Information note

Top-down development of standardized approaches for rural energy supply (biogas)

I. Background

1. CMP.6 requested the Executive Board of the clean development mechanism (hereinafter referred to as the Board) to develop standardized baselines (SB), as appropriate, in consultation with relevant designated national authorities (DNAs), prioritizing methodologies that are applicable to least developed countries (LDCs), small island developing states (SIDS), Parties with 10 or fewer registered CDM project activities as of 31 December 2010 and underrepresented project activity types or regions, inter alia, for energy generation in isolated systems, transport and agriculture.

2. As per the task of developing top-down small-scale methodologies using standardized approaches contained in the 2012 work plan of the SSC WG, the SSC WG considered an information note prepared by the secretariat with regard to standardized approaches for rural energy supply (biogas), focusing on standardized approaches for deriving specific default values of biogas generation per unit size of biogas digester.

II. Proposal on standardized approaches for region/country specific values for rural energy from biodigesters

3. With reference to the standardized approaches, based on expert inputs, the SSC WG 36 considered the following methodological approaches for deriving specific default values of biogas generation per unit size of biogas digester.

4. The technical report is attached to this document (See appendix 1).

5. The proposed specific default values of biogas generation per unit size of biogas digester are as follows:

(a) For regions/countries where climate zone is warm (temperature > 25), a default biogas generation value of 0.13 m^3/m^3 is used, provided that the Hydraulic Retention Time (HRT) of manure fed is between 30–50 days;

(b) For regions/countries where climate zone is temperate/warm (temperature 20-25), a default biogas generation value of 0.13 m^3/m^3 is used, provided that the HRT is between 40 - 60 days;

(c) For regions/countries where climate zone is temperate/cold (temperature 15-20), no default value is provided.

6. The SSC WG agreed to request the Board to launch a call for public inputs on the proposed approaches for deriving specific default values for biogas generation per unit size of biogas digester. To this objective, the SSC WG is looking for feedback on:

(a) Are the proposed specific default values for biogas generation reasonable and conservative?

(b) What kind of additional conditions or monitoring requirements should be included in the methodology to use the default values if any?

(c) Are there other appropriate approaches for standardization? If any, please recommend providing justification on the proposed approach(es).

Appendix 1: Technical Report on Standardized Approaches for Household Biogas Methodology

1. Biogas generation factors

1.1. Supply side

1. In this section it is studied whether default values could be considered based on the supply side; based on biogas production.

1.2. Background on biogas generation

2. Biogas generation, or better stated, methane recovery from animal substrate is a complex process consisting of four mains steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis (Yadvika, Santosh et al. 2004):

- **Hydrolysis**
  Hydrolytic bacteria break down complex polymers and higher molecular mass compounds into soluble organic products (simple sugars) with the help of exo-enzymes.
- **Acidogenesis**
  The acidogenic (fermentative) bacteria degrade the hydrolyzed soluble substrate to volatile fatty acids (VFA), such as butyric, propionic and acetic acid while also carbon dioxide and hydrogen are formed.
- **Acetogenesis**
  The acetogenic bacteria convert the higher VFAs to acetic acid.
- **Methanogenesis**
  Finally, acetoclastic methanogenic bacteria reduce the acetic acid to methane and another strain of bacteria, hydrogenotrophic methanogens reduce CO_2 and H_2 to methane (Denac, Miguel et al. 1988). At psychrophilic temperatures, the most important pathway is acetoclasic methanogenesis (Kotsyurbenko 2005). Methanogens are *obligate anaerobic*, they cannot function in an aerobic environment (Fulford 1988).

3. The whole chain of steps is outlined in the next figure. Of this chain of steps, hydrolysis is in general considered to be the rate limiting step (Veeken and Hamelers 1999).

