  - CSTR(Completely mixed tank reactor system)
  - Plug flow
  - Fed batch (accumulation) system

Batch plants: These plants are filled and then emptied completely after a fixed retention time. Each design and each fermentation material is suitable for batch filling, but batch plants require high labor input. As a major disadvantage, their gas-output is not steady in time

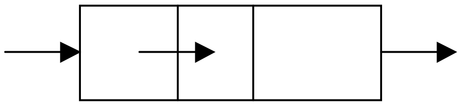


Continuous plants: These are fed continuously. The CSTR and plug flow systems are characterized by automatic overflow when new material is filled in. Therefore, the substrate must be fluid and homogeneous. Continuous plants are suitable for rural households as the necessary work fits well into the daily routine. Gas production is constant.

A CSTR system is characterized by a continuous feeding rate and a complete mixture of bacteria and substrate and at constant loading rate, a constant gas production rate is achieved in time.
The plug flow system is continuously fed and the feed passes through the reactor in a horizontal direction and concentration reduces from left to right.



CSTR system



Plug flow

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In developed countries, such as the Netherlands, active stirring is applied to mix the contents of the digester with the added substrate, so called Completely Stirred Reactor (CSTR). The concentration of the degraded substrate is the same in the reactor as at the outlet of digested substrate as a result of stirring. A derivate of this reactor exists in developing countries, the fixed dome digester, discussed in the next section (Chapter 2.6.2).

These types of reactors have different implication for the hydraulic and sludge retention time and subsequently the loading rate of substrate and the volume of the reactor. The hydraulic retention time (HRT) refers to the time water and bacteria remain in the reactor and the sludge retention time (SRT) refers to the time the substrate is in the reactor.

The volume of the reactor necessary to produce enough gas for cooking depends on the HRT, SRT and the loading rate of substrate. The implication of these aspects on the volume is described on the next section.

CSTR system, plug flow systems and system based on a similar set up always need an additional storage for the digestate, to overcome periods that digested manure cannot be applied on the field on low temperature countries this can be as long as 5-6 months. A fed batch system could be used as an alternative, but due to limited practical experience not further discuss in this paper.

2.6.2 Biogas plants in developing countries.

In developing countries there are several digesters in operation, the most familiar is the fixed dome digester, in addition the floating dome digester and bag digester are found in many developing countries. These types of digesters are respectively explained next.

1. **Fixed dome digester**

The fixed dome digester is the most popular digester, its archetype was developed in China, see figure 3. This is CSTR type digester. The digester comes in various types, notably the Chinese fixed dome, Janata model and Janata II model (Jalla, 1988), Deenbandu and CAMARTEC

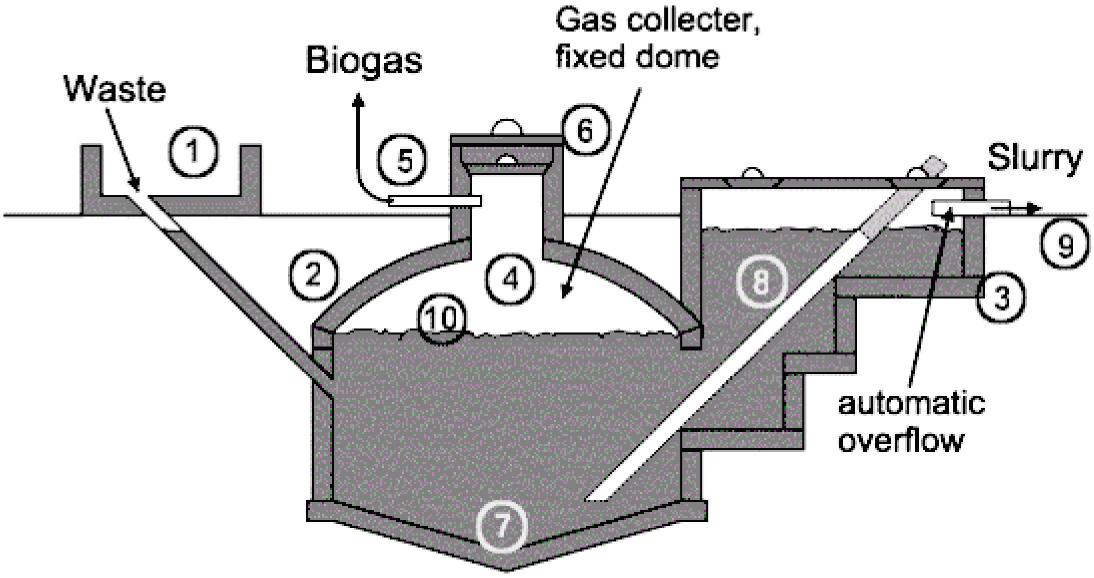


Figure 3: **Fixed dome plant Nicarao design: 1. Mixing tank with inlet pipe and sand trap. 2. Digester. 3. Compensation and removal tank. 4. Gasholder. 5. Gaspipe. 6. Entry hatch, with gastight seal. 7. Accumulation of thick sludge. 8. Outlet pipe. 9. Reference level. 10. Supernatant scum, broken up by varying level. Source GTZ**

Characteristics & function

A fixed dome digester is a closed dome shaped digester. The waste (manure, dung, human excrement) is fed to the digester. After that the methanogenic bacteria 'digest' the waste and produce biogas and slurry (digested waste). The gas is captured in the gasholder and the slurry is displaced in the compensating tank. The more gas is produced, the higher the level at the slurry outlet will be.

The level of slurry in the digester depends on the loading rate, gas production and consumption. During gas production slurry is pushed back sideways, displaced to the compensation tank. When gas is consumed slurry enters back into the digester from the compensation tank. As a result of these movements, a certain degree of mixing is obtained of slurry of different ages; therefore this design approaches a mixed digester reactor (Stalin, 2007). In such a reactor the HRT is the same as the SRT. The volume of the sludge filled part of the digester is therefore equal to the retention time of the sludge times the flow rate. The gasholder is adapted to fit the gas requirement of the end-user (family). Important to consider is the daily pattern of cooking. The longer period between the meals, the more gas is produced in between meals and subsequently the larger the gasholder should become.

The fixed dome digester is relatively inexpensive. It is simple, has no moving parts and has therefore a long lifespan, up to 20 years (GTZ, 1999). The plant is suitable for cold climates because most part is beneath the ground level. Therefore the plant is protected against low temperatures occurring during night and in cold seasons. The temperature within the digester is lower during daytime and higher during nighttime (GTZ, 1999). This fluctuation is beneficial for the methanogenic bacteria and subsequently for the biogas production. The main advantages and disadvantages:

Advantages of the digester

1. Relatively cheap and durable
2. Construction is labor intensive (local employment opportunities)
3. No moving parts
4. Well insulated

Disadvantages

1. High technical skills are required for a gas tight construction
2. Special sealant is required for the gasholder
3. Gas leaks occur when not designed well
4. Difficult to construct in bedrock
5. Amount of gas available for cooking is hard to detect
6. Enormous structural strength required for construction (Sharma et al, 1991)

Experiences for the China biogas program teaches us that special attention is required when constructing a fixed-dome digester (Daxiong, 1990). GTZ only advices to construct such a plant under the supervision of experienced biogas technicians (GTZ 2007). This should not be taken lightly; Mohamed Nazir (1991) concluded in his study *"biogas construction technology for rural area"* , that experience from Pakistan showed that the Chinese dome model failed most cases as a result of low gas pressure due to persistent leakage problems and seepage problems. Cleary, the design has many favorable aspects, but its success is dependent on the input of high technical manufacturing.

2. Floating drum digester

Floating drum digesters are mainly found in India and this is semi CSTR type reactor. A floating drum digester is shown next, figure 2.

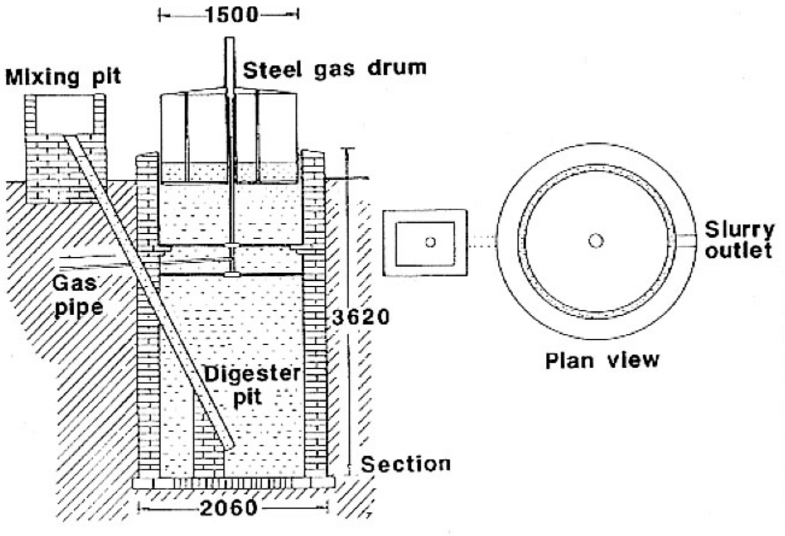


Figure 1: Cross- section of a floating dome digester, based on the original design developed by KVIC in India,
Source: www.ganesha.co.uk/Articles/Biogas%20Technology%20in%20India.htm

The ideal situations for a community based biogas digester recommends a central collection area for the plant substrate *(see Fig 3)*, be it animal manure, excrete or food/vegetable waste. Here lies the first area of logistical headache which calls for organizational skills from the responsible community. Studies by SRE (Sustainable Rural Energy) for a Community based biogas plant in Haor (Wetland) area2 involved providing all the families in the community an improved sanitary latrine which was connected to a central digester. According to SRE (2002) "a beneficiary committee has been formed and this community is entrusted with the responsibility of proper of proper operation and maintenance of the system"

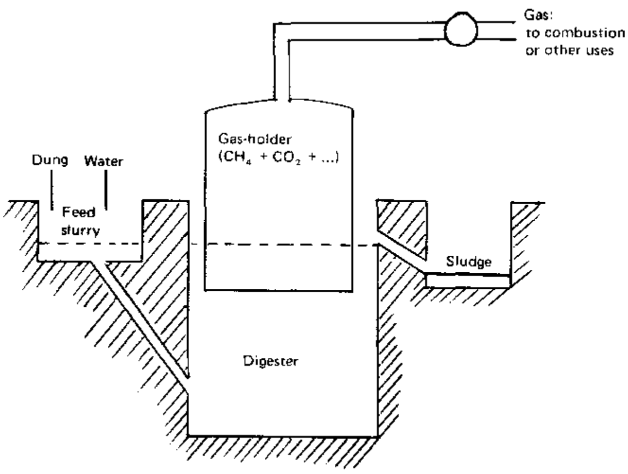


Fig 3. The design and construction of a biogas plants. For biogas plant construction, important criteria are: (a) the amount of gas required for a specific use or uses, and lb) the amount of waste material available for processing. (Diagram courtesy of *E.J. DaSilva Division of Scientific Research and Higher Education, UNESCO, Paris, France.)*

[2] Talihati Union, Nikli Upozila in Kishoregonj district.

Characteristics

The operation of a floating dome digester is not that different from a fixed dome digester. The produced gas is collecting in a movable steel drum, the gasholder. The steel drum is guided by a guide frame. When gas is consumed the drum sinks. Slurry is pushed out of the digester after the digestion (GTZ).

In contrast to the fixed dome digester, a floating drum digester is not a mixed reactor like fixed dome, but here also some mixing take place due to gas production and removal of gas.

Advantages

1. The operation of the plant is easy to understand and operate
2. Gas drum is air tight provided the drum is de-rusted and painted regularly
3. Constant gas pressure as a result of the weight of the drum

Disadvantages

1. Steel drum is relatively expensive and needs regularly maintenance (priming, painting, coating)
2. Steel drum can get stuck

A low cost option is to use a balloon as a gas holder instead , which is attached to the digester. A disadvantage is the susceptibility to physical damage.

3. Bag digester/ Balloon plants

A balloon plant or also referred to as a bag digester is a plastic or rubber bag combining the gas holder and digester. This is a plug-flow type reactor. Gas is collected in the upper part and manure in the lower part; the inlet and outlet are attached to the skin of the bag. The pressure of the gas is adjustable by laying stones on the bag. The next picture shows a bag digester as used in Bolivia on the Altiplano.

Figure 2: Bag digester in Bolivia. Source: www.tecnologiadesarrollo.tk

According to *GTZ (unknown date)* these bags have a limited life span of 3-5 years. In China red mud bags, a by product from the production of aluminum is used since 1983 with success. However, the effective life span was also limited to 3-5 years (Daxiong, 1990). The Bolivia Biogas Program, Viviendas autoenergéticas" constructed bag digesters on the Altiplano, a barren area at an altitude of 4000 meters (Technologias en Desarrollo, 2007).

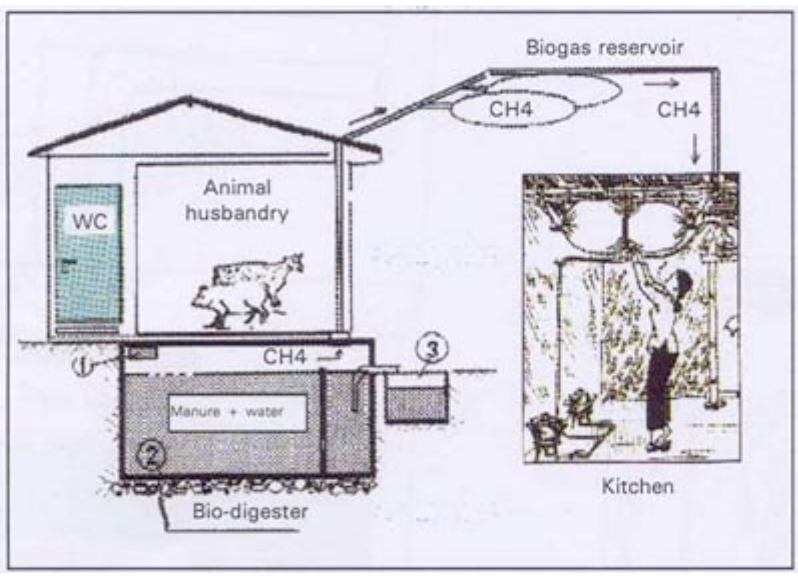
Advantages:

1. Low costs
2. Simple technology
3. Uncomplicated cleaning

Disadvantages:

1. Short life-span
2. Susceptible to physical damage
3. Hard to repair
4. Need for high quality plastic/PVC
5. Difficult to insulate

4. **Vacvina Biogas plant**



The biogas production technology is mostly suited for animal husbandry waste and human excreta. The input to the biodigester comes through a ditch attached through a siphon system, connecting the wastes from the animal shed to the biodigester.

The biodigester is a rectangular structure with a volume capacity of 5 m^3. It could be placed next to or below the animal shed. The output of the digester goes through a PVC exhaust pipe. The plastic bags used to collect biogas and used as a cooking fuel

5. **Other plants**

There are other types available, such as an earth pit plant. This kind of plant is possible with stable impermeable soil. Such a plant is basically a hole in the ground and covered and attached to a gasholder. To avoid seepage a thin layer of plaster would suffice. An overflow point in the wall would suffice as a slurry outlet.

Advantages

1. Cheap, 20% of a floating dome (GTZ, 2007)
2. Easy to construct

Disadvantages

1. Short life span
2. Only when soil conditions permit (impermeable)

In addition there are other plants available. Biogas plants in industrialized countries have been omitted as they require large investments and are only suitable for large farms.

