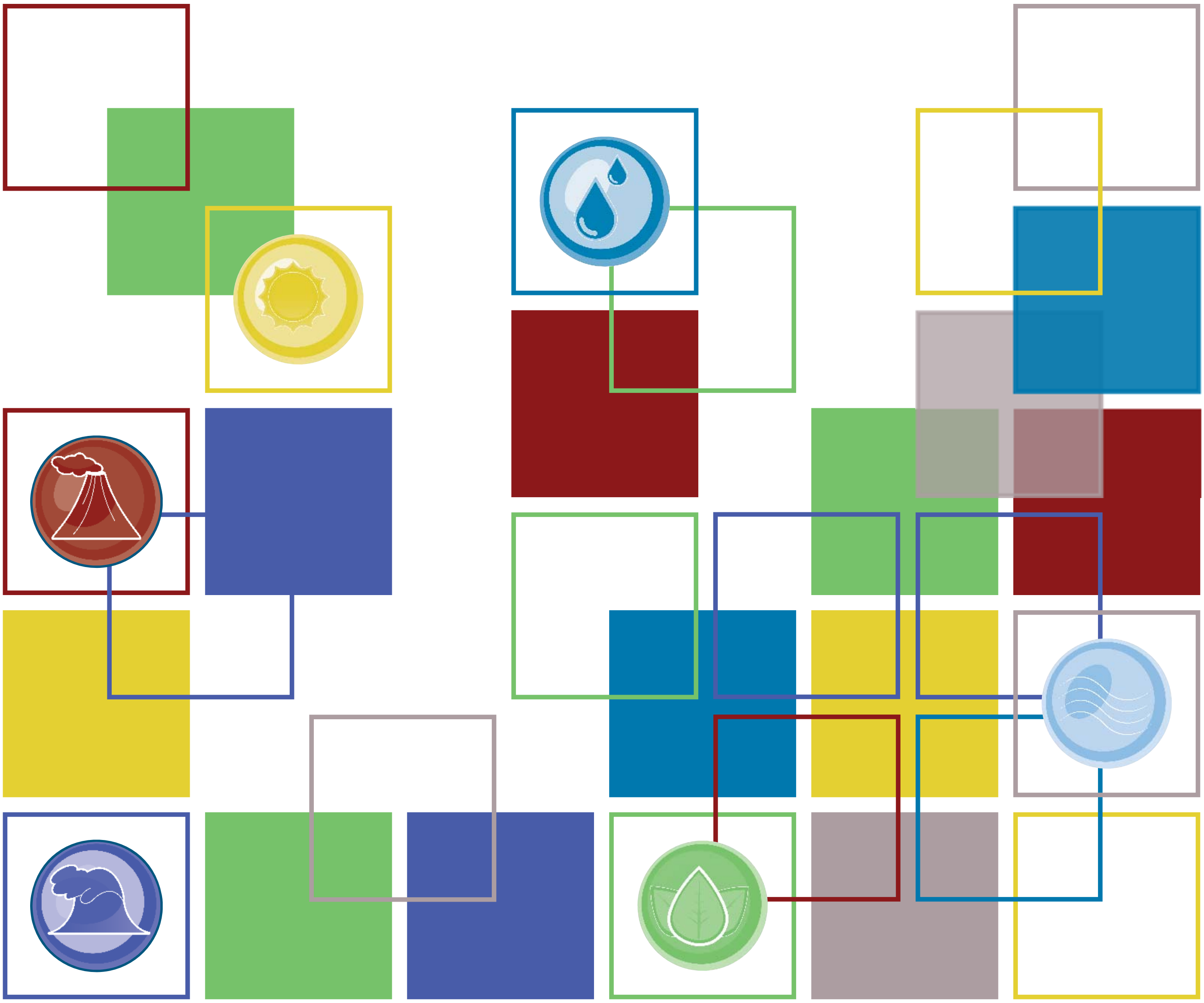
IRENA
International Renewable Energy Agency

Measuring small-scale biogas capacity and production



ISBN 978-92-95111-12-7 (PDF)

This report should be cited: IRENA (2016), *Measuring small-scale biogas capacity and production,* International Renewable Energy Agency (IRENA), Abu Dhabi

About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. www.irena.org

Prepared by Samah Elsayed, IRENA Programme Officer, Capacity Building in Statistics

For further information or to provide feedback, please contact the IRENA statistics team (statistics@irena.org).

This report is available for download: www.irena.org/publications

.

CONTENTS

1. INTRODUCTION

Interest in small-scale biogas technologies has increased in recent years across Africa, Asia and Latin America. This has been driven by the socio-economic and environmental benefits of using biogas, such as reduced firewood and kerosene consumption, lower emissions of greenhouse gases and indoor air pollutants and the possibilities to use biogas to treat human and animal wastes (Bunny & Besselink, 2006). Given this trend, biogas use needs to be accurately monitored and measured.

This guide aims to help energy statisticians to measure and estimate the capacity and production of biogas plants, as well as other aspects of biogas production. The main focus is on data collection from small-scale household, communal or farm biogas plants that produce biogas in a continuous process (i.e. feedstocks are added and biogas removed every day).