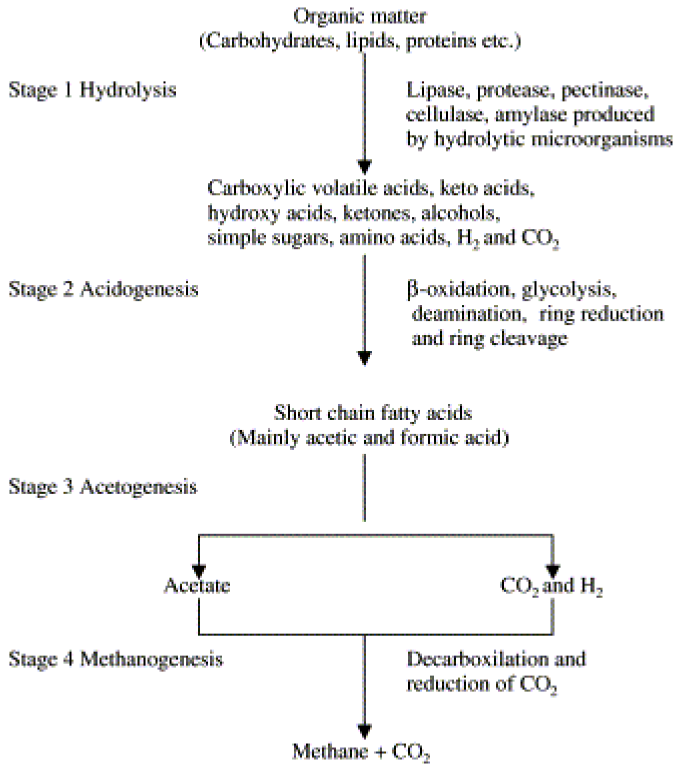


Figure 1: Pathways of Anaerobic digestion (Kashyap, Dadhich et al. 2003)

4. The consortia bacteria responsible for AD are classified according to different temperature classes, thermophilic AD occurs at proximately 45-60°C, mesophilic AD around 20-45°C and psychrophilic digestion at temperatures lower than 20°C (Kashyap, Dadhich et al. 2003).

5. Relative growth rates are proportionally related to the temperature of digestion, hence psychrophilic digestion has, as a result of the low temperatures, a lower rate of digestion compared to, say, mesophilic digestion (Lettinga, Rebac et al. 2001).

6. There are many factors that influence this above described process. The following parameters impact biogas generation directly:

i) Biodegradability of the volatile solids (VS)

7. VS consist of biodegradable and recalcitrant solids to anaerobic digestion. An example of recalcitrant VS is lignin; lignin is under normal conditions not biodegradable and will therefore not contribute to biogas production (methane recovery). The share of biodegradable VS depends on the type of animal, the species and the diet. For example, the IPCC default value for the maximum methane potential (Bo), (m^3CH_4/kgVS) is higher for animals from developed countries compared to developing countries as animal feed in the developed world is better.[1] Methane recovery per kg of VS is therefore higher for animals in developed countries in biogas plants.

ii) VS concentration in the biogas plant

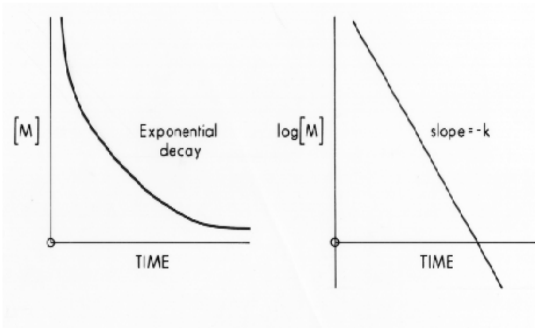
8. Animal manure is often diluted before fed to the biogas plant. The higher the dilution, the lower the VS concentration and biogas production. Sometimes manure is also diluted with

[1] 2006 IPCC Guidelines for National Greenhouse Gas Inventories: volume 4 chapter 10.

animal cleaning (or cooling) water, or when waste water from the pig pens is discharged into the biogas plant. In some countries, this can greatly reduce the retention time and decrease the amount of biogas recovered per unit of digester volume.

iii) Temperature and retention tome

9. In biological engineering a first order decay reaction is assumed for anaerobic digestion. The speed of the decay is positively correlated with the temperature. A typical first order decay reaction is shown in the next table:



The next equation shows a typical first order reaction equation.

$$C = C_0 e^{-kt}$$

Where:

C	=	Concentration at temperature ‘t’
C_0	=	Initial concentration
k	=	Reaction constant
t	=	Temperature

10. As the equation implies, the reaction speed depends on the reaction constant and the temperature. Given that household biogas plants are fed with the same feedstock, animal manure, the reaction constant will not differ that much for household biogas projects in the various countries. Hence, the reaction speed is mostly governed by the temperature in this case. The higher the temperature, the higher the microbial growth rate and subsequent reaction.

11. These findings are relevant to this work as it explains why biogas recovery is lower per unit of time in lower temperature climates. Biogas plants are designed for a specific temperature range, and at lower temperatures the HRT in these reactors is longer to accommodate for the lower microbial growth rates at similar loading rates. Consequently, biogas output per cubic meter of biogas plant is always lower in lower temperatures compared to a biogas plant operating at higher temperatures. The next table shows the recommended retention time for three types of fermentation process by temperature (GTZ 1989).

Table 1: Temperature ranges for anaerobic fermentation[2]

Fermentation*	Minimum (°C)	Optimum (°C)	Maximum (°C)	Retention time (days)
Psycrophilic	4-10	15-18	25-30	over 100 days
Mesophilic	15-20	28-33	35-45	30-60
Thermophilic	25-25	50-60	75-80	10-16

12. The growth rate of microbes involved in anaerobic digestion is proportional to the temperature. Methane recovery will therefore be faster at higher temperatures, and therefore a shorter retention time suffices compared to digestion at a lower temperature. At lower temperatures microbes need more time to breakdown organic material and therefore a longer retention time is required.

iv) Solid and hydraulic retention time

13. The solid retention time (SRT) is the time that microbes reside in the biogas plant and the HRT is the time that the load (manure) remains in the biogas plant. The SRT = HRT in mixed reactors, which is most often assumed in the case of household biogas plant. If measures are undertaken to increase the SRT, the HRT can be lower compared to mixed reactors and this could increase biogas output per unit of volume at levels above mixed reactors.

v) Other factors

14. There are many other factors involved that can promote anaerobic digestion or inhibit the process. For example, the C:N ratio, ammonia concentration, size of the particles etc. In general however, with a sufficient long HRT and SRT, animal manure is an ideal substrate for anaerobic digestion with the exception of chicken droppings as this could contain substantial amounts of ammonia and feathers which affects anaerobic digestion.

1.2.1. Survey results on biogas generation

15. 31 countries were contacted for the survey. 19 survey forms were returned from 18 countries; a response rate of 65%. The following table summarizes the received surveys by continent.

Table 2: Contacted countries and received surveys by contacted

Region	# of contacted experts in the region	# of filled in surveys	Response rate
Africa	16	9	56%
Asia	10	6	70%

[2] GTZ, 1989, <http://biogas.ifas.ufl.edu/ad_development/documents/Biogas%20plants%20in%20animal%20husbandry.pdf>

Region	**# of contacted experts in the region**	**# of filled in surveys**	**Response rate**
Latin America	5	4	80%
Total	**31**	**19**	**65%**

16. The survey included a set of questions of biogas generation factors. Biogas consumption factors by energy service were not quantified, this level of detail is most often not available. Biogas generation factors are studied by climate zone as biogas (methane) recovery is influenced by the prevailing temperature. The temperature is an important variable as this determines the growth rate of methanogenic bacteria and this the biogas production per unit of time per quantity of biodegradable material.