2.6.3 Increasing the temperature of digestion

In industrialized countries external heating is applied to optimize biogas production (GTZ 2007). These biogas plants however, are large scale and capital intensive. External heating is too expensive for small scale biogas plants (GTZ, 2007). Some options to increase the heating within the digester are discussed next:

Passive heating: Passive heating, solar heating might be an option. This is practiced in China and Bolivia. In Bolivia on the Altiplano the bag digester adsorbs heat because of the black coating (Technologias en Desarrollo, 2007), this increase the temperature of digestion and subsequently reduced the HRT. Noted should be that a bag digester has little or none insulation. Therefore the temperature of digestion is much more reactive to ambient temperature changes. Experience from India support that conclusion based a comparative study run over 13 months between a bag digester and a fixed dome digester; model Deenbandu of the same capacity (Kanwar *et a.l,* 1994). The study showed that the temperature distribution of the KIVC is less responsive to diurnal and seasonal temperature changes and in addition the gas production was higher. In the winter, 8-10 degrees, the biogas production of the bag digester was 77% lower compared to 16% of the Deenbandu digester. A bag design would not be advisable in the targeted countries; the sludge in the digester would quickly freeze in cold winter nights. And because water has a relatively high heat capacity, the melting of the sludge would take a lot of time.

Therefore, a combination between an underground digester and passive solar heating is more interesting. Figure 4 shows an example of a dome digester in combination with a solar heater.

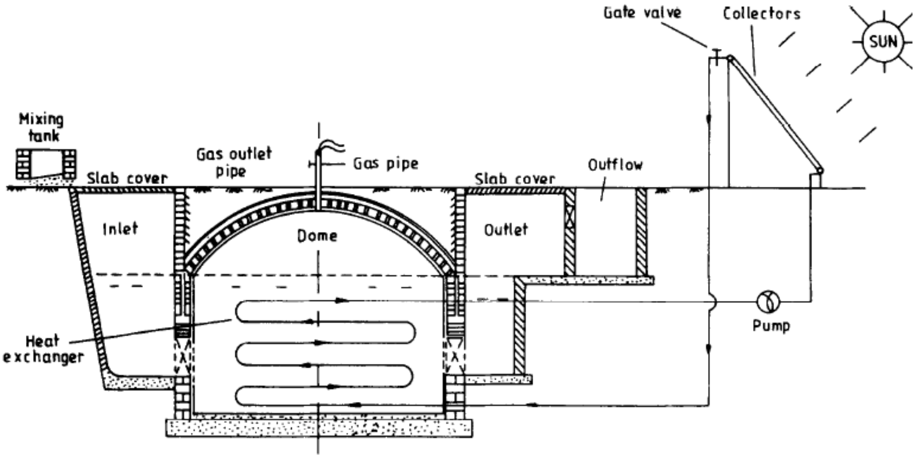


Figure 3: A cross-section of an active dome digester (Tiwari et al, 1992)

However, solar heating is only interesting when the net incoming heat flux contributes to the rate of reaction in the digester, which only happens when the sun shines. The most critical obstacle that biogas plants need to overcome in the targeted countries is the low temperatures in wintertime. Passive solar heating will only contribute if there is sufficient solar irradiation during wintertime. In the targeted countries, a mixed image emerges. According to BBC weather, Romania has 3-4 hours of sun on average during the winter. This, in addition to snowfall, low temperatures during the nights (which might freeze the heat transfer liquid in the solar collector) and the added capital investment is a significant obstacle for successful implementation. Likewise, the other countries suffer from snowfall and cold nocturnal temperatures. However, in some locations it might contribute, but a more detailed study is necessary to determine its potential. In summary, solar heating will only contribute if sunshine is abundant during wintertime.

Insulation: The previous section gave a small introduction of the effects of insulation. The Deenbandu digester proved to be much more insulating than the bag digester. This is probably caused by the fact that the Deenbandu digester is situated mainly underground and therefore less influenced by changes of the ambient temperature. This is outlined in figure 4. Deenbandu is the Indian version of the Chinese dome digester. Gupta et al (1986) studied the influence of lowering the heat transfer coefficient, thus increasing insulation and the temperature of digestion. They found considerable effects when applying high insulating materials, (<2.8 W/m2). However their study combined solar heating and insulation, it is unclear if their conclusions can be applied to systems without solar heating. According to Kishore (1989) insulating the dome of a fixed dome digester yields the most effects, insulating both the dome and walls decreases the heat loss further, but not significant. In conclusion, the extent of which biogas plants are exposed to the low ambient temperature in winter time needs to be limited, and a digester under the ground surface is preferable over a digester on top of the ground. In addition, insulation needs to be applied on the upper part of the digester

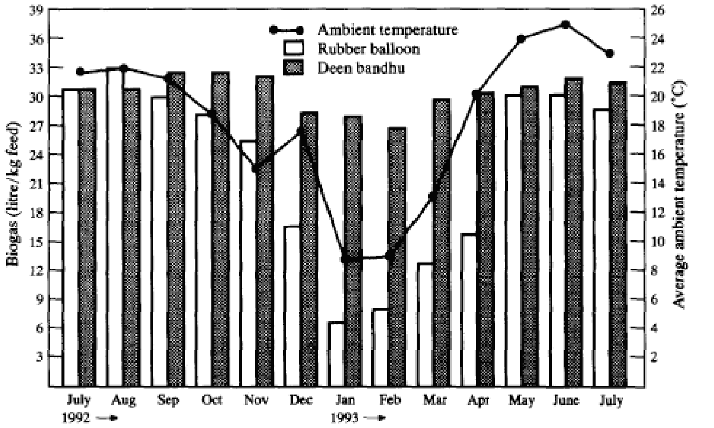


Figure 4: Digester temperature in relation to ambient temperature

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Meeting the biogas demand in wintertime

Chapter 2 focused in detail on biogas production in relation to the temperature. Based on that one can conclude the following:

- Biogas production is temperature dependent, and therefore will decrease in wintertime depending on HRT applied.
- Biogas production is limited beneath 5 degrees Celsius.

Insulation will increase the temperature of digestion as it decreases the heat loss to the surroundings.

At lower temperature, longer SRT's and there for higher HRT and reactor volumes are needed to achieve similar gas production as at higher temperature (Zeeman, 1991).

2.6.4 Gas Storage

Targeted countries gas production varies throughout the year due to temperature change. In this project, we mainly focus on maximum possibility of gas production throughout the year, except Kazakhstan and Armenia 8 months of gas production due to very low temperature.

The gas storage material is also important. It is imperative to use materials that can withstand the volatile requirements of winter time gas production. Research and experience in China has led to "cement with a low alkali content, alkali-resistant glass fiber reinforcements and complex and high molecular coatings." (Daxiong, 1990). According to the research, these materials have and good sealing properties as well as high pressure resistance. There is no doubt that these are the kind of conditions necessary for the biogas plants for our study area.

In addition to this, plastic made from the "red mud" that results as a by-product of aluminum production has been utilized to make cheap gas holders. These plastic bags float on a water seal, and help to keep the pressure of the gas at a more constant level than can be achieved within the hydraulic biogas plant alone. (Daxiong, 1990)

These plastic bags have even more advantages that can help us in our recommendations to the WECF projects; advantages such as that the plastic absorbs solar energy allowing increases in gas production of between 9 and 16% and the bags are highly leak resistant.

The issue of leak resistance of the plastic material is of importance because there is need to consider the storage of synethised gas for later use. Leak-proof material such as the Chinese plastic can be used in the Romanian and Kazakhstan project.

2.6.5 Pathogen issue

Anaerobic digestion reduces pathogenic count (Gadre et al., 1986) depending on retention and temperature. The digested biomass provides good manure, but villagers have certain inhibitions about handling the digested slurry as manure due to the fear of acquisition of diseases.
The decay rate of bacteria depends on temperature, treatment time, pH, volatile fatty acids and operation system (batch or continuous system). The anaerobic digestion process eliminates significant number of pathogens/parasitic species. However, both temperature and Hydraulic Retention Time (HRT) is an unsettled issue among the researchers. Temperature determine the elimination rate of pathogens and it is also an important determinant of which group of bacteria will function in the digester. Reports from the various experiments have shown that pathogens are killed faster and the slurry well digested in the thermophilic range of temperature (48 to 60°C). The temperature is the most important factor determines the survival of pathogenic bacteria during anaerobic digestion. In thermophilic and mesophilic digestion 90 percent reduction in viable pathogenic bacteria counted in hours and days respectively (Gibbs et al., 1995;Larsen et al., 1989).
Biogas plant runs either batch or continuous system. Kearney et al (1993) reported a great decline of pathogens in batch reactors than continuous reactor system. The idea of fixing appropriate temperature for the elimination of different parasites has not reached consensus in the literature.

As bio-waste can be contaminated with all kinds of pathogens, this aspect needs attention. During the summer most of Europe and for the whole year in southern Europe, a 3-week period of 'no-grazing' or prohibition of working of bare soil should be adequate to reduce pathogen numbers by 2 log10 after spreading sewage sludge. (Wolters, 2005). Where crops are consumed directly by humans, particularly where they may be eaten raw, a longer period between application and harvesting should be applied. The practice for agricultural use of sewage sludge land identified a 10-month period before harvest during which at least a 2 log10 reduction in numbers should occur (Wolters, 2005).

There is a much higher risk where vegetables are eaten raw, as with salads, than from processed cereals from arable land. In reality, sludge would not be used on land growing salad crops and this guidance would apply in situations where a farmer growing, for instance, arable crops fertilized with sludge plans to change the land use to salad crops without sludge. Evidence to justify the 10-month no-harvest recommendation for vegetables in ground contact was presented by Carrington et al, 1998 in Wolters,A,2005.

3. House on site biogas plant

This chapter will focus on biogas technology for house on site plants. First, method are described, secondly, based on our literature review, design criteria are formulated. Thereafter the best design is selected and adapted to operate in a climate with cold winters. Two designs are proposed, one with an attached toilet and one without. Finally, examined is if the digesters are able to operate in all the targeted countries year-round.

Methodology

Most of the information is from the experiences of different biogas plant designs operating in China, India, Nepal, Pakistan and Cambodia. The different plants are described in Chapter 2, section 2.6.2: experiences in other developing countries. Most of these countries have a climate which differs from the targeted countries by WECF, especially the winters are much colder. Therefore, the plants need to be modified to withstand lower temperatures while maintaining sufficient biogas production. Appendix 2 elaborates on the methodology and the mathematical background on these modifications. The following digester designs are examined:

1. Deenbandu dome digester[3]
2. Chinese Dome digester
3. Floating dome digester
4. VACVINA
5. Bag digester

A batch digester is not considered since the system is not able to produce gas year round. During the period the digester is emptied and refilled, the gas production stops and will not return to an adequate level for 1-2 months, a severe drawback. For that reason we consider the batch digester unsuitable for house on site operation.

Chapter 2 elaborates on the experiences from other developing countries. It will be clear that biogas plants are applied in many countries with a mixed degree of success. The focus was sometimes too much on quantity (China) or the designs where not strong enough (India).
To evaluate each type of digester design, we have formulated a list of criteria. These criteria are based on our literature review of experiences in the aforementioned countries with biogas technology. These criteria are used in section 3.1 to assess the different designs.

1. Structural integrity - *quality of the structure*
2. Reliability - *a long lifespan and sound operation*
3. Constructability - *level of expert know-how*
4. Heat losses - *the design should be optimized to retain heat*
5. Gas production - *must be able to meet demand year-round*
6. Operation and maintenance - *operation should be easy and with little maintenance*

[3] This Indian design is the improved version of the Janata (or Janta) dome digester, the Janata digester is based on the Chinese dome digester.

7. Investments costs - *low costs increase the affordability*

Followed by an enumeration of the scores of each digester on each criteria.

3.1 Overall assessment of different digesters

1. Structural integrity

A sound structure can withstand high external loads and internal pressure, which result in a long lifespan with little repairs. Furthermore, it greatly reduces the probability of cracks in the plastering and gas leaks. The next picture shows the strengths of different digester tops.

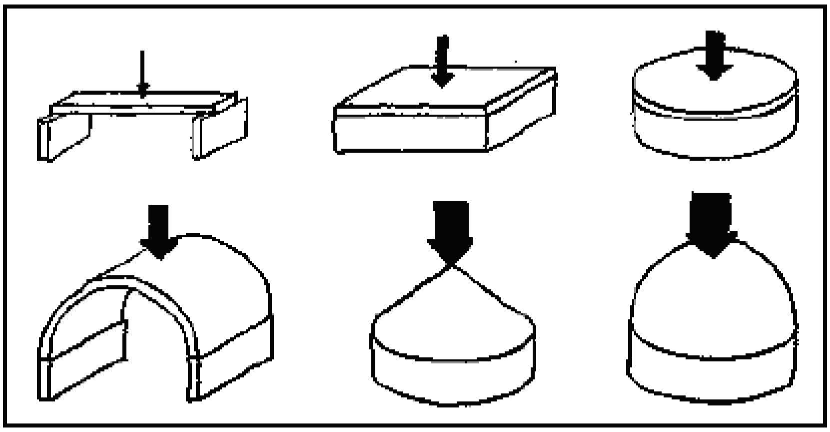


Figure 5: Shape in relation to load bearing capacity - the thicker the arrow the larger the load bearing capacity (CEM 2005)

The Deenbandhu digester has a dome similar to the shape on the right bottom of the figure which covers both the digester and gasholder. The Chinese dome digester though, has only a dome structure for the gasholder while the digester is cylindrical shaped. The Deenbandhu design can therefore withstand an higher load on its top (CEM 2005). Without must debate, the VACVINA digester (middle top of the figure) is a much less load tolerable design. The floating dome digester is a bit vulnerable due to the heavy metal drum and the fact that the drum is movable. Structural integrity is of less relevance to the bag digester, which has limited or no load bearing capacity. Therefore the bag cannot be covered with material for insulations or protection.

In conclusion, dome digester have the highest load bearing capacity. Many studies have reported its successful appliance and long life span. For example the Janata design in India (Kalia, 1998), the digesters installed with the help of SNV in Vietnam and Nepal and the digesters in China (Daxiong 1990). However, experiences in China have had a long history of failures. Nazir (1990) found that dome digesters are not suitable to operate in Pakistan due to the high temperature differences which lead to cracks in the plastering, and hence gas leaks. This is probably the result of bad plastering or construction and not a results of the inherent design flaws.

2. Reliability

Lifespan

The Deenbandhu design is certified for a life span of 20-40 years. The Chinese dome for 20+ years (CEM 2005). In practice the Chinese dome has due to a lower structural integrity a lower life span (Nazir 1991). The VACVINA design has a lifespan of probably less than 20 years, while the bag digester a mere 3-5 years (Daxiong, et al. 1990) (GTZ 1999) .

Flow distribution

With flow distribution we refer to the flow of substrate from the inlet to the outlet. The better the mixing, the less material will settle (the less built up of settling layers of sludge) and hence the least amount of maintenance in the form of emptying the digester is necessary. In addition, in a system where sludge does not settle, mixing is more optimal and therefore the whole volume of the digester is used for digestion.
The manure flow distribution is most optimal in the Deenbandhu due to its dome shape and shell shaped bottom (CEM 2005). The Chinese dome has a somewhat less optimal flow since the design is not completely dome shaped, differences are however likely to be marginal. The VACVINA has a bad sludge flow distribution because sludge which is heavier than substrate tend to clog in the corner of the rectangle shaped digester. Over time, settling layers are formed. This reduces the effective volume of the digester and therefore the HRT, resulting in a lower gas production at lower temperatures. A bag digester has as a result of the rectangle shape yet with round corners (due to the bag) and plug flow operation a good flow distribution.