The methods described here may also be used for large-scale biogas plants or plants producing electricity, but such facilities should have monitoring devices to measure production more easily and accurately.

WHAT IS A BIOGAS DIGESTER?

The main part of a biogas plant is the digester, which is an airtight container in which bacteria break down organic waste through a process of anaerobic fermentation.[1] This generates a gas (biogas) that is mostly methane and carbon dioxide (CO_2). This gas can be used for cooking, heating and lighting, or it can be used to generate electricity. As more material is added to the digester, a liquid waste (slurry) is also produced, which can be used as a fertiliser.

Biogas digesters can vary greatly in capacity, ranging from small-scale units used by households to larger communal and industrial digesters. Feedstocks added to the digester can include many types of biomass such as animal, food and agricultural waste, but materials that are difficult for the bacteria to digest (e.g. wood) should be avoided. The amount of biogas produced depends on a range of factors including the type and amount of biomass used, the digester size and temperature.

WHY ARE BIOGAS STATISTICS COLLECTED?

The amount and type of biogas data collected will depend on how this information will be used. For example, project and policy monitoring may require the collection of specific and detailed data, while monitoring of renewable energy targets may only need very basic data that can be obtained from a few biogas questions in a census or household survey. The following are some examples of how biogas statistics may be used and the sorts of data that might be needed.

KEY REQUIREMENTS FOR DIGESTER OPERATION

- An airtight environment with no oxygen
- Moderate temperatures
- No light
- Small feedstock particles with broken down fibres and minimal lignin (wood) content
- For some feedstocks a starter bacteria is also necessary

National energy statistics

In some countries, biogas contributes significantly to the national energy balance. It may be used both as a fuel and to generate electricity. To produce these statistics, biogas data collection should focus on plant capacity and production of biogas and electricity.

Project and policy monitoring

More detailed biogas statistics may be required to monitor implementation of biogas projects, programmes and policies. Important variables to monitor can include: the number and size of biogas plants installed; their condition; the amount of biogas produced; and a range of socio-economic impacts.

Tracking progress towards targets

Household biogas plants are often used to produce biogas for cooking, as biogas is a clean and modern alternative to using solid biofuels. Statistics about the numbers of households using biogas are needed to track progress towards clean energy goals, such as the energy access target under the Sustainable Development Goal for energy (SDG 7) "to ensure access to affordable, reliable, sustainable and modern energy for all."

Measuring environmental impacts

Biogas can reduce the environmental impact of energy use in many ways. Switching to biogas can reduce CO_2 emissions from energy use, as well as methane emissions (if biogas is produced from

[1] Anaerobic fermentation means that the fermentation or digestion occurs in the absence of oxygen.

waste). It can also have positive benefits for indoor air pollution and land degradation when it replaces the use of solid biofuels. To measure these impacts, information may need to be collected about several social and environmental indicators as part of the collection of biogas statistics.

International energy statistics

This guide, produced as part of the statistics capacity building programme at the International Renewable Energy Agency (IRENA), is intended to help countries collect and report their biogas data in an internationally comparable format.

In energy balances, biogas data is usually reported in megajoules (MJ), so conversion factors to convert from cubic metres of gas to MJ are given in section 4 of the guidance. Other advice is also given in the text about where different elements of biogas production and consumption should be recorded in an energy balance

With the methodologies and techniques described here, it is hoped that the availability of biogas data will improve, so that IRENA's statistics will capture more information about this rapidly growing part of the renewable energy sector.

Guidance structure

The remainder of this document is divided into four sections.

The first section describes the main variables influencing digester operation such as the digester technology, the type and amount of feedstock used, plant capacity and digester temperature.

The second section looks at two ways to collect data about the capacity of a biogas plant. This includes guidance about how to make volume calculations based on typical biogas plant designs.

A third section describes five different ways to estimate or measure biogas production and consumption, including: estimates based on digester size; estimates based on appliance use; estimates based on feedstock use; estimates based on fuel substitution; and direct measurement of gas production.

The final section describes how the environmental and socio-economic impacts of biogas use may be monitored, including: emissions reductions; effects on women and children; and health benefits.

2. THE MAIN PARAMETERS AFFECTING BIOGAS PRODUCTION

This section presents an overview of some of the main variables that affect biogas production including: the digester type; digester size (measured either as volume or expected production level); the type and amount of feedstock used in the digester; feedstock retention time; and temperature.

KEY DIGESTER TYPES

- Fixed dome plant (Hemisphere, Deenbandhu and Chinese designs)
- Floating drum plant
- Balloon/bag digester

DIGESTER TECHNOLOGIES

There are a number of different designs of small-scale biogas digesters and recording the type of digester is important for estimating its capacity, particularly in cases where the digester is partly underground. If the owner of the digester has an operator's manual or watched it being installed, then they should know what type of digester they have. If they do not know, then the data collector will need to look at the digester to determine its type.