17. The survey specified biogas production by climate zone. During the analysis, the obtained figures were classified according to the IPCC climate zones (≥ 25 °C = climate zone warm and 15-25 °C temperate) and cold (<15°C). The zone temperate is separated in upper temperate, 20-25 °C and lower temperate (15-20 °C), see the next tables:

Table 3: Biogas production factors for the climate zone: Warm

Climate zone 1: ≥ 25°C annual average temperature						
Country	Temp.	HRT	National standard or programme data on specific biogas production *** (m^3 biogas/m^3 digester volume)			
	°C	days	cattle	Dairy cattle	pig	buffalo
Cambodia	25	40	0.3		0.3	0.3
Bangladesh	28	45	0.19			
Myanmar	25-30	30	0.4			
Burkina Faso	29	45	0.4			
Tanzania	30	30	0.2	0.3	0.35	
Cameroon	NA	21	1.6*			
Nepal	NA	55	0.28			
Bolivia	24**	37		0.23	0.33	

** Outliner, value is not used*

*** included in the warm zone*

**** none of the standards were national standards*

18. Specific biogas generation per unit of digester volume is in the range of 0.2 to 0.4 m^3/m^3 for cattle, for pigs in the rage of 0.3-0.35, dairy cattle between 0.23 and 0.3 and for buffalos only one value is available 0.3, from Cambodia. The next table describes the biogas production values for the upper temperate zone.

Table 4: Biogas production factors for the climate zone: Upper Temperate

Climate zone 2: 20 -25 °C annual average temperature						
Country	Temp.	HRT	National standard or programme data on specific biogas production (m^3 biogas/m^3 digester volume)			
	°C	days	cattle	Dairy cattle	pig	buffalo
Myanmar	20-25	40	0.34			
Tanzania	20-25	40-50	0.2	0.3	0.35	
Zambia	21	60	0.3			
Bolivia	20	45		0.22	0.33	

19. The biogas production rates are somewhat lower than the first climate zone, also the HRT is longer. The next table shows that this is observed to a greater extent for the zone lower temperature.

Table 5: Biogas production factors for the climate zone: Lower Temperate

Climate zone 1: Lower temperate: 15-20°C						
Country	Temp.	HRT	National standard or programme data on specific biogas production (m^3 biogas/m^3 digester volume)			
	°C	days	cattle	Dairy cattle	pig	buffalo
Myanmar	20	50	0.24	-	-	-

20. Only one value is available for the zone cold, from Bolivia, at 12 degrees with a HRT the biogas production is around 0.22 m^3/m^3 for dairy cattle. The figures listed in the lower temperate and cold zone are from only two countries and only 1 value for both cattle and dairy cattle. The next table shows the average biogas production factors by climate zone.

Table 6: Biogas production factors by climate zone

Climate zone	Average HRT	Average biogas production rates (m^3 biogas/m^3 digester volume)			
	days	Cattle	Dairy cattle	Pig	Buffalo
Warm	40	0.2-0.4	0.23-0.3	0.3-0.35	0.3
Temperate/warm	47.5	0.2-0.34	0.22-0.3	0.33-0.35	NA
Temperate/cold	65	0.24*	0.22*	NA	NA

** based on only 1 survey and the value of dairy cattle is from the climate zone cold.*

1.2.2. IPCC guidance and literature

Biogas production

21. According to the IPCC 2006 guidelines the methane potential of manure expressed in $m^3CH_4/kgVS$ of animals in the studies regions are the same, but volatile solids (VS) excretion differs. Consequently, if per head of animal, the biogas potential is higher in some regions, see the next table for example, which shows that cows in Asia have a higher VS excretion rate than cows from Africa.

Table 7: Cow manure characteristics by region

Region	Mass (kg)	Bo (m^3 CH_4/kgVS)	VS (kg/hd/day)
Latin America	400	0.13	0.29
Africa	275	0.13	1.9
Asia	350	0.13	2.8
Indian subcontinent	275	0.13	2.6

Source: IPCC 2006 Volume 4 chapter 10

22. Biogas recovery per kilo of manure however, could be the same for cows from Asia and Africa if the share of VS in total manure is the same. GTZ (1989) provides a number of default values for the biogas yield for a number of animal manures, see the next table.