3. Constructability

Constructability refers to the level know-how that is required to construct a digester. A high level might impair constructability as the knowledge is not available at the place of construction.
Of the models examined, the VACVINA and the bag digester are the most easy to construct. A major drawback of the bag digester is however; the use of high quality PVC or other plastics as a construction material which might only be available in the main or capital cities, for example in Bolivia this is the case (Rivero), where the materials are only found in the capital city, La Paz. The VACVINA plant is less difficult to construct compared to the Deenbandhu or the Chinese dome digester. Furthermore the VACVINA design is less prone to gas leaks compared to the dome digesters since the gas pressure in the digester is much lower; the gas is collected in an inflatable plastic bag instead of an internal gasholder (CEM 2005). Additionally, the construction is more straightforward due to the rectangular design. A dome shaped digester, Deenbandhu and the Chinese dome digester, need extensive plastering, which requires a lot of attention and care. In the past many of these digesters, especially the Chinese dome digester failed to meet expectations because of insufficient plastering (Nazir 1991) (Sharma and Pellizzi 1991).

If the soil is composed of rocks, all the designs, except the bag digester are not feasible, without an enormous digging effort. In that case a design need to be adapted to be built above ground or less deep, that however, would expose the digester to cold ambient air resulting in a lower temperature of digestion and hence a lower gas production.

4. Heat emission

Heat losses happens when heat is transferred from a warm body to a cold body. In our case, heat will transfers from the digester to the colder surroundings (soil and ambient air) in the winter. This flux of heat, needs to be minimized to retain the heat in the digester. To minimize heat losses, we take the following factors into account: 1. Surface volume ration, 2. Insulation, 3. Location of digester.

1. Surface volume ratio
Mathematically, a sphere shaped object has the smallest surface area per volume unit. This means that the contact of the digester with the colder surroundings is the least per unit of volume. The less contact a hot body has with a colder body per unit of volume, the less heat is lost. The Deenbandhu digester followed by the Chinese dome digester are the most sphere alike, and have therefore the least heat losses. The VACVINA digester has the most contact with the surroundings per unit of volume because of its rectangular shape.

2. Insulation
All digesters benefit from insulation. The Deenbandhu followed by the Chinese dome digester have the smallest surface to volume ratio and require therefore the least amount of insulation. A floating dome digester loses a lot of heat resulting from the metal drum. Metal is an excellent heat conductor. The bag digester is the least suited to apply insulation directly on the surface of the bag. The surface is variable (depending on the amount of gas stored and amount of manure), and therefore insulation has to be flexible. A bag digester in an insulated space could be an option.

3. Location of the digester
Building a digester under the ground level will shield the digester from extreme temperatures during the winter, preferably under a barn (heat transfer from animals and good shielding from the low ambient temperatures) (Zeeman, et al. 1988). However, during the summer the digester will not heat up as fast as the ambient temperature does. Nonetheless that is not a drawback, given that a digester needs to be constructed to meet the most critical conditions; wintertime. Consequently the digester will operate sufficiently in the summer. Only the bag digester is hard to construct underground, the volume of the bag is variable and therefore it cannot be covered with soil. Such a digester needs some shielding from wind and direct exposure to cold air.

5. Gas production

In theory, each digester can be dimensioned to achieve the necessary gas production, unless the digester content freezes. In practice however, many studies have shown that gas production beneath 5 degrees in negligible. Daxiong et al (1990) measured for example a biogas yield of 0,05 m^3/m^3 at 5 degrees of the Chinese dome digester, while the same digester, with the same feed, produces 0,33 m^3/m^3 at 23 degrees. Therefore, the volume necessary to achieve 1m^3 biogas has to be 20 m^3 at 5 degrees, and much smaller if the digester would only operate at 23 degrees. The feeding of the digesters is the same in both cases, however the feeding per m^3 of reactor is much higher of the digester operating at 23 degrees.

Such a volume for 5 degrees is quite large for a household digester, while a smaller volume will result in insufficient gas production in times when the ambient temperatures is around 5 degrees. Consequently people have to rely on other fuels for cooking, and need to own and use more than one stove and fuel. In the light of sustainable energy provision, it is not desired. How to increase the temperature of digestion or to retain heat is described in chapter 2.

6. Operation and maintenance

Maintenance

The manual of GTZ asserts that a dome digester needs to be cleaned every 5 years, which is probably also true for a floating dome digester. During the operation of a digester some materials settle, such as sand or other heavy non digestible materials, and therefore cleaning is necessary (GTZ 1999). Cleaning consist of emptying the complete digester. A cleaning rate of once every five year is consistent with what we found in literature, for example Kalia and Kanswar (1998) evaluated long term performance of fixed dome plants. They found a steady decrease in gas production rate over the years, probably due to the settling of materials leading to a reduction of the effective digester volume (Kalia and Kanswar 1998). After cleaning, the biogas production increased to the highest levels of the first years of operation. Kalia et al (1998) therefore suggested to clean the digester every 5 years. Other digesters face the same settling problems, and as mentioned earlier, especially the VACVINA digester. A bag digester has such a limited life span that cleaning does not have to be considered. To avoid a long period with no gas production, we suggest to recycle most of the content of the emptied digester apart from the settled materials. The steel drum of the floating dome needs a new coating once in every three years by applying corrosion resistant paint (Nazil, 1991). Additionally, the plastic gas storage bag of the VACVINA is vulnerable to leaks and needs regular maintenance (leak stopping) or replacement (CEM 2005). Higher quality materials could be more leak resistant and more resistant to damage.

Operation

The operation of all the plants is not essentially different. Fresh manure needs to be fed and at regular intervals the digestate has to be transported to a storage facility or to the fields. In addition, pipes to the storage bag (if available) and to the stoves needs to be checked on regular bases for leaks, especially if the pipes are made of PVC or another plastic.

7. Investments costs

Investments costs are dependent on many aspects, such as type of material, amount of material, availability of certain materials and input of technical know-how. The bag digester is the cheapest digester (GTZ 1999). The VACVINA, and Deenbandhu have comparable construction costs, while the Chinese dome is a little bit more expensive. CEM (2005) estimated the following construction costs for the following models in Cambodia: Deenbandhu ($243), Chinese dome ($293) and the VACVINA ($237). The floating dome digester is more expensive as a result of the movable drum. The drum is constructed of mild steel, which is relatively expensive and therefore is likely to be the most expensive. These investments costs are however only applicable to Cambodia, in other countries the investment costs are different, resulting from different expenditures on construction materials and labor costs. However, the estimations of CEM give an indication of the comparative investments costs of the different digesters designs.

Overall assessment

The following table is drawn based on the assessment of the designs based on our criteria. The criteria are weighed equally and based on the aforementioned criteria.

Table 1: Overall assessment of the different designs*

Criteria **	Deenbandhu	Chinese dome	Floating dome	VACVINA	Bag digester
Structural integrity	1	2	3	3	5
Reliability	1	2	3	4	5
Constructability	3	4	5	1	2
Heat emission	1	2	4	3	5
Operation & maintenance	1	1	2	3	1
Investment Costs	3	4	5	2	1
Overall score	**10**	**15**	**22**	**16**	**19**

* 1= best score on a criteria, 5 is the worst

** on gas production each digester scores in theory the same, all can be dimensioned to meet a certain gas yield

Table 1 follows that the Deenbandhu design scores best. This is not surprising, the digester is an improved version of the Janta digester which is based on the Chinese dome. The Deenbandhu is stronger and cheaper than the Chinese dome and less heat is lost. Deenbandhu means in Hindi, friend of the poor, quite fitting . A toilet can also be attached to the digester, this is elaborated in the next section.

3.2 Adaptation of the Deenbandhu digester to colder conditions

The main design criteria to meet sufficient biogas productions is: *a design is based on the critical periods of the year, using the temperature of digestion instead of the ambient air temperature*, stressed by the German Development Bank (GTZ 1999). Therefore the Deenbandhu digester needs to be adapted to lower temperatures, quite differently from temperatures in India.

The model Deenbandhu digester 2000 is shown next:

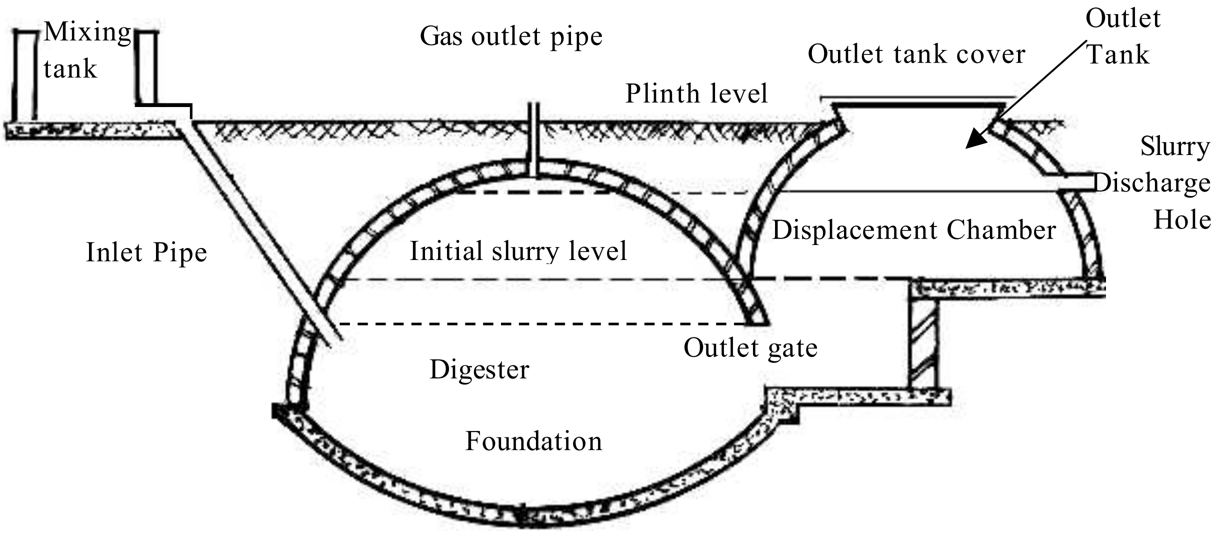


Figure 6: Deenbandhu 2000 digester

The model above shown, is an improved version of the first version of the first Deenbandhu plants. The main modification are: the shape of the outlet tank, changed from square shaped to a dome and a reduction of construction materials necessary for the construction. The model above is designed by AFRPO (Action for Food Production) in India (AFPRO n.d.). The coldest regions where this models is in operations are India's hilly regions are 11-14 degrees in wintertime and some areas in Nepal (Kanwar and Guleri 1994). These temperatures are significantly higher than temperatures in, for example, Romania's winter season. The digester need therefore to be adapted, and we will take two measures to do so in account, increase the HRT and reduce the dilution of manure.

The Deenbandhu digester is normally fed with substate diluted 1:1 with water. Consequently the volume of the reactor is twice the volume needed if only substrate is fed. The Deenbandhu digester can be modified to operate on only substrate, solid state operation. Solid state refers to the feeding of the substrate without diluting it with water. A smaller volume with the same gas production is then possible, and moreover, the storage requirement of the digestate is reduced accordingly. Solid state operation of the Deenbandhu digester is examined by Singh and Anand (1994). They showed that with some minor modifications a digester can be adjusted to solid state performance without increasing the cost of the digester (Shyam 2001). Fresh undiluted pig manure can be fed without problems, however, for cow manure some water might still be necessary (Singh and Anand 1994). A total solid concentration (TS) should be less than 18% before fed to a solid state digester. A rule of the thumb to determine if TS is smaller than 18%

is to make a round ball of manure of 12,5 cm, and if the ball does not retain its sperical shape no water needs to be added (Shyam 2001).

Technical design of the proposed digester

Our design will be based on the Deenbandhu digester. As described in Chapter 2, a lower temperature results in a longer HRT to obtain a similair methane yield. Therefore the digester volume needs to be increased proportinally. To achieve this, a reference digester operating in India operating at 25 degrees is adapted, to account for a lower ambient temperature and changed to a (semi) solid state operation to avoid an enormous increase of reactor volume. Semi solid state refers to the fact that the manure is not fed completely undiluted, but mixed with some water to avoid clogging of the inlet. In the case of pig manure, no additional water is necessary (Shyam 2001).

Digester design (Sing and Sooch, 2004) and of the proposed digester for solid state operation at 25 degrees (this report)

- Deenbandhu digester operating in Punjab India
- Reactor type: Semi CSTR
- Mean temperature 25 degrees
- HRT: 40 days
- Manure is diluted 1:1 with water
- 2 m^3 volume
- Feedstock: 25 kilo cow manure per day
- Biogas production 40 liter per kg manure,
- Daily biogas production of 1 m^3
- Feeding frequency: daily 1 or 2 times.
- Source: (Singh and Sooch 2004)

We have used formula 1 of appendix 1to determine the effects of a lower temperature on the loading rate and the HRT. The next figure, figure 4, shows the relationship between temperature and the volume to obtain the same methane yield. In addition the reference digester is shown but operating at semi solid state and of another digester, the Janata digester.

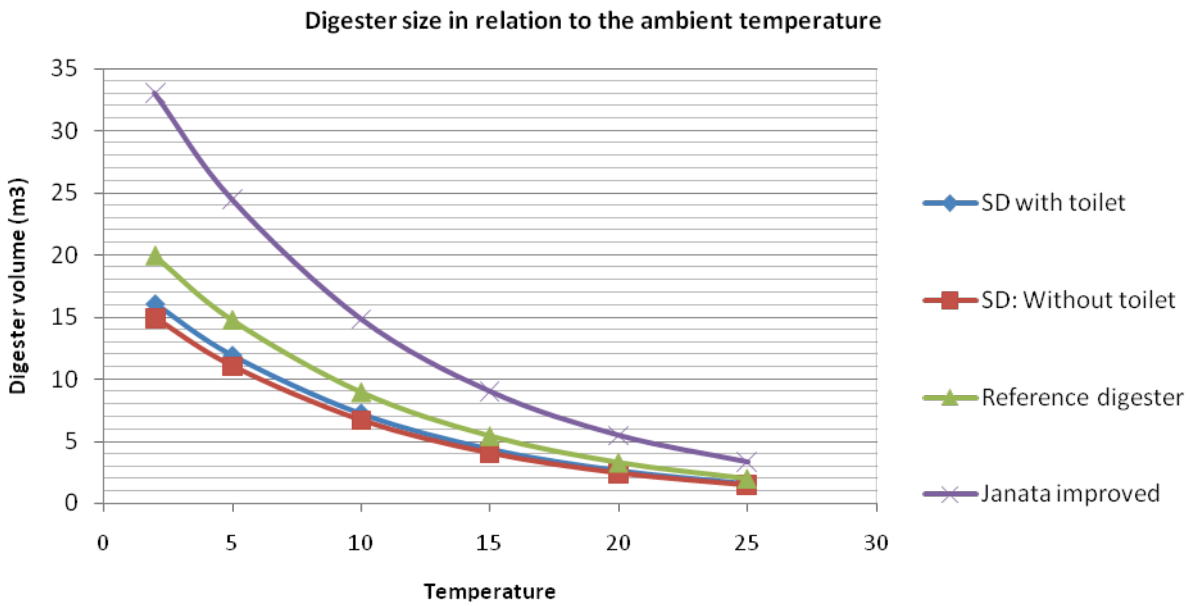


Figure 7: Calculated reactor volume for different temperatures to achieve the 1 m3 biogas per day compared to achieved during manure digestion at 25 degees and an HRT of 40 days.

In figure 4 is the volume of the reference digester related to the temperature using equation 1, see Appendix 2. The figure shows an increase in volume at lower temperatures to obtain a similar yield for different digesters. That trend (gas production versus temperature) is also found by Zeeman (Zeeman, 1991). In practice, at 0 degrees there is hardly no methanogenic activity, resulting in an infinite reactor volume to obtain sufficient gas. Therefore all calculations start from 2 degrees, the predictive values of formula 1 is considered of limited values beneath the 2-3 degrees.