Fixed dome plant

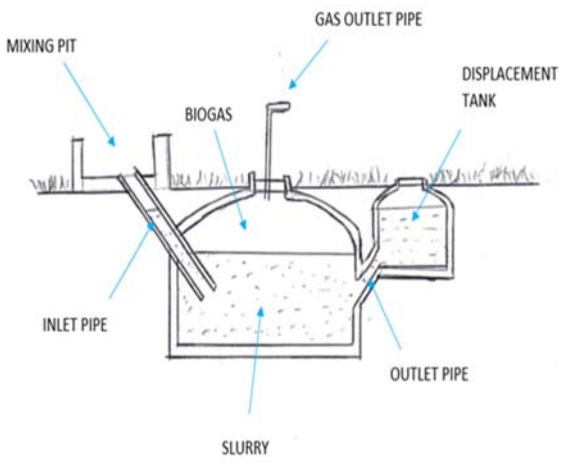


Figure 1: Fixed dome plant

The fixed dome plant was originally developed in China, where there are now several million of these types of biogas plant.

The digester in a fixed dome plant consists of an underground pit lined with concrete or brick, with an inlet pipe that is used to add feed to the digester. Gas is produced under pressure and is stored under the dome at the top of the digester. Biogas is removed from the digester using a pipe attached to the top of the dome.

As biogas is produced, slurry is pushed out from the digester through the outlet pipe into a displacement tank. When the biogas is used, this slurry flows back into the digester. Some designs may also include an additional gas storage tank connected to the gas outlet pipe.

The typical Chinese fixed dome plant often consists of a cylindrical digester with a round top and flat or curved bottom. Other variations of the fixed dome plant include the Deenbandhu and Deenbandhu 2000 model biogas plants developed in India, which have a dome at the top and a curved base (Kudaravelli, 2013). Another type is the CAMARTEC model designed by GIZ for use in Tanzania, which is built as a series of brick rings in the shape of a dome on top of a flat base (Sasse et al, 1991).

Floating drum plant

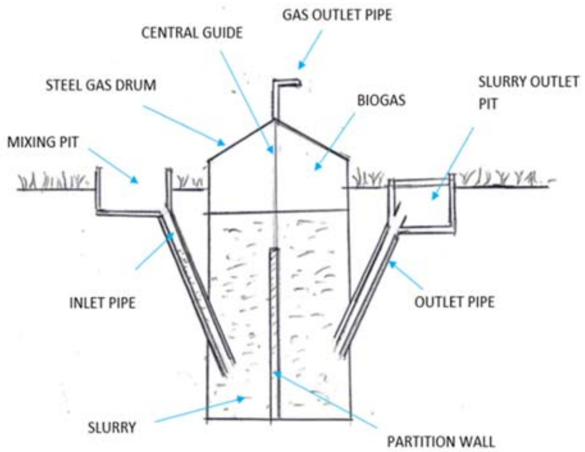


Figure 2: Floating drum plant

The floating drum plant was designed and developed in India. It comprises a brick lined pit that is often partly underground (the digester) and a drum above ground is used as the gas collector. A popular design is the Khadi and Village Industries Commission (KVIC) digester. The drum is typically made of steel although some newer designs use fiberglass reinforced plastic.

Water and feedstocks are combined in a mixing pit which then flows into the underground digester through the inlet pipe. As gas is produced, it is collected in the drum, which moves up and down a central guide pipe depending on the amount of gas being stored. The gas is held under pressure from the weight of the drum, which can be increased with the addition of weights.

As more feedstocks are added, slurry flows out through the outlet pipe. A gas outlet pipe is also attached to the drum to remove gas from the plant.

A variation of this design is the small-scale above ground floating drum plant developed in India by the Appropriate Rural Technology Institute (ARTI). The ARTI biogas plant is made for the digestion of household food waste and is made from two plastic water tanks with their tops removed and the smaller tank placed upside down inside the larger one. Pipes are added to the outer tank to add feedstocks and remove the slurry and a gas outlet pipe is added to the top of the inner tank (AIDG, 2009).

Balloon/bag digester

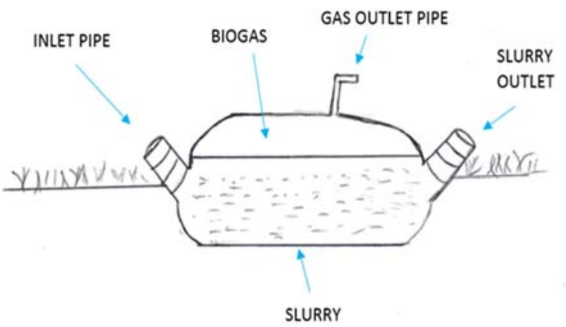


Figure 3: Balloon digester

Balloon digesters are often used in Latin American countries. This type of digester is usually made from a large, strong plastic bag connected to a piece of drainpipe at either end, with these pipes being used to add feedstocks and remove slurry.

To avoid damage to the bag, the digester is usually placed in a trench and the trench is slightly deeper at the slurry outlet so that the slurry will settle there. As gas is produced the top of the bag inflates and the gas can be removed through an outlet pipe in the top of the bag. Gas pressure can be increased by placing weights on top of the bag (Vögeli et al, 2014).