Table 8: Biogas yields at a temperature of 30°C and at a retention time of 10-20 days

Substrate	Biogas yield (l/kg VS)
Pig manure	340-550
Cow dung	90-310

Source: GTZ (1989) Biogas plant in Animal Husbandry[3]

23. Digestion in household biogas reactors will be at lower temperature than the conditions under which the GTZ biogas yields were obtained. However, since the HRT is likewise longer at lower temperatures, the GTZ values are indicative of the minimum and maximum biogas yield. The range provided by GTZ indicates that any prediction regarding biogas output depends on many parameters. This range, or uncertainty, makes it difficult to recommend standard biogas production values.

Biogas recovery and influence of technology

24. Anaerobic systems have, according to the IPCC, a MCF of 0 to 100%. The ‘0’ probably refers to a perfectly imperfect system whereas the ‘100%’ is only achieved at

[3] GTZ (1989) Biogas Plant in Animal Husbandry:

<http://biogas.ifas.ufl.edu/ad_development/documents/Biogas%20plants%20in%20animal%20husbandry.pdf>

infinite retention time. Consequently, it is impossible to calculate potential biogas recovery rates of a default biogas plant.

Table 9: Rated biogas yields by technology[3]

Technology	**Biogas yield (m^3/m^3 digester)**	**Remarks**
Floating-drum	0.3-0.6	Popular model in the past
Water-Jacket	0.3-0.6	
Fixed dome	0.2-0.5	Well disseminated model
Balloon type (plastic bag	0.3-0.8	Popular model in Latin America
Earth pit	0.1-0.5	Not well known biogas models, dissemination is probably low
Ferro cement	0.3-0.6	
Horizontal-Shallow	0.3-0.7	

25. Biogas production varies considerably by technology and between technologies. The main differences between the technologies arise from differences in the reactor design.

1.2.3. Discussion on supply side

26. In the section 1.1.1, it was argued that biogas generation rates are governed by the temperature and that at lower temperatures a longer HRT is required because the microbial growth rate is lower compared to higher temperatures. Therefore, the biogas production per cubic meter of biogas plant is lower at a lower HRT.

27. The section 1.1.2 described the biogas production factors obtained from national standards or programme standards and recorded in the survey forms. A standard does not always match with on the ground practices, by, for example:

- Animal population has changed since the installation of the biogas plant (i.e. farmer has sold his pigs, diseases);
- The farmer does not feed all the manure into the biogas plant (i.e. cattle are roaming around freely during the day, manure is used directly as fertilizer);
- The HRT is very short as the biogas plant is fed with waste water from cleaning the pig pens.
- Different technologies will give different results with the same parameters.

28. Therefore, the survey included a question of achieved biogas recovery compared to the reference standard used by the programme/biogas project activity. The respondents answered that the achieved biogas recovery compared to the standard was in the order of 70% to 100%. In Cambodia it was claimed that 100% was attained, whereas in Myanmar only 70%. Interestingly, in Cambodia a biogas recovery value is used of 0.3 m^3 per cubic meter of biogas plant volume while in Myanmar this is 0.4, by applying an average achievement of 70%, the values in Myanmar are very close to the one in Cambodia of $0.3m^3/m^3$ recovery.

29. Closer inspection of the values in Cambodia revealed that the value provided is an average of the minimum and maximum biogas recovery (0.2 and 0.4), see the next table

Table 10: Biogas production from biogas plants in Cambodia[4]

Plant size	**4 m^3**	**6 m^3**	**8 m^3**	**10 m^3**	**15 m^3**
Dung requirements (kg/day)	20-40	40-60	60-80	80-100	100-150
Estimated gas production (m^3/day)	0.8-1.6	1.6-2.4	2.4-3.2	3.2-4.0	4.0-6.0
Specific biogas generation (m^3/m^3)	0.2-0.4	0.27-0.4	0.3-0.4	0.32-0.4	0.27-0.4

30. A 4 m^3 biogas plant is designed for a daily feeding of 20 to 40 kg/day and will generate around 0.2 to 0.4 m^3 cubic meter of biogas per day. The average provided by the NBP (National Biodigester Programme) Cambodia is 0.3, comes therefore with a range of ±33%.