The SD digester with toilet and the other without toilet are elaborated in the next section. The reference digester is the one described above and the Janata improved is the predecessor of the Deenbandhu digester.

The Janata which has a HRT of 55 days in reference situation (25 degrees, volume is 2m3) has the largest volume at lower temperatures. These values are close to the values observed by Daxiong, (Daxiong, et al. 1990), this is not unexpected since the Janata digester is the Indian version of the Chinese dome digester. Furthermore, the proposed digesters are beneath the line of the reference digester. This is the result of the semi solid state operation, compared to the 1:1 dilution of manure of the reference digester. The effective feeding rate is the same (same amount of VS), but since the manure is less diluted a smaller volume suffices.

3.3 Suggested digester design

Next a digester design is proposed which is adapted to operate at a colder climate and semi solid state. First one without an attached toilet and thereafter a model with an attached toilet.

A digester suitable for cold climate operation without toilet

Our design is modified on the following aspects compared to the reference digester:

- Semi solid state (2:1 dilution), to avoid clogging of the inlet
- Critical temperature limit is 5 degrees, lower temperatures result in insufficient gas production
- HRT is increased to obtain 1 m^3 biogas at 5 degrees
- Insulation and a well insulated cover on the inlet and outlet

Results

For a detailed sheet with all the calculations refer to Appendix 3, hereunder the main results from those calculations are shown.

HRT

The hydraulic retention time is 296 days. This is a relative large value. However, literature shows that 100 days or even 180 days are advised in less cold conditions and additionally, the overall gas production are somewhat higher at a very long HRT (GTZ 1999).

Volume

The HRT of our design needs to 7,39 times larger than the reference digester resulting in a total volume of 14,8 m^3. However, since we will suggest to use the digester in semi solid state operation, a decrease of 33% in volume is possible, resulting in 11,1 m^3. The volume of the gasholder has to be around 0,4 to 0,6 m^3 to store sufficient gas for cooking (GTZ 1999), an average of 0,5 m^3 is used. Consequently, the total capacity of the digester is 11,5 m^3. If however, pig manure is the main feed, the volume could be around 33% reduced resulting from the higher methane yield of pig manure (60 liters instead of 40 liters per kg). That volume could be even smaller if pig manure is being fed without water.

Biogas production

1 m^3 of biogas is produced during each day when the temperature of digestion is 5 degrees or higher. During more optimal conditions for anaerobic digestion (higher temperatures) also at least 1 m^3 is produced

Slurry storage

During the off grow-season months, slurry can't be applied to the fields. This period is assumed to be 5 months. A storage facility is required for that period, for a 5 months period the facility needs to have a volume of 6,8 m^3.

A digester suitable for cold climate operation with an attached toilet

A toilet can be attached to the digester if necessary. Best practice would be to keep the animals above the digester in a shed to retain as much heat as possible (Zeeman 1988) . A sketch of a Deenbandhu digester with a toilet and a shed from above is shown next:

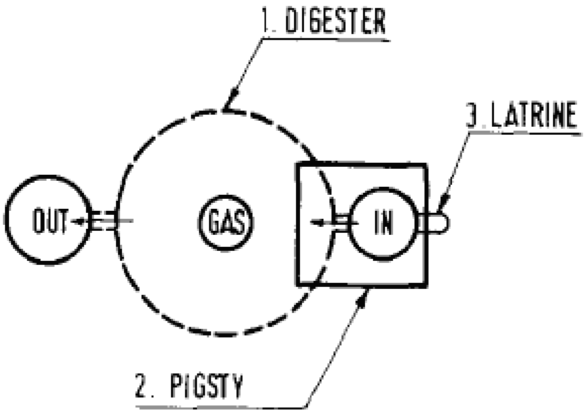


Figure 8: A bird eye view of a 3 in 1 Deenbandhu digester

The pigsty (or any other animal shed) is situated above the inlet of the slurry in the picture. Next to the sty a latrine is attached. In that way, the inlet of the digester is not exposed to the cold ambient air during the winter. The outlet however, is more exposed. It is therefore important to construct a large sty for the inlet and outlet, or to cover and to shield the outlet from direct exposure to the air and wind.

The human excreta, human nigh soil (HNS) which leaves the toilet is fed to the digester directly. On average 2 liters of water is necessary to flush the HNS. Humans produce around 0,4 kg of HNS per day which is flushed with 2 liters of water, consequently the digester is fed with a very diluted waste stream. However, the total amount of HNS per day is far too low for sufficient gas production. Therefore, a considerable additional amount of other substrates (manure) need to be fed.

Reactor design

The principles of the modified Deenbandhu design which we suggestion in the previous section is used. Some modifications are done to accommodate the use of HNS.

- HNS is 0,4 kg per person per day
- HNS of 5 persons is fed and diluted with 2 liters per person per day
- Additional substrate is cow manure
- Dilution of cow manure is minimal as a result of the diluted HNS waste stream.
- Cow manure dilution is 20% (5:1) to avoid clogging of the inlet.

Results

HRT

Similar to the suggested digester without an attached toilet, 296 days.

Volume

The volume necessary for the HNS waste stream (2 kg HNS and 8 kg water) at a HRT of 296 days is 3,5 m^3 and 8,4 m^3 for the manure waste stream. A total volume for both the HNS and manure waste stream is therefore 11,9 m^3. If however, pig manure is the main feed, the volume could be around 33% smaller resulting from the higher methane yield of pig manure (60 liters instead of 40 liters per kg)

Biogas production

1 m^3 of biogas is produced during each day when the temperature of digestion is 5 degrees or higher. During more optimal conditions for anaerobic digestion, higher temperatures, still around 1 m^3 is produced

Slurry storage

During the off-grow season months, slurry can't be applied to the fields. This period is assumed to be 5 months. A storage facility is required for that period, for a 5 months period the facility needs to have a volume of 4,6 m^3.

3.4 Application of the suggested digesters to the targeted countries

To apply these results to the targeted countries the following the following assumptions have been made:

- The temperature of digestion is with appropriate insulation 2-3 degrees higher than the soil temperature, in line with GTZ (1999).
- The digester is positioned 20 cm beneath the ground level
- Both inlet and outlet are well insulated and protected from contact with wind and direct exposure with the ambient temperature.
- Appendix 5 shows that even in wintertime with a mean temperature far below zero, the soil does not freeze below 20 centimeters. However, we assume that when the ambient temperature falls below -5 degrees, the temperature of digestion falls below 5 degrees as a result of the heat losses of the inlet and outlet and of the heat flux to the soil.
- Manure is added freshly at a temperature of at least 5 degrees

The next table shows if year-round gas production is possible in the target countries based on our assumptions. Note, that the temperatures of each countries are based on the table in appendix 1, the actual temperatures can be very different.

Table 2: Target countries and gas production

Country	Months beneath -5 °C	Months with sufficient biogas
Romania	0	12
Kazakhstan	**5**	7
Armenia	**2**	10
Kirghizstan	0	12
Georgia	0	12

Table 2 shows that Kazakhstan has only for 7 months gas and Armenia only for 10 months. The other countries have sufficient gas to meet their demands for year-round.

Conclusion: Semi solid state digester

Based on our findings we suggest a digester operating semi solid state, with a HRT of 296 days and with a volume of around 11-12 m3 depending on the use of HNS. However, in practice these values could turn out to be quite different. Firstly, all the calculations are based on a digester operating at tropical conditions and secondly the relation between the temperature of digestion and the ambient temperature might be different. Thirdly, temperatures differ considerably within countries, therefore table 2 is limited in its prediction value.

A pilot digester can answer many questions and will reveal the correctness of our assumptions. We suggest a pilot digester based on our suggestions to be constructed in one of the targeted countries.

4. Community based biogas plants

4.1 Background on community based plants:

Publications on community based biogas plants suggest the need for good technical organization from the same community who are responsible for the day to day affairs of the issues surrounding the maintenance and upkeep of the plant. Maniates, (1985) argues from an Indian background where community biogas facilities have not fulfilled their potential. According to him “problems lie in (the) village social organization and politics, and solutions will not be found until rural-based biogas technology is viewed as a technical addition to a broader political and social response to rural poverty” (Maniates, 1985)

It is therefore a necessity beforehand to put into place a well arranged community chosen authority that will address squabbles and communicate with one voice for the rest of the community. Power games are inevitable as a certain cliché can attempt to assert power over the rest. Maniates (1985) points out that “in most regions family sized plants are in the hands of the rural elite.”

Arafa (1986) provides similar arguments from an Egyptian community perspective. The success of a community based plant relies on “an appropriate mixture of mutually supporting technical, economic, institutional and developmental approaches…” (Arafa, 1986)

In the Egyptian village of Basaisa “a community- based organization (Community Cooperative for Development) was developed at Basaisa to manage and co-ordinate the different activities at the village level and to disseminate the knowledge and experience gained to other villages in the area” (Arafa, 1986).There is no doubt that a similar type of organizational structure/s will be needed for the target communities of (WECF).

4.2 Lessons from elsewhere:

While admitting that the scale or size of the Danish community biogas plants is larger that what we can anticipate for the Kazakhstan or Romanian situations, there are some lessons we can draw from the inception phase of the Danish programs. According to an article by Raven and Gregersen, (2006) “in 2002, (in Denmark) there were 20 centralized biogas plants (also known as community plants) and over 35 farm scale plants in operation, together producing about 2.6 PJ renewable energy and processing about 3% of all manure in Denmark”

The article aims to provide lessons and give insight in how a bottom-up approach stimulated a broad learning process and the formation of a rich social network. This is certainly one of the important elements that can lead to the success or failure of a community based biogas plant. The right approach, preferably a Multi stakeholder one, can influence the acceptance or rejection of a biogas project.

Raven and Gregersen, (2006) state that a “centralized plant might benefit from improved technology and economies of scale, while it discharged individual farmers from the operation of the plant”

The basic idea of this type of plant "is a centrally placed biogas plant, to which a number of farmers supply manure." (Raven and Gregersen, 2006)

Below is a diagrammatic representation of the logistical setup we are suggesting for the community biogas plants:

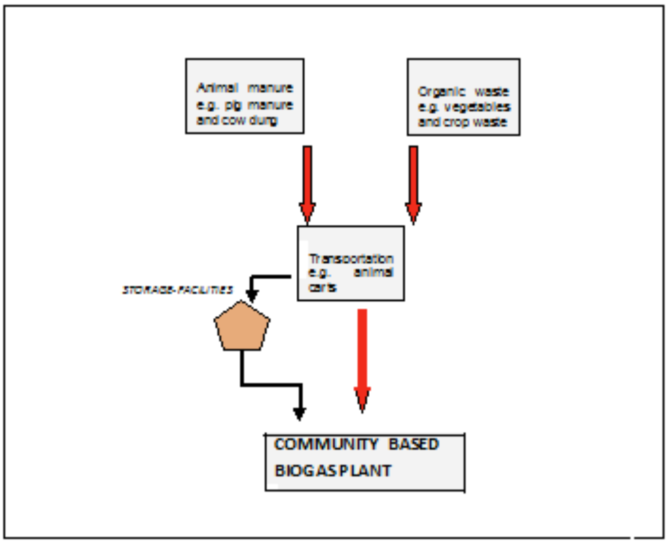


Figure 9: Diagrammatic illustration of the community based biogas plant. Much logistical work has to be done to provide a conducive environment for the project.

According to the set up in Fig 1, the community responsible for the use and maintenance of a particular biogas plant are to organize themselves and elect members to be responsible for the running of the plant. Simple transport such as an animal drawn cart can be used to ferry substrate such as dung and other household waste to a common storage site convenient to the community and as close as possible to the common biogas plant. This is already the set up currently used in Kazakhstan by households to dispose of their waste materials. A common area is used by villagers to dump their waste in one spot. All that is needed is to then construct a common structure to hold this waste in an adequate manner. Raven and Gregersen, (2006)

The community plant will need to have a good compressor that can be used to allocate the community members their share of the synthesized gas. They will each need a good storage tank (pressurized and portable) to bring from their homes to get their share if the gas. As mentioned earlier a good logistical plan by the responsible community members themselves will be needed.

4.3 School based biogas plants:

The idea of a school based biogas plants is on almost similar design criteria for a community based one. SRE (2002) highlight a case study of a system at Zakaria Education Institute under Senhati Union in Dighalia Upazila, Khulna District.

According to SRE (2002) the institute was established in 1965 and currently 388 students are studying in this institute of which 267 students are residential. The institute has inadequate sanitation and has taken advantage of this by starting a community based biogas plant using human waste. The report states that about 400 people, students and teaching staff together will be encouraged to use 3 public latrines and this is anticipated to bring a big sense of hygiene, sanitation and also increase the quantity of biomass that can be available to produce gas for cooking.

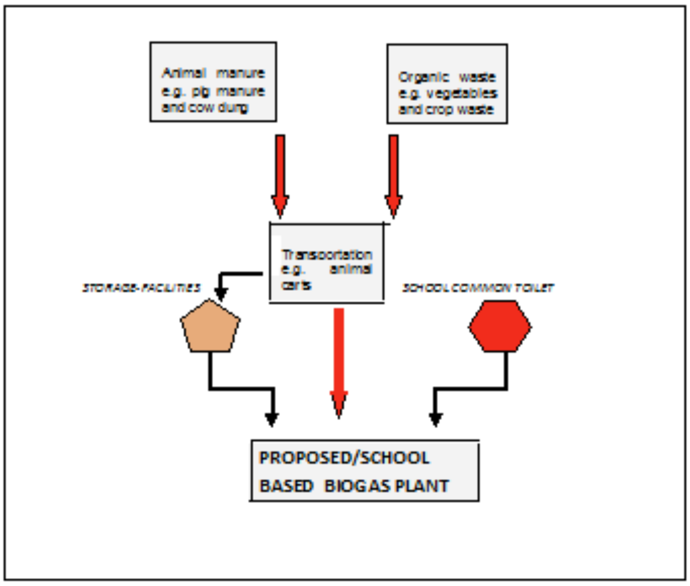


Figure 10: **The concept of the school based community biogas plant. The common toilet offers an opportunity to increase the substrate available for use.**

The major difference with the logistical setup for the community plant and the school based plant is that the school based plant can make use of a common toilet that will contribute to the overall substrate in the plant dome through human night soil (excreta). The same logistical plans can be made where a member from the community can be responsible for the day to day issues of the plant and use of an animal drawn cart or small truck can be done in order to ferry other substrate from sources such as school agricultural fields.

The use of the biogas at the school level is not quite clear but possible heating of classrooms has been suggested as well as possible heating of food for the school cafeteria.

Set backs:

It is imperative to mention that the task of producing biogas in cold climates is a huge one that is not all that easy to achieve, even if one is to attempt this at large community basis. Proper coordination needs to be put into place for a good system to operate. China, for instance, has an approximate 25 million Chinese people using a biogas digester with a capacity of 8-10 m^3 (cubic meters) which can produce 250-300 m^3 biogas each year in southern areas and 150-200 m^3 in China's colder northern provinces. This supplies peasants with cooking fuel for eight to 10 months a year. (Daxiong, 1990)

To achieve high output at low temperatures is quite a huge task that needs other auxillary conditions to be in place such as a well insulated plant and this factor may increase the average cost of installing the plant.

4.4 Potential Plants for Community level:

Our team is limited by lack of enough ground data of the study areas for which we are recommending the biogas projects. This inevitably reduces our capacity to offer more full proof and proven suggestions. However we are going to offer some ideas and hope that they can possibly be implemented later on by WECF.