In China, a common variation of this design is the bag digester, which is a circular concrete, brick or plastic lined container covered with a plastic bag or tent. As with a fixed dome plant, inlet and outlet pipes are used to add feedstocks and remove slurry and the gas is collected and removed from the bag.

Plant capacity

The capacity of a biogas plant is the maximum total volume of gas and slurry that it can contain. However, not all countries measure biogas plant capacity in this way. For example, in India, the expected amount of gas produced each day may be called the plant capacity or plant size. Biogas production can be reported in this way because the feedstocks used in India usually do not change very much, leading to a predictable daily production level. In other countries (e.g. China), the feedstocks used for biogas production vary greatly from place to place and at different times, so plant capacity is recorded as the volume of the plant rather than the volume of production per day (INFORSE South Asia, 2007).

To avoid confusion, this guidance will use "rated daily gas production" in calculations when the calculations use an expected daily production level and will use "total plant volume" if the calculations are referring to the volume of the plant.

Rated daily gas production

The rated daily gas production is the volume of gas that a biogas plant is designed to produce each day if operated under optimal conditions. Measured in m^3/day, this shows the amount of biogas that is produced (not the amount of methane).

The energy content of biogas will mostly depend on the methane content of the biogas, which should be about 65%. This needs to be taken into account when converting figures from gas production to energy production. Biogas will also contain other gases such as carbon dioxide, nitrogen and small amounts of hydrogen, but these have little impact on the energy content of the biogas.

Total plant volume

The total plant volume is the sum of two components: the digester volume and the gas storage volume. It is measured in m^3.

The digester volume is the maximum amount of slurry that the plant can hold, while the gas storage volume is the amount of gas it can hold when full of slurry. The latter is usually a proportion of the former. The digester volume may also include a safety margin or "dead zone volume", which is used to prevent waste overflow on days when biogas production is higher than normal or biogas use is unusually low.

Total feedstock volume

The total feedstock volume is the average amount of material added to the biogas plant each day. This includes the amount of waste and other feedstocks added each day (waste volume) and the amount of water added to these inputs (added water volume). The total feedstock volume should be recorded in m^3/day, but this can be measured in litres and converted to cubic metres (with three decimal places) by dividing the measured amount by 1,000 (i.e. 1 m^3 = 1,000 litres).

Waste volume

The waste volume is the volume of organic material added to the digester. This can include animal, human, food and agricultural waste, as well as other feedstocks collected and used in the digester.

Added water volume

For optimal biogas production, water must usually be added to the waste, and other feedstocks put into the digester. The owner or operator of the biogas plant should know how much water they must add when they are putting material into the digester. However, if this is not known or cannot be measured directly, the added water volume can be assumed to equal the waste volume (most biogas plant manuals recommend adding water to the waste in a ratio of 1:1).

MAIN PARAMETERS

- Plant capacity
- Total feedstock volume
- Feedstock properties
- Feedstock retention time
- Temperature

Feedstock properties

For each type of material added to the biogas digester, the amount of biogas produced will depend on how much of the material can be digested and converted into biogas by the bacteria in the digester.

The amount of material (feedstock) that can be digested will depend on two variables: the total solid content and the volatile solid content of the material added to the digester. If these two figures are known, then the amount of biogas that can be produced can be calculated using figures found in various studies (see Section 4 for some examples).

Total solid content

Most organic material contains a significant amount of water. This is known as its moisture content and, as it is only water, does not contribute to biogas production.

The total solid content of a feedstock is the opposite of this and is the amount of dry matter present in the material. This is measured as the weight of the dry matter divided by the total (wet) weight of the feedstock and is recorded as a percentage of the total (wet) weight.

So, for example, if 1 kilogram (kg) of household kitchen waste contains 600 g of water, then its moisture content is 60% and its total solid content is 40%.[2]

Volatile solid content

The volatile solid content is the proportion of the solid material that can be digested by the bacteria and turned into biogas in the digester. This will be different for each type of waste or feedstock.

The volatile solid content is measured as the weight of volatile solids in the material divided by the total weight of solids in the material and is recorded as a percentage of the total solid content. Estimates of the volatile sold content of different feedstocks are not measured in the field, but are usually taken from the biogas literature.

Feedstock retention time

The retention time is the average amount of time that feedstocks will stay in the digester before they are pushed out through the outlet pipe. The retention time is measured in days and is simply calculated as the digester volume divided by the total feedstock volume (i.e. daily waste and added water volume). Because the digester volume is usually measured in m^3, this is why the feedstock volume is also usually recorded in m^3.

Temperature

The temperature within the digester is an important variable that affects the speed of gas production (production per day) and the total amount of biogas that can be produced from any feedstock.

In small-scale biogas plants, the bacteria that produce biogas work most effectively when the temperature of the slurry is 20-45°C. Within this range, biogas production will vary, so the size of a biogas plant is usually designed to ensure that daily gas production is maximised.