31. A survey was held in Cambodia for their second monitoring period of their voluntary Gold Standard project amongst 150 households in January 2012. The survey included a measurement of manure availability using calibrated newton scales. Data from that survey was used to estimate under and overfeeding of the biogas plants.

Table 11: Feeding and overfeeding of biogas plants in Cambodia[5]

Biogas plant size*	**4**	**6**	**8**
Prevalance (% of all biogas plants)	48%	45%	6%
Feeding as per standard (kg/day)	20-40	40-60	60-80
Overfeeding**	7.84%	1.56%	5.56%
underfeeding**	10%	77%	56%
Share with feeding outside operation	17.65%	78.13%	61.11%

** The share of biogas plant larger than 8 m^3 is very small and was not included in the monitoring survey.*

*** Under or overfeeding is determined based on a loading rate that is respectively lower or higher than the standard.*

32. A large percentage of the 6 and 8 cubic meter biogas plants are either under or overfed, this is much lower for the 4 cubic meter biogas plant. The main reason why the 4 m^3 biogas plant is not underfed is because only biogas plants are installed at households that have enough manure for the smallest biogas plant; households with less manure are not eligible. There are various reasons that explain underfeeding:

- Socio-economic conditions: Selling of animals, children went to study in Phnom Penh and nobody was able to properly care about the biogas plant;
- Biogas plants are built larger on purpose to accommodate for a future increase in the number of animals;

[4] NBP Cambodia 2012. Personal communication
[5] Survey data of NBP Monitoring report II by Eric Buysman (2012)

- Animal diseases, i.e. blue ear.

33. Significant for this report is that feeding according to the standard is not a common practice. This is also not to be expected as the number of animals that small holder farmers own constantly varies. This especially the case with pig farming, where the farming practices are cycles of fattening and selling of pigs. At the moment the pigs are sold, only a few sow remain behind with or without piglets. Cow farming in Cambodia in contrast, is more stable as cows are also used for draught power and often only sold when the farmers needs cash.

34. The average biogas production rate may be applicable if the average feeding is similar to what the average biogas production is based on. The next table studies this:

Table 12: Calculated biogas production versus biogas production as per standard

Biogas plant size (m^3)	**4**	**6**	**8**
Average feeding*	29.07***	35.63	52.94
Calculated biogas **production	0.29	0.24	0.26
Feeding as per standard (kg/day)	20-40	40-80	60-80
% biogas generated compared to 0.3 m^3/m^3	97%	79%	88%

** Amongst 150 randomly selection households*

*** calculated based on average feeding rate as per standard of 40 liter biogas/kg manure*

**** one outliner removed of 25 kg manure/m^3.*

35. Based on actual feeding practices in Cambodia, only around 79% to 97% of the average biogas production as per standard is achieved. The example of Cambodia shows that a standard, even if the standard is an average of the biogas output of a biogas plants, is not always achieved.

36. In Vietnam a study on biogas recovery was conducted in 2006[6] where the biogas production was monitored of 100 biogas plants for 3 days. The average biogas output of these digesters was around 0.14 m^3/m^3; a relatively low value compared to the survey results. Closer inspection into the data revealed that the biogas plants were not operating according to Vietnamese design standards, which prescribe a HRT which varies according to climate zone between 25 and 60 days. Only 25% of the biogas plants operated according to the prescribed HRT and only 38% had a HRT between 20 and 70 days. The average HRT is 78 days of the 100 plants and with that HRT the VS loading rate is very low which result in a very low biogas production per cubic meter of digester volume.

37. Compared to the Cambodia standard, in Vietnam not even 50% of the average biogas yield is achieved. The main reason for this is the very long retention time caused by underfeeding of the biogas plant. The VS loading rate could have been twice as high and consequently the biogas recovery rate could be around twice higher.