Suggestions of plants to use:

1. **The solar heated biogas plant:**

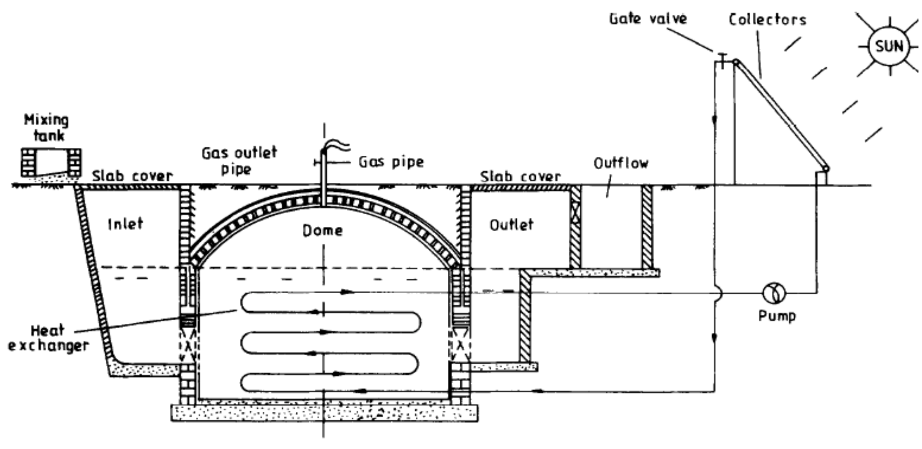


Figure 11: concept of a solar heated digester ***(source:*** **(Tiwari et al, 1992)**

Solar heating is only possible when the net incoming heat flux contributes to the rate of reaction in the digester, which only happens when the sun shines. The most critical obstacle which biogas plants need to overcome in the targeted countries is the low temperatures in wintertime. Passive solar heating will only contribute if there is sufficient solar irradiation during wintertime. However, in some locations it might contribute, but a more detailed study is necessary to determine its potential. In summary, solar heating will only contribute if sunshine is abundant during wintertime.

Advantages:

- If enough sunlight is available it can contribute immensely to the overall digester reaction temperature thus increasing reactor performance and/or reduce the reactor volume.
- The cost of construction and operation is spread over a community hence reducing the cost per individual person as compared to using the plant on household level.

Disadvantage:

- Solar heating is only possible when the sun shines which is not always possible for the target areas we are proposing the technology for.
- Snowfall and low temperatures during the night might freeze the heat transfer liquid in the solar collector.
- There's need for added capital investment for the successful implementation of the project.

Having said all these advantages and disadvantages, the most significant fact which can be noted is that if reactors are to be developed that can contribute some biogas during the cold times of the year, external heating of the plants may have to be considered. It might be a necessary extra cost on the overall investment cost of the plant. More detailed calculations need to be made in the future on the potential temperature increase of the reactor content for different regions. Similar calculations have been made for application of thermophilic manure digestion in Egypt. (El Mashad, 2000)

2. The underground inoculum circulating plant:

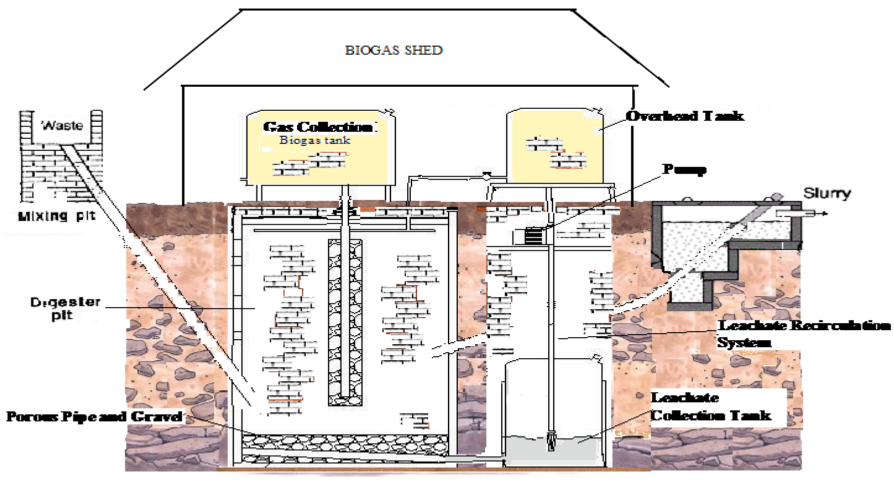


Figure 12: An inoculum circulating biogas system that uses a small pump to re-circulate inoculum back into the reactor. ***(Adapted from Balasubramaniyam, 2005)***

This is based on a concept of inoculum heating and re-circulation. It will need further testing by WECF *(possibly a small pilot plant)* before full scale adaptation. This is adapted from a research project that was implemented in Sri Lanka. *(Balasubramaniyam, 2005)*

The plant must be placed below the ground level to help insulate the plant temperatures. A heating system is used which utilizes heating coils heated up using part of the gas produced from the digestion process. This heating coil system can be placed in the overhead tank *(See Fig above)* to help maintain the temperature at (say) approximately 20-25°C. A depth of ***3 m*** is acceptable for this design. The concept behind the design itself is a biogas plant capable of re-circulating the inoculum and leachate in such a manner as to create a simple stirring mechanism to keep the gas production process high in the digester. This design should allow the leachate to be heated up in the overhead tank as it comes up to the surface by pump *(up to temperatures of at least 20-25°C)* and this should help keep reaction high during the colder times. ***Heating will only be done intermittently and, if done efficiently enough, will only cost a small fraction of the gas produced from the system.***

MATERIAL REQUIREMENTS:

The inoculum circulating plant requires bricks, good insulation materials *(e.g. use of double walling and possible investigation into use of cement with a low alkali content, alkali-resistant glass fiber reinforcements and complex and high molecular coatings),* non corrosive piping material, a compressor *(for gas storage and distribution under pressure), gas*-heated coils *(for heating up the leachate in the overhead tank)* and small pump of the magnitude of 1-3 Hp as well as simple construction structures to house the plant itself.

NB. These recommendations are open to more modifications. More empirical research is still needed to validate the potential of such a system in cold climate areas.

Advantages:

- The design makes use of produced gas to heat up the inoculum pumped up from the ground to assist in keeping reactor temperatures high during the cold period. This might help make production of gas viable during the extreme periods.
- The cost of construction and operation is spread over a community hence reducing the cost per individual person as would be expected in using the plant on household level. This might help make the concept affordable on a community level.
- If temperatures can be sufficiently kept high *(e.g. around 20-25 °C)* this can assist to maintain winter time production of methane sensible and viable for the community's requirements.

Disadvantages:

- Pilot scale development of this plant is needed as it is a relatively new concept for community level plants in poor communities.
- Inadequate data is currently available on this plant to recommend it for a full scale project. ***It is not recommended especially if WECF has no funds for further research work in its potential use.***
- The design itself appears vulnerable to blockages and technical problems which will make it necessary to have on-site maintenance personnel available.
- By its nature of design and the extra requirement for underground placement the design will require strict and well coordinated operation which will vet the type of substrate to be used in the plant. For example to avoid blockages, it may be necessary to avoid solid plant waste in the plant and to utilize diluted-type of substrate e.g. pig manure.
- If the heating mechanism is not operated efficiently enough the cost of heating the system will draw on too much of the produced gas creating uneconomical operating conditions.

3. Other possibilities for community plants:

In Chapter 2 we have documented a series of other biogas plants that can be used. The ones that stand out as possible options for use on a community level are as follows:

- Floating drum digester *(See Chapter 2)*
- Fixed dome plant *(See Fig below)*

The concept behind these designs has been analysed in Chapter 2 and these plants appear as feasible for pilot plant analysis to ascertain potential usability in cold climates on a community level.

The major concept that stands out is to place the plant underground so as to insulate for the extreme temperatures. As stated before, more pilot studies are needed before implementation on a large scale.

4.5 Suggestions to (WECF) projects on community level:

The concept of heating up a plant by use of either gas produced from the reactor or using solar energy is a relatively new one and if WECF is to take it up it will need some experimental plants to work with before they can operate this on a large scale. Because of this limitation the recommendation for their current project will come from the tried and tested plants. For this reason we propose the fixed dome plant for the community based plants. It is necessary at this point to state that winter time production in the absence of heating is extremely difficult and almost certainly uneconomical. For this reason it may be an important consideration to overlook winter time production. It is still advisable overall for WECF to run some pilot scale plants first and foremost for the suggestions that we have given.

The Fixed Dome Plant:

(*See Fig below)*

The fixed dome digester is relatively inexpensive. It is simple, has no moving parts and has therefore a long lifespan, up to 20 years. The plant is suitable for cold climates because the most part is beneath the ground level. Therefore the plant is protected against low temperatures occurring during night and in cold seasons. The temperature within the digester is lower during daytime and higher during nighttime. This is beneficial for the methanogenic bacteria and subsequently for the biogas production. GTZ, (2000)

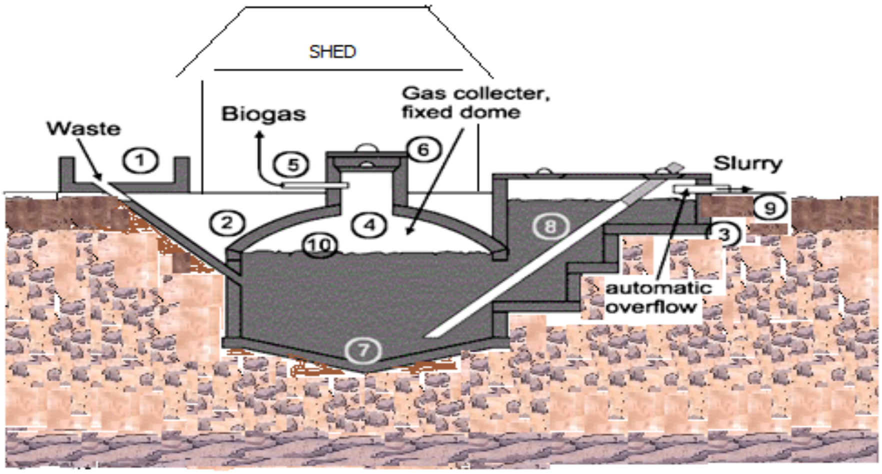


Figure 13: Fixed dome plant recommended for the community based plants for WECF projects. Source GTZ, 2000)

The main advantages are as follows:

- Relatively cheap and durable
- Construction is labor intensive (local employment opportunities)
- No moving parts
- Well insulated

Disadvantages:

- High technical skills are required for a gas tight construction
- Special sealant is required for the gasholder
- Gas leaks occur when not designed well
- Difficult to construct in bedrock
- Enormous structural strength required for construction (Sharma et al, 1991)

Results for Fixed dome plant on a community level:

The following results are based on the Annex calculations and also based on the calculations done for the household level plants:

To obtain a daily yield of 1 m3 biogas at 5 degrees ambient temperature the HRT needs to be 296 days and the volume 11.9 m3 with a daily feeding of 2 kg HNS with 10 liters of flush water and 23.6 kg of cow manure. With a gas holder of 0.5 m3, the total gross volume is 12.4 m3. To store the effluent during the non-growing season of 5 months, a storage facility of 7.4 m3 is required.

Size and shape of plant:

Our proposed biogas plant is cylindrical in shape. Based on this we can propose a typical dome shaped community plant of around 21 m^3 with a floor dimension of around 3m diameter and 3m height. We expect that below 1 metre of depth there's nearly an increase in soil temperature of around 10^{o}C *(see Appendix 4)*

We assume that each household owns at least two cows.
Given that 1 cow produces (approx) 10kg dung and 1 kg dung = 0.04m3/day gas *(Nagamani & Ramasamy, no date)*

We have estimated that normally 1 m3 of biogas is enough to cook three meals for a family of 5-6 members (Practical Action Org., (2006).

At the end of the day a well operated plant can have a target output of ***13.3 m³ /day*** i.e.

We approximate that a 21 m^3 plant should be adequate for 13 families i.e. at the approximated requirement of 1 m^3 per household.

HRT = *approx*. 296 days or less.
Volume of plant = 21 m3
No. of cows per household = 2
Output dung per household = *approx*. 10 kg
Daily feeding = 2 kg HNS with 10 litres of flush water.
Size of winter Storage facility = 21-30 m3

From this simple estimation we can propose that the bigger the number the number of households, then the bigger their biogas plant should be.

5.Costs-Benefits Analysis

5.1 Introduction

During this chapter we will discuss the criteria for a good economical analysis in the biogas plants implementation. Despite what one could think, an economical analysis does not deal only with the mere cost calculation, but keeps in account several aspects. The recent literature suggests to approach the economical feasibility of a project by evaluating not only the costs it can generate, but also the benefits. Since the benefits generated by a biogas plant are not represented just by direct monetary flows, it could result hard to understand the extent of these benefits. For this reason we should find how to express this benefits extent in a monetary way. The same could be done with the non-monetary costs. Once we do it everything will become more understandable and easier to compare. But how can we transform a benefit such as the reduction of deforestation in money? It is a complicated procedure but in the following paragraph we will give the key concepts for understanding this analysis.
"In general, the monetary benefits from biogas plants for enterprises and institutions as well as from plants for well-to do households should be quite reliably calculable. These groups normally purchase commercial fuels e.g. oil, gas and coal as well as mineral fertilizers. In industrialized countries, it is common practice to feed surplus electric energy, produced by biogas-driven generators, in the grid. Biogas slurry is a marketable product and the infrastructure allows it's transport at reasonable cost. Furthermore, treatment of waste and waste water is strictly regulated by law, causing communes, companies and farmers expenses which, if reduced with the help of biogas technology, are directly calculable benefits.
In contrast, small farmers in developing countries collect and use mostly traditional fuels and fertilizers like wood, harvest residues and cow dung. No direct monetary savings can be attributed to the use of biogas and bio-fertilizer. The monetary value of biogas has to be calculated through the time saved for collecting fuel, the monetary value for bio-fertilizer through the expected increase in crop yields, health and environmental benefits from these practices.
Both in theory and in practice, this is problematic. In practice, a farmer would not value time for fuel collection very highly as it is often done by children or by somebody with low or no opportunity costs for his/her labor. In theory, it is difficult to define the value of unskilled labor.
Similarly, the improved fertilizing value of biogas slurry will not be accepted by most farmers as a basis for cost-benefit analysis. They tend to judge the quality of slurry when counting the bags after harvest." (GTZ,1999) moreover in areas where dung or fuelwood are plentiful, these farmers feel the biogas less valuable as a fuel. Where normally "free goods" are monetized, both the benefits (gas and slurry) and the costs (dung and possibly water) are valued higher.
However, most economic analyses of biogas systems suffer from additional shortcomings:
1. They tend to underestimate the benefits of using slurry effluent by valuing it in terms of commercial chemical fertilizer, based on the nutrient content of the slurry. This method assumes that slurry is either substituted for chemical fertilizer or could be sold for a price equivalent to the economic value of its nutrient content. While in some settings this substitution effect may occur, poor farmers can rarely purchase chemical fertilizer and there is no way economically to trade biogas slurry. A more useful way to value the slurry is to observe the net increase (if any) in local agricultural output, and value this surplus net of any additional handling costs when compared with current manuring practice.

2.Although sun-drying of all manures reduces their nutrient content, biogas slurry still contains more nutrients than either dried dung or composted wastes on an equivalent weight basis. Tests conducted by the US Department of Agriculture showed that over several seasons, there is little difference between the fertilizer impact of digested slurry and compost.
However, the slurry releases its nutrients more readily, and hence a more immediate crop response should be more valuable to a farmer. (Lichtman, 1987)
Because a monetary calculation is not the only factor featuring in the decision to construct and operate a biogas plant, other factors come in which are less tangible: convenience, comfort, status, security of supply and others that could be subsumed under 'life quality'." (GTZ)
In our analysis we will use the framework suggested by Bi and Haight in the their study conducted in the Hainan province (China). We will give more details about the building costs of a biogas plant in rural areas, hence our analysis framework will be as follow:

- Building costs
- Energy-related benefits
- Fertilizer related benefits
- Economic-related benefits
- Health-related costs/benefits
- Environmental-related benefits (Bi, 2007)

5.2 Building costs

The first step of this analysis consists in the calculation of the labor and material costs for the constructions of a bio-digesters. In order to give an idea about the extent of these costs, we will show the calculations based on the conclusion presented in the previous chapters. Because of the innovative design of the community base biogas plant suggested in chapters 5 and 4 we are not able to give reliable data, therefore we prefer to focus on the household based plants.