In colder climates, the slurry may need to be heated to keep it within this temperature range, in which case some of the biogas may be used for this purpose. If this is the situation in a country, then this share of the biogas production should be recorded as consumption in the energy sector in that country.

2 Note that this calculation does not include any additional water added to the waste before it is put into the digester.

3. PLANT CAPACITY

The section starts by describing how administrative data and local knowledge should be used to develop the overall approach to collecting biogas capacity statistics. It then presents two options for collecting this data:

1. Survey of standardised plant types
2. Survey of biogas plant dimensions

To simplify calculations, tables at the end of this report present estimates of total plant volume for a range of different digester types and dimensions (diameter, height, length, etc.).

ADMINISTRATIVE DATA

In many countries, most small-scale biogas plants have been built under biogas projects or programmes supported by the government, non-governmental organisations (NGOs) or other similar agencies. These organisations may have databases that record useful information such as the number of biogas plants built in different areas, the type and size of biogas plants built and possibly even the detailed location of biogas plants (for an example from China, see Appendix 2).[3]

If administrative data such as this is available, it should be collected as part of the development of a biogas survey, because it can be used to improve survey design. Even if such information is not available, obtaining local knowledge and expert opinion may still be useful to assist with some aspects of the survey design.

Biogas plant designs and capacities

Information about the different types of biogas plants in a country can be used in the questionnaire design.

For example, if all of the biogas plants in a country are built to one design, then the dimensions that should be measured and recorded in the biogas survey can be standardised on the questionnaire, the conversion of these measurements into volumes can be simplified, and the training of data collectors can focus on these measurements. Furthermore, if biogas plants are built in a limited number of standard sizes that are well known to plant owners or can be easily recognised in the field, then it may be possible to collect capacity data using a few simple categories (see Module M1 below).

If there is a wide variety of different biogas plant designs used in a country or if biogas plants are built in many different sizes, then a more complicated questionnaire design may be needed to collect the measurements required to calculate capacity.

Sampling and interpretation of results

To reduce the cost of data collection, survey locations are often organised into clusters and information about the number of biogas plants in different parts of a country can be used as part of the process to select survey locations.

For example, at a very simple level, administrative data can show where most biogas plants have been built, so that the selection of survey sites can focus on those areas. For a more complex survey design, this information can also be combined with other relevant variables (e.g. local climatic data) to stratify locations before selecting clusters.

Administrative data is also be useful for interpreting the survey results, so that the total capacity recorded in the survey can be multiplied by an appropriate factor to produce an estimate for the whole country.

If the administrative data includes details about variables such as the size and types of biogas plants in different parts of a country, it may also be used to adjust the survey results to make them more representative (post-stratification).

Annual updating between surveys

The third important use of administrative data is to update national biogas statistics between surveys.

Most types of biogas digester should work for many years, so collecting detailed biogas data every year will not be cost-effective. Instead, data can be collected using surveys every five years, and administrative data can be used to update these statistics (with estimates) in the years between surveys.

For example, the number of new biogas plants built in a country each year can be compared to the number at the start of the year, so that capacity and production figures can be increased by a similar proportion. If administrative data is available split into plant types and/or size categories, then the

[3] Other useful data sources for survey development include household or business energy surveys, population and housing censuses, living standards surveys or agricultural censuses. If information about energy use is collected in these surveys (e.g. the types of energy used for cooking in households), then this can also be used to develop a sampling strategy for a biogas survey. Indeed, where biogas is important in a country or growing rapidly, energy statisticians should make sure that it is included as a possible answer to any energy questions in national surveys (see Section 5).

national statistics can be updated using this more detailed information.

The main problem with annual revisions such as this is that they do not take into account the capacity of biogas plants that stop working in a year. This should be subtracted from the capacity of new plants built in a year to get the net additions to capacity. However, considering that most biogas plants have probably been built in the last 5-10 years in many countries, such an adjustment may not be necessary in most places.

Survey of standardised biogas plant types

If administrative data suggests that most biogas plants in a country have been built to a standard specification and in a limited number of sizes, then it may be possible to collect data by asking owners or operators about the size of their biogas plant.

For example, biogas plants built under the National Domestic Biogas and Manure Program (NDBMP) in Bangladesh have been built in twelve different sizes, with six different levels of expected biogas production for owners that will feed the digester with cattle or poultry waste. Deenbandhu biogas plants in India are also often built to take cattle waste and produce one of four possible levels of daily gas production: 2 m^3, 3 m^3, 4 m^3 and 6 m^3 (Kudaravelli, 2013).

If biogas plant owners or operators know the expected daily gas production of their plant or have an operating manual or guidebook, then this information can be collected using questions such as those shown in questionnaire Module M1.

It is recommended that this approach should only be used where capacity is measured as daily gas production, as biogas plant owners will probably not know the total volume of their plant and will not be able to answer questions about this.

Table 1: Standard sizes (models) of fixed dome biogas plants used in Bangladesh

Rated daily gas production (m^3/day)	Effective digester volume (m^3)	
	Cow	Poultry
1.2	3.0	2.3
1.6	3.8	3.0
2.0	4.8	3.9
2.4	5.8	4.5
3.2	7.8	6.0
4.8	11.8	9.3

Source: derived from NDBMP (2013).