[6] Biogas User Survey (2006)

Biogas generation values by climate zone

38. Results have shown that in Vietnam only 50% is achieved compared to the average biogas production according to the standard in Cambodia. In Cambodia itself, around 83% is achieved whereas in other countries, i.e. Myanmar, this was set at 70%. A conservative correction factor for biogas production compared to the standard is therefore 50% or lower.

39. The recommendation of biogas production values takes therefore temperature into account and is based on:

- Average biogas production as reported in table 6 of cattle (most conservative)
- Adoption of the factor 50%, which represents the share of amount of biogas recovered compared to the standard.

Table 13: Conservative biogas production values

Climate zone	**Temperature**	**Valid for the estimated HRT range**	**Biogas yield*** m^3/m^3	**Biogas yield with 50% discount factor** m^3/m^3
Warm	>25	30-50	0.23-0.3	0.133
Temperate/warm	20-25	40-60	0.22-0.3	0.13
Temperate/cold	15-20	Not enough data		

** According to lowest biogas yields by animal in table 6*

40. However, these values are only valid under certain conditions:

i) Feeding rate and design capacity

- Many plants will not be in use up to design capacity and many may be in use at a much lower rate. This happens for instance when many farmers are forced to sell their animals due to economic conditions, diseases, etc. If farmers only keep a few animals after such an occurrence, the biogas plant may only be used for 25% of the rated capacity. Even with the adoption of 'conservative' value, this would greatly overestimate biogas production.

ii) Measures should be in place to maintain a suitable HRT/SRT

- The HRT should remain between a certain value, i.e. 25% lower or higher than rated HRT of each climate zone. Monitoring the HRT can be cumbersome, a proxy value could be the number of animals and that measures are implemented to ensure that manure is not diluted above a certain dilution ratio. A more detailed study is required on the HRT/SRT and in specifically the VS loading rate.

iii) Compensation for atmospheric pressure

- At extreme altitudes the atmosphere pressure is much lower than sea level. Henceforth, the volumetric biogas production is higher at higher altitudes, but the heat content is lower (methane density is lower). This required more study.

iv) Feeding

- The biogas plant is fed with cattle, dairy cattle, pig or buffalo manure, or a combination of these. The recommended biogas values are not valid for feeding of waste from, other animals.
- Feeding should be according to standard, i.e. a biogas plant of a certain unit should not be fed by more or less animals than specified by the standard.

v) Technology

- The calculated values are applicable to fixed dome biogas plants. Table 9 suggests that these biogas plants have lower biogas yields compared to other models. It is therefore very likely that the calculated conservative value is applicable to other technologies as well.

Note: it is very difficult to establish a reliably estimate for biogas production per unit of biodigester volume as biogas production is only indirectly related to the size of the biogas plant. Actual output entirely relies on feeding practices. The study from Vietnam underlines this and shows that biogas production can be much lower under certain conditions.

1.3. Demand side

41. In developing countries, the household energy demand is greatly influenced by eating and cooking habits. Gas demand for cooking is low in regions where the diet consists of vegetables, meat, milk products and small grain. The gas demand is higher in cultures with complicated cuisine and where whole grain maize or beans are part of the daily nourishment.

42. As a rule of thumb[7], the cooking energy demand is higher for well-to-do families than for poor families. Energy demand is also a function of the energy price. Expensive or scarce energy is used more carefully than energy that is effluent and free of charge. The gas consumption for cooking per person lies between 300 and 900 liter per day, the gas consumption per 5-member family for 2 cooked meals between 1500 and 2400 liter per day.

43. However, this relationship is not proportional to the household members due to efficiency effects and because the amount of food consumed differs per household member (i.e. children versus adults). Moreover, a complicating factor is that biogas use is not for all services related to the household size, i.e. pig feed preparation, biogas lighting bear little relation with the size of the household.

44. In addition, a biogas plant is often constructed not based on energy need but on manure treatment capacity or based on amount that households can pay. In those cases, there is no direct link between energy demand and energy production. It is therefore deemed impossible to relate household size with biogas production.

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[7] <http://biogas.ifas.ufl.edu/ad_development/documents/biogasdigestvol2.pdf>