The table below shows the costs of each of the factors necessary to build an household base biogas plant.

Table 3 Material requirement and breakdown Costs of a 10m3 Biogas plant (Fixed Dome)

Description	**Unity**	**Price**	**Qty**
A. Construction Materials	-	-	-
- Cement	-	-	-
Plains	Bag	5.320	27
Hills	Bag	5.880	30
- Bricks of stones	Piece	4	2400
- Sand	Bag	1,35	110
- Gravel/Aggregates	Bas	600	60
B. Biogas Appliances	-	3,625	-
C. Pipe and Pipe Fittings	-	1.071	-
D. Reinforcement Steel	Kg	390	17
E. Labour (unskilled)	MD	2.100	45
F. Construction and One Year	-	4,1	-
G. 5 Year Guarantee Charge for the Plant	-	1	-
H. Participation Fee	-	500	-
TOTAL Plains	-	**24,056**	-
TOTAL Hills	-	**24,616**	-

Source : GGC, 1996 US $ 1.00 = NRs 56.00

A further graphical elaboration of these data shows the cost incidence of each item on the total budget.

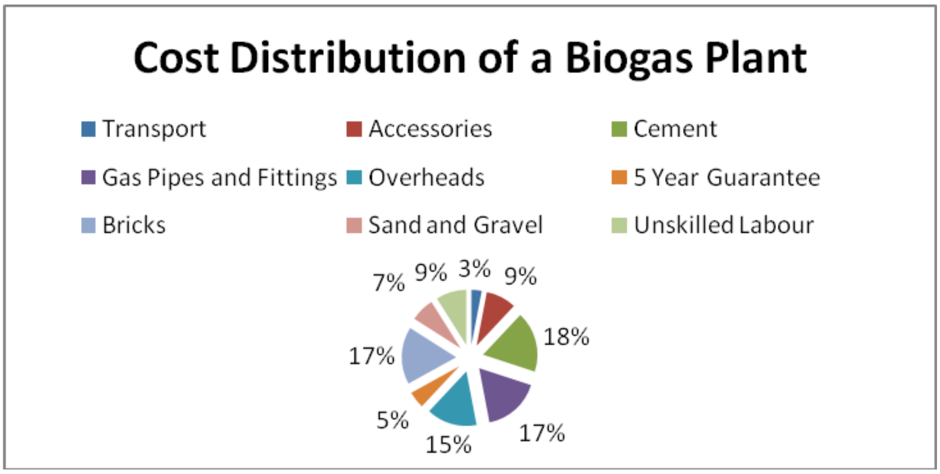


Figure 14 Cost Distribution of a Biogas Plant
Source: elaboration from GGC.

By now it should be clear that most of the expenditure is due to the capital investment (the cost of the row materials for the construction) and to the work used in the plants constructions.

Converting the total costs from Nepalese Rupee to US Dollars it results an expenditure of 384 USD or 263 € for each 10m3 plant. Other recent experiences, such the Chinese (in the Hainan province), show similar total costs. In the aforementioned case the average total cost is less than 400 USD for each plant of 8 m3. All the mentioned experiences have been developed in warm areas, therefore the plants design was easier since here they did not have any problems due to the temperatures. In the areas we are studying the plants design will be more complex since we have to keep in account other components such as the isolation system and probably higher labour costs. Because of a lack of information about the actual prices of construction materials and the labour costs we can not give a definitive cost of the plants in the studied areas. A further distortion element is the variance of these process among the different countries. However, keeping the isolation system in account, the material costs and the labour costs for the aforementioned system, our expenditure estimation is likely to be around 700 €.

5.3 Energy-related costs/benefits

In rural areas, the advantage of biogas can be seen especially from the replacement of an inefficient but traditional fuel with a more efficient and flexible one (Kaale, 1990). Anaerobic digestion technology can help rural people meet their fuel needs by the reliable energy secure means in developing rural areas (Akinbami, 2001). The main problem in the economic evaluation is to allocate a suitable monetary value to the non-commercial fuels which have so far no market prices. For the majority of rural households, biogas could be the main source of energy for daily cooking and lighting in the form of firewood, dried cow dung and harvested residues. But even if the particular household does not purchase the traditional fuel, its value can be calculated from the fuel prices on the local market. Theoretically, the firewood collector of the family could sell the amount no longer needed in the household.

As an example, the rural households in India use the following quantities of non-commercial fuel per capita daily:

- firewood: 0.62 kg

- dried cow dung: 0.34 kg

- harvest residues: 0.20 kg

The benefit flow obtained within the Indian biogas program in terms of kerosene saved has been estimated around 474 Indian Rupees for an hypothetical family scale digester of 2 m3 gas/day gas output and 5678 Indian Rupees for a village system of 42.5 m3 gas/day (Values are in 1980 Indian Rupees at Rs 7.90= $1.00). In the latter case the literature shows an annual benefit flow due to firewood saved equal to 240 Indian Rupees. (Litchman 1983, Chap. 6)

For rural households in the People's Republic of China the daily consumption of firewood is similar: between 0.55 - 0.83 kg per person.

Which sources of energy have been used so far and to what extent they can be replaced must be determined for the economic evaluation of biogas by means of calorific value relations. The monetary benefits of biogas depend mainly on how far commercial fuels can be replaced and their respective price on the market.

1 m3 Biogas (approx. 6 kWh/m3) is equivalent to:

· Diesel, Kerosene (approx. 12 kWh/kg) 0.5 kg
· Wood (approx. 4.5 kWh/kg) 1.3 kg
· Cow dung (approx. 5 kWh/kg dry matter) 1.2 kg
· Plant residues (approx. 4.5 kWh/kg d.m.) 1.3 kg
· Hard coal (approx. 8.5 kWh/kg) 0.7 kg
· City gas (approx. 5.3 kWh/m3) 1.1 m3
· Propane (approx. 25 kWh/m3) 0.24 m3

In Meiwan Xincun Village in Hainan province (China) a 6 m3 anaerobic digester has an annual net energy output of 3.5 million kcal .(Bi, 2007)

In this village the anaerobic digestion practice has eradicated the villagers' reliance on fuel-wood which was obtained mainly by deforestation. The importance of the forest resource to the local environment was generally accepted by most residents. Some residents even noted that they benefited from the practice in terms of the time saved from daily collection of fuel-wood, animal waste and crop residues. However, it could not be ignored that all respondents had planned to continue relying on fuel-wood to meet their energy needs if they had not adopted anaerobic digesters. One governmental official explained the situation by referring to the direct correlation between poverty and resource exploitation in developing rural areas. This relationship suggests that the attempt to prevent deforestation through education or regulation will not be effective until the energy security problem is resolved first. (Bi, 2007)
The Nepalese experience shows that one 6 m3 biogas plant can replace the use of 3 tons of fuel-wood or 38 liters of kerosene annually. It is also calculated that it produces 27 tons of

digested slurry and reduces 4.2 tons of carbon dioxide equivalent per year. This shows the savings of 11.6 trees annually, i.e., 0.055 ha of forest (2002).
It has been estimated that, because of the Nepalese biogas program, the operational biogas plants have reduced dependence on fuelwood by 80% and on kerosene by 60%. (Pokharel, 1990)
This would result in a net reduction of approximately 300 thousands tons of carbon dioxide equivalent annually. This will help savings of about 25 thousands tons of carbon dioxide equivalent per year.(Shakya, 2002).
These numbers are probably too optimistic in the case of country with long cold winter since during the winter period it is not possible to produce as much as in the countries aforementioned. This is something we should keep into account during our analysis.
However the biogas plant described in Chapter 2 is able to provide the household enough biogas to replace the use of kerosene for cooking. Since in Romania the households monthly kerosene consumption is around 1.5 gas bottle, and each gas bottle costs around 12.5 € we can assume savings on kerosene consumption equal to 150€.
This saving has be considered as a positive monetary flow deriving from the saving in kerosene consumption from cooking.

5.4 Fertilizer-related benefits

If and to which extent biogas slurry can be monetized as benefit, depends largely on the previous use of the substrate to be digested. The more wasteful the current method of using farmyard manure is, the easier it is to monetized benefits. In most traditional systems, for example, the urine of livestock is not collected as manure. Often, the dung and fodder residues are heaped in the open, leading to heavy losses of minerals through sun radiation and wash-out by rain. (gdz).
The digestion slurry and solids contain 30–50% organic matters, 10–20% humus, 75.8 mg/l of nitrogen, 2.0 mg/l of phosphorus, 66.6 mg/l of potassium, and various microelements (Ka, 2000) making the 'wastes' of anaerobic digestion a good source of natural fertilizer. Agricultural yields have the potential to increase by 6–20% (Marchaim, 1992). Some 98% of the respondents in Xincun Village in Hainan province (China) reported that they have reduced using chemical fertilizers in their agricultural practices under the guidance of experts from Danzhou Biogas Station. This reduction did not often result in diminished agricultural yields. Although increases where not always reported by, some residents did acknowledge the positive benefits of the digested slurry in terms of supplying plant nutrients, improving soil aggregation, increasing water-holding capacity of the soil, stabilizing the humid content and prevention from leaching of nutrients. Results of recent experiments carried out by Danzhou Biogas Station in 2000 affirm that there are significant increases of organic matters in the soil as well as the yields of main agricultural products (natural rubber, rice and vegetables) of the village as a result of applying digestion slurry in agriculture.(Bi, 2007)
The application of slurry from biogas plants and its impact on agricultural production both on cereal and vegetable is hard to quantify. However, it has been estimated that about 10 to 15 agricultural productions could be increased with proper compost application of the slurry in the field. It also helps in improving the texture and the structure of soil condition.(Shakya, 2002).
Increases in agricultural production as a result of the use of bio-fertilizer of 6 - 10 % and in some cases of up to 20 % have been reported. Although improved yields through biogas slurry are difficult to capture in a stringent economic calculation, for demonstration and farmer-to-farmer extension they are very effective. Farmers should be encouraged to record harvests on their plots, before and after the introduction of biogas. Statements of farmers like: "Since I use

biogas slurry, I can harvest two bags of maize more on this plot" may not convince economists, but they are well understood by farmers. (gtz)
The Romanian average wheat production per hectare is 2.5 tons/ha (Ionescu (Bigioi)) and the wheat average price is around 150 $ per ton (102 € per ton).(Hubbard, 2000)
If we use hypothesize an increase of 10% in the average production it means an increase of 0.16 tons of wheat per hectare. Using an average wheat price of 102 € per ton this represent a positive monetary flow of 17 € per hectare per year.
Since the average endowment in land of a Romanian household is around 1 ha we can hypothesize an income increase of 17 €per year.

Table 4 Summary of digestion slurry in agriculture by Danzhou biogas station.

Subject	Result	Comparison
Effects on soil quality	Condition 1: Applying digestion slurry to 1 hectare farmland around 2,000 kg/year for three consecutive years.	The contents of organic matter in the soil after using digestion slurry increased about 30%
	Condition 2: Using chemical fertilizers only without digestion slurry .	The density, rift, temperature and water-holding capacity of the soil after using digestion slurry improved.
Effects on natural rubber yield	Condition 1: Applying 1,500 kg digestion slurry, 15 kg carbamide and 30 kg compound chemical fertilizers to one fifteenth hectare of rubber farm land.	The yield of dry natural rubber was 94.8 kg in condition 1—a 17% increase compared to condition 2
	Condition 2: Applying 50 kg carbamide and 100 kg compound chemical fertilizers in one fifteenth hectare of rubber farm land	A net income increase per hectare of 135 RMB Yuan in condition 1 as a result of increased yield of natural rubber and reduced costs for chemical fertilizers
Effects on rice yield	Condition 1: Applying 900 kg digestion slurry, carbamide 6 kg to one fifteenth hectare of rice land	The yield of rice in condition 1 was 472.7 kg—a 12% increase compared to condition 2
	Condition 2: Applying 26 kg carbamide and 25 kg phosphorus fertilizer to one fifteenth hectare of rice land	Comparing more labour in condition 1 against more costs for chemical fertilizers in condition 2, condition 1 saved 10.5 RMB Yuan
		A net income increase per hectare of 13.6% in condition 1 as an effect of increased yield of rice and reduced costs of chemical fertilizers
Effects on vegetable yield	Condition 1: Applying digestion slurry with chemical fertilizers	The yields of vegetables in condition 1 were 20% greater than those in condition 2
	Condition 2: Applying chemical fertilizers only	Vegetables in condition 1 have better texture and are more resistant to rotting

Source: Chen, 2000

5.5 Economic-related benefits

Previous experiences, such as the Nepalese Biogas Program, suggest that the primary impact of biogas on poverty alleviation has been to reduce the economic and, in many cases, the financial costs expended on fuel for cooking and lighting. Although most of the adopters of biogas technology have been among the larger and medium-scale farmers, smaller-scale farmers have been increasingly attracted to the program. The policy of a flat rate subsidy favors smaller plant size and smaller-scale farmers more than larger-scale farmers. In addition, the increasingly active involvement of NGO's in the promotion, organization, financing and construction of biogas plants on the basis of self-help, has the added benefit of bringing biogas plants within the reach of smaller farmers with fewer cattle. However, biogas does not benefit those farmers without cattle who generally represent the very poorest strata of society.
Cattle-less, landless and marginal farmers may benefit only indirectly, from increased employment opportunities and greater availability of firewood. (Matthew S. Mendis, 1999)
The Chinese Experience of the Meiwan Xincun Village in Hainan province (China) suggests that in terms of economic benefits there are monetary savings. While most residents affirmed the economic benefits of anaerobic digestion technology in terms of savings of labour input (Table 4) and expenses on energy and chemical fertilizers, the economic viability cannot be ignored (Biswas, 1997). The anaerobic digesters experience indicates that although local residents need to pay for the digester, the economic viability of the technology can be satisfied when appropriate monetary incentives are provided. With an annual investment of about 122 RMB Yuan (11.6 €) (Table 4) and labour input of about 236 man-hours (Table 6), villagers are able to run and maintain an anaerobic digester in their households. In other words, the cost and labour input per cubic meter of biogas are 0.14 RMB Yuan (0.01 €) and 0.27 man-hours.
Initial investment and labour input should not be excuses to refuse anaerobic digesters. On the other hand, financial compensation for digester adopters is strategically important as poverty can be a stumbling block for the introduction and diffusion of small-scale rural technologies. With the economic burden being alleviated by way of governmental initiatives and other support, the diffusion of anaerobic digesters in the village was quite successful and villagers regarded the short-term investment as appropriate.(Bi, 2007)
We have objective difficulties in estimating the monetary flow deriving from the labour hours saved from the implementation of a biogas plant. The literature gives data abut the labour cost in the formal sector, but here we are dealing with workers employed in the informal sector; hence we can not give reliable data about this monetary flow.