M1: Plant capacity (rated daily gas production)

1. Have you used your biogas plant in the last year? *(tick one)*

   Yes ☐
   No – I stopped using it last year ☐
   No – I haven't used it for over a year ☐

2. What is the main type of waste that this plant is designed to use? *(tick one)*

   Cattle ☐
   Poultry ☐
   Don't know ☐

3. How much gas is the plant designed to produce each day? *(tick one or write in)*

   Don't know (go to ....) ☐
   1.2 m^3/day ☐
   1.6 m^3/day ☐
   2.0 m^3/day ☐
   2.4 m^3/day ☐
   3.2 m^3/day ☐
   4.8 m^3/day ☐
   Other (write in) ☐

Daily gas production statistics can be converted to total plant volumes during data processing, using the design specifications for biogas plants built in a country (for example, see Table 1).

It is also recommended that plant owners should be asked whether they have used their plant in the last year. This information can be used to estimate how many biogas plants stop working each year. Routing in the questionnaire ("go to" instructions) can also direct the data collectors to collect the measurements of a biogas plant if its owner does not know the rated daily gas production.

Survey of biogas plant dimensions

If there are many different types and sizes of biogas plants in a country or if plant owners do not know the capacity of their plants, then it will be necessary to measure or estimate the dimensions of each plant and calculate its total volume.

Most biogas plants are built using one of the designs described in Section 2 and, for each of these, the total plant volume can be calculated from one or two simple dimensions (usually diameter and length or height). For situations where part or all of a biogas plant is buried under ground, these dimensions may be difficult to measure directly. Therefore, the following text also presents some ideas about how these dimensions may be estimated.

To calculate gas production, it may also be necessary to know how the total plant volume is divided into the digester volume and gas storage volume. In most cases, these two volumes cannot be measured directly, so Table 2 below presents average values for the digester and gas storage volumes (as a proportion of total plant volume). These figures should be adjusted to reflect local biogas plant designs if expert knowledge or other information is available.

Table 2 also presents multiplication factors that can be used to estimate the total plant volume (and its two components) from the rated daily gas production of different types of plants. The main assumption in the table is that the gas storage volume in a biogas plant is usually designed to hold 60% of the rated daily gas production. Again, these figures can be adjusted with local information if available.

Questionnaire Module M2 presents some questions that could be used to record biogas plant dimensions. This should be adjusted to reflect the types of digesters used in a country (i.e. some of these questions may not be needed).

The remainder of this section describes how data collectors can measure these dimensions in the field and how they can be used to calculate plant volume for each of the main types of biogas digester.

M2: Plant capacity (type and dimensions)

1. Indicate the type of biogas plant that is being measured. *(tick one)*

Fixed dome plant (hemisphere)	☐
Fixed dome plant (Deenbandhu)	☐
Fixed dome plant (Chinese design)	☐
Floating drum plant	☐
Balloon/bag digester	☐
Non-standard design (go to Q3)	☐

2. Write in the dimensions of the biogas plant as indicated below. *(to the nearest cm)*

	m	cm
Diameter		
Digester height (floating drum)		
Gas holder height (floating drum)		
Length (balloon/bag digester)		

3. If non-standard design, sketch the plant below and show the main dimensions

Table 2: Proportions and multiplication factors to convert total plant volume and rated daily gas production into digester volume and gas storage volume

Biogas plant type	Digester and gas storage volumes as a share of total plant volume			Multiplication factors to convert gas production to plant volume		
	Digester volume	Gas storage volume	Total volume	Digester volume	Gas storage volume	Total volume
Fixed dome plant	80%	20%	100%	2.4	0.6	3.0
Floating drum plant	70%	30%	100%	1.4	0.6	2.0
Balloon/bag digester	75%	25%	100%	1.8	0.6	2.4

Note: If a fixed dome plant has a rated daily gas production of 1.2 m^3/day, the multiplier above suggests that total plant volume would be 1.2 x 3 = 3.6 m^3. However, the above figures are averages and should be replaced by figures based on local biogas plant designs where available (e.g. see Table 1).

Fixed dome plant (hemisphere design)

This plant design consists of a hemisphere with a flat bottom. Countries that use this design of biogas plant include: Viet Nam (KT Model); Tanzania (CAMARTEC Model); and Cambodia (modified Deenbandhu design).

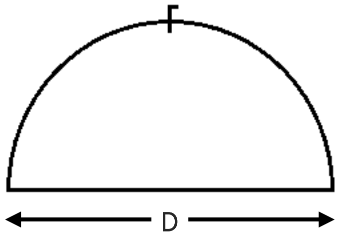


Figure 4: Fixed dome plant (hemisphere design)

Measurement: For this type of biogas plant, it is only necessary to measure the diameter of the base of the digester (D). This can be done as follows:

- If the dome is located above ground, the diameter can be calculated by measuring the circumference of the dome at its base and dividing this measurement by 3.14 (π). An alternative is to measure across the top of the dome and divide the measurement by 1.57.

- If the dome is buried underground, the diameter can be estimated by measuring the distance from the gas outlet pipe to the closest side of the displacement tank and multiplying the answer by 2. (This assumes that the displacement tank has not been built partly on top of the dome).

Volume calculation: For data processing, the total plant volume (V_p) can be calculated as the volume of a hemisphere:

$$V_p = \frac{2}{3}\pi\left(\frac{D}{2}\right)^3$$

Following Table 2, the digester volume (V_d) can be calculated by multiplying the total plant volume by 0.65 and the gas storage volume (V_g) can be found by multiplying the total plant volume by 0.35 (for variations to these calculations, see Heegde, 2010).

A lookup table showing total plant volume, digester volume and gas storage volume for a range of diameters is given in Table 10 in Appendix 1.

Fixed dome plant (Deenbandhu design)

The Deenbandhu design combines a hemisphere with a curved base. Based on the specifications of a number of different sizes of Deenbandhu digesters given in Kudaravelli (2013), the depth of the curved base of this design (k) is usually about 40% of the radius (r) of the digester.

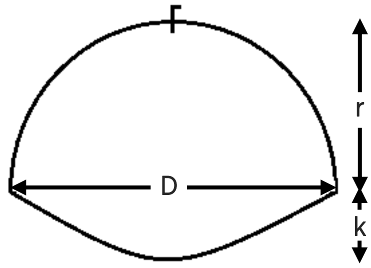


Figure 5: Fixed dome plant (Deenbandhu)

Measurement: To calculate the volume of a Deenbandhu digester, it is also only necessary to measure the maximum diameter (D) of the digester and this can be done in the same way as described for the hemisphere design.

Volume calculation: For data processing, it is necessary to calculate the radius (r) of the digester (r = D/2) and the depth of the curved base (k = 0.4r). The total plant volume (V_p) can then be calculated as the volume of a hemisphere and sphere segment:

$$V_p = \frac{2}{3}\pi r^3 + \frac{1}{6}\pi k(3r^2 + k^2)$$

The digester volume (V_d) and gas storage volume (V_g) can be calculated as before (by multiplying the total plant volume by 0.65 and 0.35 respectively) and a lookup table for these volumes across a range of diameters is given in Table 11 in Appendix 1.

Fixed dome plant (Chinese design)

The Chinese design of a fixed dome plant consists of a hemisphere on top of a cylinder with a curved or flat bottom. This type of digester is common in China and may also be found in other countries that have received assistance and training from the Biogas Institute of the Ministry of Agriculture in China (BIOMA).

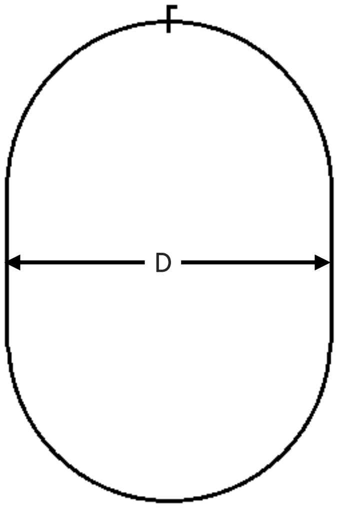


Figure 6: Fixed dome plant (Chinese design)

Measurement: A standard plant design has been developed by the Biogas Training Centre in Sichuan, China (LGED, 2002) and the volume of plants built following that specification can be calculated from the diameter of the plant (which can be measured as described previously).

Volume calculation: the total plant volume (V_p) following this design can be calculated from the measured diameter (D) as follows:

$$V_p = \frac{D^3}{2.2368}$$

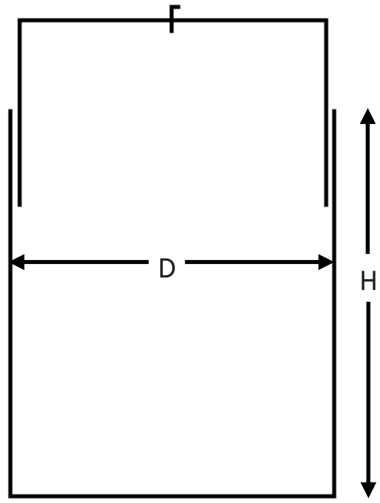
The digester volume (V_d) and gas storage volume (V_g) can be calculated as before and a lookup table for these volumes across a range of diameters is given in Table 12 in Appendix 1.

Above ground plants: Plants built above ground are likely to have a flat bottom. In such cases, the height of the cylindrical part of the digester should be measured and the volume can be calculated using a combination of the formulae for a hemisphere design and the balloon digester design (see below).

Other combinations of a cylinder with a flat base and dome or curved top may also exist. In such cases, height and diameter should be measured and local formulae should be developed to calculate total plant volume from these measurements.

Floating drum plant

Floating drum plants are usually circular, so their volume can be calculated as the volume of two cylinders. The larger cylinder is the digester, which may be partly or totally underground and the smaller cylinder is the gas storage tank, which is placed on top and inside this.