Table 5Annual inputs and outputs of a 6 m^3 anaerobic digester in Meiwan Xincun Village (China)

	Quantity	**Kcal(10^3)**
Input		
Human manure	2,700 kga	-
Livestock manure	5,100 kgb	-
Agricultural wastes	600 kgc	-
Man-hours	236 hd	-
Initial investment (digester with 30-y–ear life)	42 RMB Yuane	-
Costs for equipment replacementf	80 RMB Yuan	-
Concreteg	168 kgh	315i
Steel (digester and other equipment with 30-year life)	0.33 kgj	0.69k
Steel truck/tractorl for transportation (10-year life)	10 kg	200k
Petroleum for transportl (10 km radius)	34 l	340m
Total input		856
Total outputn		4,38

Source(Bi, 2007)

a A mature person produces about 600 kg of manure annually (Gansu Agriculture Department [GSAD], 2004). The total amount of human manure processed is estimated by multiplying this number by 4.5 which is the average number of persons
b A pig (40–50 kg) produces 2.0–2.5 kg of organic matter everyday (GSAD, 2004). The average number of pigs in each household is 5. Given the diversity of livestock being raised by each family, the authors conservatively estimate livestock manure processed in a digester at 5,100 kg per year
c Estimated by biogas specialist from Danzhou Biogas Station (Interview, 2003)
d See Table 4
e The average initial costs for an anaerobic digester in MWXCV was 1,258 RMB Yuan. When this amount is divided by 30, the annual initial investment is 42 RMB Yuan
f Including 30 RMB Yuan for the machine and 50 RMB Yuan for the ferric oxide
g Weight ratio of cement/sand/gravel/water is 1:1.9:4.9:0.6
h Concrete needed to built a 6 m3 digester is about 5040 kg (Chen, 2000). One thirtieth is about 168 kg
i Slesser and Lewis, 1979
j Total steel needed is about 10 kg (Chen, 2000). One thirtieth is about 0.33 kg
k 1 kg of steel = 20,700 kcal for mining, production, and transport (Pimentel, et al. 1973)
l Estimated
m A litre of fuel is assumed to contain 10,000 kcal. Included in this figure are mining, refining, and transportation costs (Pimentel, et al. 1988)
n A 6 m3 anaerobic digester has a capacity to yield 876 m3 biogas and 1 m3 biogas contains 5000 kcal (Chen, 2000)

Table 6 Labour Input before and after anaerobic digestion (man hours)

BEFORE ANAEROBIC DIGESTION			ANAEROBIC DIGESTION (digester with 30-years life)		
	Weekly	Yearly		Weekly	Yearly
Chopping trees for firewood	5,5	286	Initial labour input		2
Collecting other resources of fuel	2,5	130	Inputting manure and agricultural wastes	0,5	26
Collecting agricultural wastes	2,5	130	Getting slurry out	1	52
Collecting livestock manure	3,5	182	Equipment inspection and replacement	0,5	26
Making fire ready for cooking	4,5	234	Collecting agricultural wastes	2,5	130
Total		962	Total		236

Source (Bi, 2007)

5.6 Health-related benefits

In the rural areas we are studying most of the households are currently burning traditional fuel such as dung and kerosene in order to satisfy their energetic requirement.
Much smoke is created from burning traditional fuels such as fuel wood, animal dung and crop residues. The smoke contains damaging pollutants, which may lead to severe illness, including pneumonia, cancer, and lung and heart diseases.(Smith, 1993)
Biogas is clean and efficient with carbon dioxide and water as the final products of combustion. The shift from the traditional fuels to biogas reduces people's exposure to thick smoke and the susceptibility to lung diseases.(Bi, 2007)
Studies conducted in Nepal show that indoor air pollution and smoke exposure in rural Nepal, expressed in respirable suspended particles, carbon monoxide and formaldehyde, are amongst the worst in the world. Poor indoor air quality is one of the major risk factors for acute respiratory infections with infants and children which, in turn, is among the most important cause of child mortality in Nepal. A case study on the introduction of smokeless fuel wood stoves in rural hill region of Nepal found such stoves to have a significant beneficial effect on the level of respirable suspended particulates exposure and considerable effect on carbon monoxide and formaldehyde concentrations. Biogas stoves, because of its relatively clean combustion characteristics, have even more pronounced beneficial effects than smokeless fuel wood stoves. One attempt of estimating the economic value of smoke exposure reduction reported a value of USD 100 per household (around 68 €). (Reid, et al., 1986)
Eye ailments are commonly associated with smoke-filled rooms. The use of biogas stoves is expected to significantly reduce eye ailments associated with smokes for fuel wood stoves. Many biogas users have reported improved eye health. However, smokeless rooms are not always considered a benefit. Smoke is traditionally used to ward off harmless and harmful insects. Some users of biogas stoves have indicated that the stoves fail to keep away insects and especially mosquitoes. (Matthew S. Mendis, 1999)
If this is true for the Nepalese experience a survey conducted within the Meiwan Xincun Village in Hainan province (China) shows how all the residents surveyed affirmed improvements of their health through improving the indoor environment of kitchens and eliminating the smoke when cooking. Moreover a technical expert also noted the health-related benefits of anaerobic digesters in terms of reducing the breeding of vermin, such as mosquitoes, flies and harmful germs, and the transmission of pathogens in the village.(Bi, 2007)
We do not know much about the presence of harmful insects in the areas we are studying, but the reduction of harmful germs and pathogens in the village could be with no doubt interesting.

5.7 Environment-related benefits

For many years the rational behind using biogas technology (or anaerobic technology) was the search for renewable sources of energy. In the meantime, other environmental protection aspects gain additional importance: A technology which previously just filled a "niche" is now becoming a key environmental technology for integrated, solid and liquid waste treatment concepts and climate protection both in industrialized and developing countries. Biogas technology is linked to the atmospheric budgets of many greenhouse gases. Another major environmental target is the mitigation of deforestation and soil erosion through the substitution of firewood as an energy source.

The macro-economic benefits from biogas use in this field should be approached within the scope of the specific condition in the household energy sector and possible alternative protection measures. (GTZ,1999)
Different experiences all over the world show how the implementation of biogas programs benefited the environment in different countries.
For instance, the introduction of biogas plant in Nepal has significantly contributed to the improvement of the local, national and global environment. From a local perspective, the use of biogas has significantly improved the indoor air quality of the household who switched from the wood stoves to biogas stove. In addition the installation of biogas plants has resulted in better management and disposal of animal dung and human excrement. This fact alone has improved the sanitary conditions in the immediate vicinity of rural houses employing biogas plant.
From a national perspective, biogas plants have helped in reducing the pressure of deforestation. This in turn has important implication for watershed management and soil erosion. In addition, biogas plants, where the slurry is collected and returned to fields, helped in reducing the depletion of soil nutrients. This in turn reduces the pressure to expand the area of land cleared for agriculture that is principal cause of deforestation in Nepal. Furthermore the Nepalese operational biogas plants are estimated to displace the use of 100,000 tons of fuel-wood and 1.27 million liters of kerosene annually. The savings helps to slow down the rate of deforestation in rural Nepal.
In global terms the biogas fuel helps to reduce gas emission by displacing the consumption of fuel-wood and kerosene. The biogas is assumed to be produced on sustainable basis and therefore the CO_2 associated with the biogas combustion is reabsorbed in the process of vegetal food production. (Matthew S. Mendis, 1999)
Further information obtained by the Chinese experience in the Meiwan Xincun Village show how the anaerobic digestion technology provides safe and clean disposal of human and animal manure and agricultural wastes. Since toilets and animal enclosures were connected to the digesters at a household scale, positive waste management has become a spontaneous behavior in the Meiwan Xincun Village. The rural living environment has greatly improved, mainly as a result of the shift to a more positive set of waste management practices. As fuel-wood is no longer the main source of energy in the village, the forest resources also are well preserved. With recent effort, forest coverage in the village has reached 85%, which contributes to maintaining water and soil fertility, protecting wild species, cleaning air and reducing noise (He, et al., 1992).
After the implementation of the biogas program it has been conducted a survey within the village. While all officials and technical experts interviewed agreed that the rural environment is very good, 87% of the residents declared that the environment of Meiwan Xincun Village has improved compared to 10 years ago. Both leaders and residents of the village are optimistic about long-term improvement in rural environmental quality.(Bi, 2007)

6. Economic Viability

6.1 Introduction (Objectives, methodology and decision criteria)

As soon as the cost and benefit components of a biogas plant in planning can be quantified, and as soon as other important parameters (time horizon, interest rate, annual allowances, exchange rates, inflation rates) are determined, the economic viability of a biogas plant can be calculated. Typically, the financial analysis of projects points out the financial viability of investment alternatives.
We will now answer to the following question:
Is a project a financially viable solution to the problem on hand? (**absolute viability**, i.e. the question is dealt with whether the project's revenues are sufficiently high to meet capital cost and operating cost).

6.2 Procedure of dynamic approach

Due to the fact that the same amount of a credit or debit can have a very different value depending on when the transaction takes place, dynamic analysis differ from the static methods.
The need for a dynamic approach results from the fact that, as the costs and benefits of each option arise in different years, it is necessary to make them comparable.

6.2.1 Investment criteria

The dynamic approach deals with a consideration of benefits and costs over several years and therefore shall be pointed out more detailed.
The investment criteria we are going to use is the Net Present Value (NPV).
This is the most common investment criteria and is defined as follows:

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+k)^t}$$

Where:
PV - Net Present Value
Ct - Costs in year t
Bt - Benefits in year t
k - discount rate
t - number of years from the present
n - total number of the years of the analysis period
This step answers the question as to whether the return on investment for a project is sufficiently high to cover its average capital costs. This is the case when the NPV is positive. (GTZ, 1999)

6.3 Practical Example

We are now going to show an example using the monetary flows indicated in chapter 6.

Because of the lack of actual data, the aim of this example is to show how to evaluate the project once the data will be available.

The flows indicated in the previous chapter are here indicated:

Building Costs = 700 €

Energy Savings Gain = 150 €/year

Yield Increase Gain = 17 €/year

Medical Expenditure Reduction = 68 €/year

We assume a discount rate on capital (k) of 10% (but it likely to change according to the different countries and the different areas).

We hypothesize a duration of the plant of 20 years.

The calculation will be as follow:

$$NPV_{t=1}^{20} = -700 + \left[150 \times \frac{(1+0.1)^{20}-1}{0.1 \times (1+0.1)^{20}}\right] + \left[17 \times \frac{(1+0.1)^{20}-1}{0.1 \times (1+0.1)^{20}}\right] + \left[68 \times \frac{(1+0.1)^{20}-1}{0.1 \times (1+0.1)^{20}}\right] =$$

$$= -700 + 1277.03 + 144.73 + 578.92 = 1300{,}68$$

Since the NPV is now positive we can conclude that the household biogas plant are economically feasible.

Moreover we shouldn’t forget that we didn’t include other sources of positive monetary flows (such as the labour savings) because of the objective difficulties in their estimation.

7. Conclusions

We are now going to give some conclusions about the biogas plants as a mean for reducing the poverty in cold climate area.

Because of the positive value of the NPV we could conclude that the use of biogas plants could reduce the poverty in certain areas where the climatic conditions allow a sufficient biogas production (such as Romania, Kirghizstan and Georgia) .

What we should keep in account is that in our calculations we did not consider all the transaction costs involved in the implementation of such a program and other benefits, such as the gain from the CDM mechanism and the lobour saving. Hence this value has to be considered as an approximation of the real value.

8. Recommendations to WECF:

- There's more research needed in the psychrophilic conditions of biogas production. There's a huge literature gap.

- The suggestions we have given are not tested empirically e.g. the concept of the pump leachate circulation for the community biogas plants. This makes it necessary to start small pilot scale studies before implementing the structure/s on a larger scale.

- Community consultation based approach should be used to implement successful projects i.e. wide scale consultation of beneficiary communities.

- With the concept of a heating plant *(i.e. inoculum circulating plant and the solar heating one)* there's need to research in the effects of different temperatures in gain and losses of additional energy supplied to the plant.

- In the small scale plant the use of heated water to dilute the waste could help to increase or maintain viable temperatures within the plant.

- It may be worth researching to find out if it is more profitable to store for winter times than to produce gas continuously using a heating mechanism.

- It is a good idea to encourage beneficiary communities (such as in Kazakhstan) to continue implementing a central collection system for the substrate waste material for convenience and efficiency in transportation.

- A trade off should be done to see what is more convenient between household plants and community plants.

- Actual performance of a house on site plant at 5 degrees needs to be studied. We suggest to construct a plant based on our calculations in one of the targeted countries. Judging from the temperature distribution in the different countries, Romania, Georgia or Kirghizstan are the best countries for a first trial plant. However, actual temperature conditions are location specific, therefore first the actual temperature of a certain location need to be examined. When doing so, the conditions must not be lower than on average -5 degrees (over a month) in wintertime. Additionally, the soil should not be composed of rock and care should be taken with a high water level which might pose an obstacle for construction.

- A pilot plant should also be used to examine actual biogas production per substrate, and actual biogas demand per family size.

- In countries (locations) where winter months are long and below -5 on average, house on site biogas production is not reliable in wintertime. In the summer a biogas plant is possible. However, alternative cooking fuels are necessary in wintertime, and it is questionable if a summertime biogas plant would really add to poverty reduction in that case.
- If a pilot plant is constructed and in operation with success, we advice to set up a provincial or even nationwide biogas program. We recommend that for several reasons:

a) That would greatly reduce the overhead costs per biogas plant made by WECF and for example bureaucratic costs.

b) In that case a training center for biogas engineers on biogas plant construction is possible (for knowledge dissemination and to improve the quality of construction.)

c) Additional funds from the EU are more likely to invest if the program is on a large scale benefitting many households.

d) Additional revenues from for example CDM are only feasible when the project is at a certain size.

e) Learning by doing, doing by learning, biogas plant construction for each next plant is easier.

NGO's such as SNV have a lot of experience with national biogas programs, for example in Nepal, Laos, Vietnam and Cambodia. They could be a reliable partner for a biogas program. Additionally, GTZ has invested a lot of time and money in biogas programs.

REFERENCES:

- AFPRO.*Deenbandhu 2000 Model Biogas Plants.*http://www.afpro.org/Innovations.htm (accessed Februari 22, 2008).
- Akinbami, J. F. K. J. F. K. "Biogas energy use in Nigeria: current status, future prospects and policy implications." *Renewable & sustainable energy reviews* 5, no. 1(2001): 97.
- Arafa, S., 1986. "Energy and village development: the Basaisa experience (Egypt)", Science Dept., the American Univ. in Cairo, 113 Kasr Aini Street, Cairo, Egypt.
- Bi, L. L. "Anaerobic digestion and community development: A case study from Hainan province, China." *Environment development and sustainability* 9, no. 4(2007): 501.
- *Bioenergy and the enviroment. Environment Institute of the United Nations Environment Programme UNEP*, 1990.
- Bioenergy Development under SRE, 2002.
- *Biogas Nepal, 2001*, 2002.
- Biswas, W. K. W. K. "Economic viability of biogas technology in a Bangladesh village." *Energy* 22, no. 8(1997): 763.
- CEM (Consulting Engineers Mekong) (2005) *Evaluation Study for Biogas Plant design – Final.* For SNV Cambodia. Available on http://www.nbp.org.kh/download_doc/Plant%20design%20study%20Cambodia.pdf
- CEM. "Evaluation Study for Biogas Plant design - Final." *National Biodigester Programma Cambodia.* 2005. http://www.nbp.org/download_doc/plant%20design%20study%20Cambodia.pdf (accessed Januari 22, 2008).
- Crutzen, P.J., 1991. Methane's sinks and sources. Nature 350, 380–381.
- Daxiong, Q., Shuhua, G., Baofen, L., & Gehua, W. (1990) Diffusion and Innovation in the Chinese Biogas Program. Tsinghua University Beijing. World Development Vol 18, p 555-563.
- Financing for Development (FMO) FMO and SNV provide farmers in Cambodia with biogas installation and microloan (in Dutch). Available on the internet: http://www.fmo.nl/en/recent/newsitem.php?id=201&archive=1&PHPSESSID=baa Accessed on 29-01-2007
- Gadre, R.V., Ranade, D.R. & God bole, S.H. 1986 A note on survival of Salmonellas during anaerobic digestion of cattle dung. *Journal of Applied Bacteriology*-60, pp.93-96.
- GTZ. "Biogas Digest Volume II. Biogas - Application and Product Development. Information adn Advisory Service on Appropiate Technology." 1999. http://www.gtz.de/de/dokumente/en-biogas-volume2.pdf (accessed Februari 8, 2008).

- GTZ. "Biogas Digest Volume II. Biogas - Application and Product Development. Information adn Advisory Service on Appropiate Technology." 1999. http://www.gtz.de/de/dokumente/en-biogas-volume2.pdf (accessed Februari 8, 2008).

- Gupta, R, A,, and G,N, Tiwariz. "An Improved Solar Assisted Biogas Plant (Fixed dome type): A transient Analysis." *Energy Conversation 28*, 1988: 53-57.
- He, Q., W. Y. Jing, and Y. T. Wang. *Introduction of environmental studies*. Beijing: Tsinghua University Press, 1992.
- http://www.appropedia.org/Biogas_and_liquid_biofuels_%28original%29
- http://www.climate-zone.com/climate/kazakhstan/celsius/pavlodar.htm
- http://www.geographyiq.com/countries/kg/Kyrgyzstan_climate_c.htm
- Hubbard, L. J. L. J. "Romanian wheat prices: Is there a need for stabilisation?" *Food Policy* 25, no. 1(2000): 55.
- Ionescu (Bigioi), D. S. "BREAD MARKET IN ROMANIA."
- K. Aoki et al, 2006. "Thermophilic biogas plant for dairy manure treatment as combined power and heat system in cold regions.", a Department of Animal Science, Obihiro University of Agriculture and Veterinary Medicine, Japan b Mitsui Engineering and Shipbuilding Co., Ltd., Japan.
- Ka, Q. Q. *The main contents of anaerobic digestion slurry*
- Kaale, B. K. B. K. *Traditional fuels*
- Kalia, A.K & Kanwar, S.S. (1998) *Long term evaluation of a fixed dome Janata Biogas plant in HillY condition.* Department of Agricultural Engineering, H.PKrishi Vishvaviduyalaya, Bioresource Technology 65 (1998) 61-63
- "Khoiyangbam, R, S., Sushil Kumar, M.C., Jain, N, G., Kumar, A., Kumar, V." *Biotechnology 95*, 2004: 35-39.
- Lichtman, R. R. "Toward the diffusion of rural energy technologies: some lessons from the Indian biogas program." *World Development* 15, no. 3(1987): 347.
- Maher, K.K., Murthy, M.V.S and Gollakota, K.G. (1994), "Psychrophilic anaerobic digestion of human waste", *Bioresource technology*, 50, pp.103-106.
- Maniates, M., 1985. "Community biogas plants: social catalyst or technical fix?" University of California, Berkeley, California, USA.
- Matthew S. Mendis, W. J. v. N. (1999) The Nepal Biogas Support Program: Elements for Success in Rural Household Energy Supply, ed. E. a. D. Department, and E. a. E. T. D. Climate, Ministry of Foreign Affairs, pp. 27-29.
- Milich, L (1999), "The role of methane in global warning: Where might mitigation strategies be focused", *Global Environmental Change*, 9, pp179-201.
- Nagamani, B & Ramasamy, K(no date), Biogas production technology: An Indian perspective, Fermentation Laboratory, Department of Environmental Sciences, Tamil Nadu Agricultural University, Coimbatore 641 003, India
- Nazir, M (1991) *Biogas Plants Construction Technology for Rural Areas.* Biotechnology and Food research Centre PCSIR Laboratories Complex. Bioresource Technology 35 p283-289

- Nedwell, D.B. (1999) "Effect of low temperature on microbial growth: lowered affinity for substrate limits growth at low temperature", *FEMS Microbiology Ecology,* 30, pp.101-111.
- Pokharel, R. K. "Impact of biogas plants on environmental stability." (1990).
- Practical Action Org., 2006. "Biogas and liquid befouls."
- R.P.J.M. Raven and K.H. Gregersen, 2006 "Biogas plants in Denmark: successes and setbacks", Elsevier Ltd, Copenhagen, Denmark.
- Ranade, D.R., Yeole, T.Y and God bole, S.H.(1987) "Production of biogas from market waste", *Bio mass 13*, Department of Microbiology, MACS Research Institute, Law College Road, Pune-411 004, India, Pp.147-153.
- Reid, H. F., K. R. Smith, and B. Sherchand. "Indoor smoke exposures from traditional and improved cookstoves: comparisons among rural Nepali women (health)." *Mountain Research & Development* 6, no. 4(1986): 293.
- Rivero, O., C.. *Biogas en Bolivia Programa* **"***Viviendas autoenergéticas" Una nueva forma de ver el futuro energético-ambiental del país, en área rural.* Technological en Desarrollo [ONLINE] Available on http://www.tecnologiadesarrollo.tk. Assessed on 12-01-2008
- *Rural Biogas Construction and Overall Utilization Technologies*, 2000.
- Safley, Jr.L.M and Westerman, P.W. (1992) "Performance of a low digester temperature lagoon", *Bioresource technology*, 41, pp. 167-175.
- Safley, L.M (Jr) and Westerman, P.W. (1994), "Low temperature digestion of dairy and swine manure", *Bio resource Technology*, 47, pp.165-171.
- Shakya, I. I. "Development of biogas in Nepal." *International energy journal* 3, no. 2(2002): 75.
- Sharma, Neeta, and Giuseppe Pellizzi. "Anaerobic Biotechnology and Developing countries - technical status." *Energy Coversions 32*, 1991: 447-469.
- Sharma, Neeta, and Giuseppe Pellizzi. "Anaerobic Biotechnology and Developing countries - technical status." *Energy Coversions 32*, 1991: 447-469.
- Shyam, M. "A Biogas plant for digestion of fresh undiluted cattle dung." *Boiling point 47*, 2001: 34-35.
- Singh, Jatinder, K, and Sarbjit Singh Sooch. "Comparative study of economics of different models of family size biogas plants for state of Punjab, India." *Energy Conversion and Management 45*, 2004: 1329-1341.
- Singh, L., Maurya, M.S., Ramana, K.V and Alam, S.I. (1995) "Production of biogas from night soil at psychrophilic temperature", *Bioresource technology*, 53, pp. 147-149.
- Singh, R, and R, C Anand. "Comparative performance of Indian small solid-state and conventional anaerobic digesters." *Bioresource 47*, 1994: 235-238.

.

- Smith, K. R. "Household fuels and health." *Urja Bharati* 3, no. 3(1993): 31–32.
- Stalin, N., Prabhu (2007) *Performance evaluation of Partial Mixing Anaerobic Digester*. ARPN Journal of Applied Sciences. Vol 2, No3. P1-6
- Sutter, K., Wellinger, A. (1988), The ACF system: a new low temperature biogas digester. In: Welte, E., Szabolcs, I. (Eds.), Agricultural Waste Management and Environment Protection, Proceedings 4th International Symposium of CIEC, pp. 61–70.
- URL: www.appropedia.org/index.php?title=biogas_and_liquid_biofuels&action=history
- URL: http://216.239.59.104/search?q=cache:4YIF_ynhaGwJ:www.lged.org/sre/bio-nergysre.htm+community+based+biogas+plants&hl=en&ct=clnk&cd=2
- Wolters,A(2005) Solid waste management in Garla Mare managing the beauty of the danube delta , Waste management techniques, Open university Netherlands
- Zeeman, G. Sutter, K. Vens, T. Koster, M. Wellinger, A. "Psychrophili digestion of dairy and pig manure: startup procedure of batch, fed-batch and CSTR-type digesters." *Biological Wastes 26*, 1988: 15-31.

APPENDIX 1:

Table1: Monthly temperature variation

	Romania		Kazakhstan		Armenia		Kyrgyzstan		Georgia	
	Max(C)	Min(C)	Max(C)	Min(C)	Max(C)	Min(C)	Max(C)	Min(C)	Max(C)	Min(C)
Jan	2	-5	-12	-22	-4.4	-13.6	3	-6	10.8	-1.1

Feb	4	-4	-8	-20	-1.9	-12	4	-5	11.3	3.2
Mar	10	1	-2	-13	3.6	-6.3	12	3	15.3	8.4
Apr	17	6	12	-1	12.5	0.8	18	7	18.9	14
May	22	11	21	6	18.2	6.1	25	11	23.1	18.2
June	26	14	25	11	22.1	9.6	31	17	27.2	22.1
July	28	16	27	14	25.8	13.1	33	18	29.6	24.3
August	28	15	26	12	26.4	13.3	32	17	27.9	24.3
Sept	24	11	18	5	22.6	8.7	27	12	24.1	20.7
Oct	17	6	10	-1	16.1	2.9	19	6	20.2	13.7
Nov	8	1	-2	-11	7.6	-2.7	13	2	16.2	7.7
Dec	3	-3	-8	-18	-0.3	-9.1	6	-4	11.4	2.7

APPENDIX 2

Elaboration on the Methodology

In chapter 2 it became clear that a decrease of the temperature of digestion results in a decrease of methane yield per unit of digester volume. To compensate for a lower methane yield during cold periods, the reactor needs to be larger to allow a longer residence time, thus increasing the HRT.

The following equation shows the relationship between the loading rate of a reference digester with the loading rate of a digester operating at a different temperature. At lower temperatures the formula gives a lower loading rate and thus a longer HRT.

$$\frac{LR_2}{LR_1} = e^{p(T2-T1)} \quad \textbf{(1)}$$

Where:

LR_2	=	Loading rate at temperature T_2 (kg VS / m^3) of reference digester
LR_1	=	Loading rate at temperature T_1 (kg VS / m^3)
T_1	=	Temperature of digestion of a conventional digester
T_2	=	Temperature of a digester at a low temperature
P	=	0,1, rate constant C^{-1}

This formula is taken from Safley et al(1990), it gives an indication what the loading rate at a given temperature should be, compared to a reference digester with a known loading rate and temperature to achieve a similar methane yield.

The loading rate is expressed in volatile solids per m^3 reactor volume. VS is a proportion of the total manure fed to the reactor. Therefore, the loading rate can also be expressed in kilo manure per reactor volume, since the proportion of VS is the same for LR_1 and LR_2, consequently the outcome of the fraction (LR2/LR1) is the same.

The lower loading rate per unit of digester volume result in a longer HRT. This is shown by the next equation:

$$HRT = \frac{V}{Q} \quad \textbf{(2)}$$

Where:

HRT	=	retention time (days)
V	=	Reactor volume (m^3)
Q	=	Flow of substrate (m^3/ day)

An lower loading rate per unit of volume results in a longer residence time, as a result the flow is smaller.

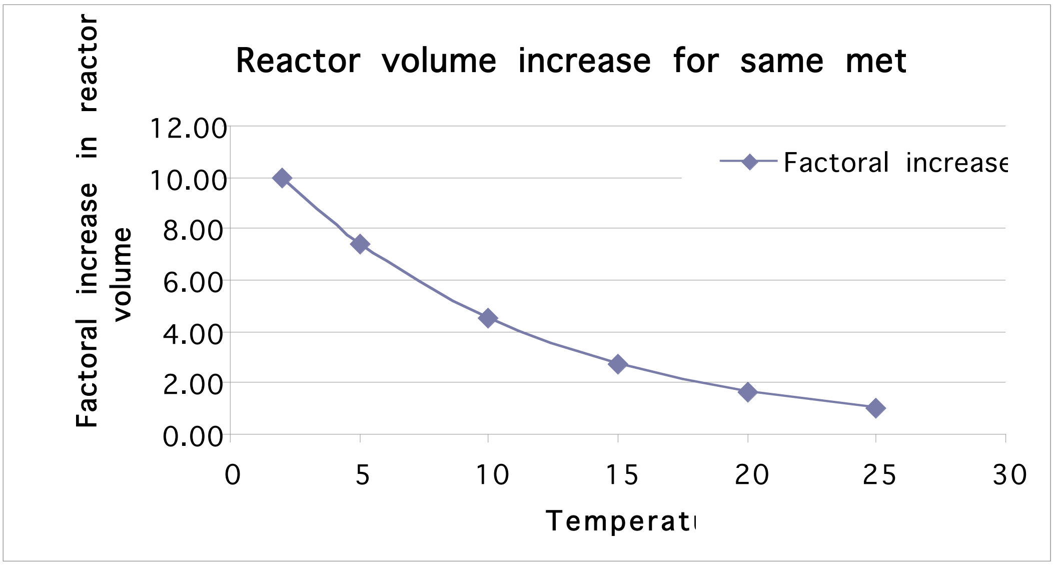
To calculate the volume of the digester necessary to achieve the same methane yield at a lower temperature compared to the reference digester, the following equation is used:

$$\frac{V_2}{V_1} = \frac{LR_1}{LR_2} \qquad (3)$$

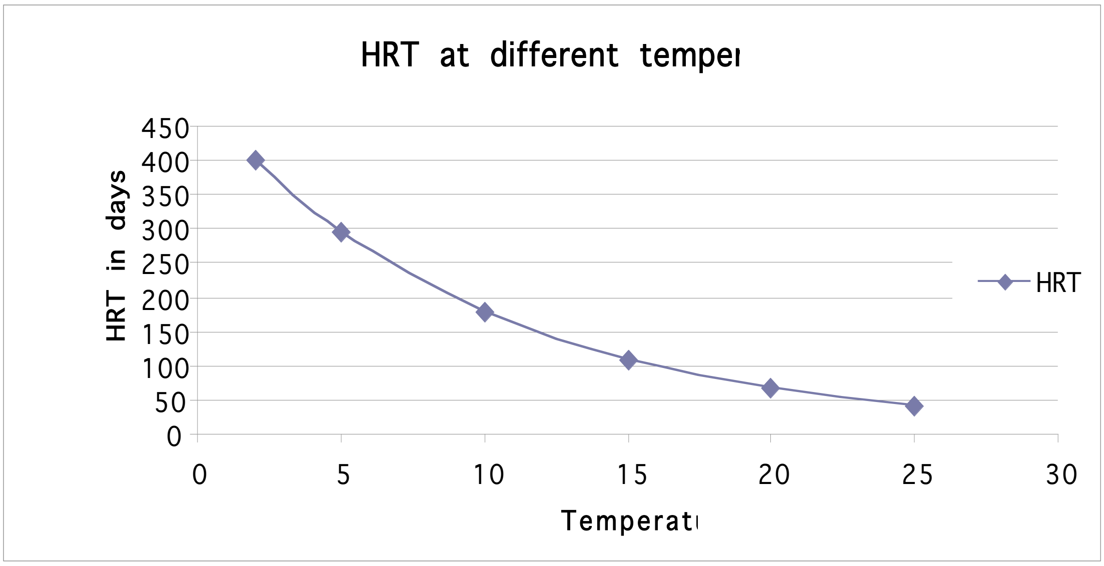
The decrease of the loading rate is inverse proportional related to the increase in volume and HRT. Thus, if the loading rate is twice as low, the volume becomes twice as large.

In summary, a digester dimensioned to operate at lower temperatures has a lower loading rate per volume and a proportionally larger volume to obtain similar methane compared to a reference digester digester at higher temperatures of digestion.

The next graph shows the increase in volume necessary to obtain the same methane yield compared to a conventional digester at 25 degrees. The graph shows that at 2 degrees, the volume needs to be 10 times as large, and at 5 degrees around 7 times. The reference digester operates at 25 degrees.



The increase of reactor volume was necessary to allow a longer residence time. The next graph shows the impact on the residence time at lower temperatures.



As became clear in chapter 3, digestion beneath 5 degrees is not considered feasible. On the graph we see the HRT at 5 degrees is somewhat beneath 300 days, for the case of the household digester 296 days.