TAKING MEASUREMENTS

Measurement: For this type of biogas plant, it is necessary to measure both the diameter of the digester (D) and the height of the digester (H). This can be done as follows:

- The diameter of the digester can be measured directly if a tape can be placed across the top of the gas storage tank. Alternatively, it can also be calculated by measuring the circumference of the digester or gas storage tank and dividing this measurement by 3.14 (π). If the circumference of the digester is measured, the thickness of the walls of the digester should be subtracted from the answer to get the internal diameter of the digester.

- If the digester is completely above ground, then the height of the digester should be measured from its base to the top of the digester wall. If it is partly underground, then the maximum height of the gas storage tank should be measured (or estimated if it is not full) and the digester height should be estimated as a multiple of this. For example, the gas storage volume in the KVIC floating drum design is 30% of the total plant volume, so the digester height can be calculated by multiplying the height of the gas storage tank by 2.3 (i.e. 70/30).

Volume calculation: The total plant volume (V_p) can be calculated as the sum of the digester volume (V_d)

and the gas storage volume (V_g), where these are calculated as follows:

$$V_d = \pi \left(\frac{D}{2}\right)^2 H$$

$$V_g = 30/70 \times V_d$$

$$V_p = V_d + V_g$$

The calculations above assume that floating drum plants are cylindrical and are built so that the gas storage and digester volumes are in the ratio of 30:70. If the ratio of gas and digester volumes are different in a country (or plants are not circular), then the above calculations should be adjusted to reflect this. Similarly, if floating drum digesters are built to several different designs in a country, then it may be necessary to use a more complicated questionnaire and take more measurements so that volume can be calculated.

The above calculations have been based on the standard specifications for a KVIC plant and a lookup table (based on this) showing total plant volume, digester volume and gas storage volume for different diameters and heights is given in Table 13 in Appendix 1.

Balloon digester

When fully expanded the shape of a balloon digester will be similar to that of a cylinder, so the total plant volume can be calculated as the volume of a cylinder. A review of the literature on balloon digesters suggests that the digester volume is around 75% of the total plant volume and the gas storage volume is around 25%, so these two figures can be used to divide the total plant volume into these two components.

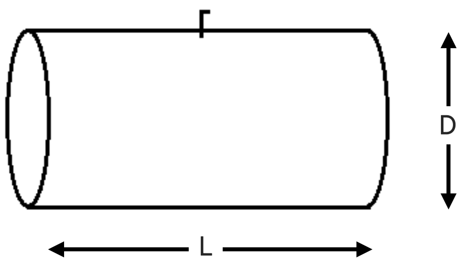


Figure 7: Balloon digester

Measurement: To calculate the volume of a balloon digester, it is necessary to measure the diameter of the digester (D) and the length of the digester (L). This can be done as follows:

- The diameter of the digester should be measured from top to bottom across one of the ends of the digester when the bag is fully expanded. If the bag is not fully expanded, this may be estimated measuring the distance and asking the biogas plant owner how much higher it expands. Alternatively, if the bag is made of two pieces of plastic (with visible seams), it may be possible to measure across the top of the bag from seam to seam and divide that measurement by 1.57 to calculate the diameter.

- The length of the bag should be simply measured from one end to the other. This measurement should be taken across the top of the bag in a straight line (by holding the tape tight) and should not include any part of the bag that would form the ends of the cylinder when fully expanded. Again, it may be possible to measure from seam to seam if the circular ends of the bag have been joined to the main part of the cylinder with visible seams.

Volume calculation: The total plant volume (V_p) can be calculated as the volume of a cylinder as follows:

$$V_p = \pi \left(\frac{D}{2}\right)^2 L$$

The digester volume (V_d) and the gas storage volume (V_g) can be calculated by multiplying the total plant volume by 0.75 and 0.25 respectively.

A lookup table showing total plant volume, digester volume and gas storage volume for various diameters and lengths of balloon digesters is given in Table 14 in Appendix 1.

Chinese bag digester: The volume of a bag digester of the Chinese design (circular digester with a bag on top) can be measured and calculated in a similar way to the floating drum plant.[4] However, if the digester is partly or totally underground and cannot be measured directly, it will be necessary to ask the biogas plant owner to estimate the depth (height) of the digester.

The gas storage volume (in the bag) should be about one-quarter of the total plant volume, so it can be calculated as the measured digester volume (V_d) divided by three (i.e. 25/75 = 1/3), but the ratio of gas storage and digester volumes should be checked with local biogas plant designs and adjusted in the calculation as necessary.

4 By measuring and calculating the digester volume, estimating the gas storage volume relative to that and adding the two volumes together to get total plant volume.

4. BIOGAS PRODUCTION AND CONSUMPTION

Five different methodologies are presented here for calculating or estimating biogas production and consumption. Estimates can be based on plant capacity, appliance use or feedstock use or by comparing fuel use in households with and without a biogas plant (the fuel substitution method). Biogas production may also be measured directly.

Biogas production is usually measured or estimated in cubic metres over a period of time, but it should be converted and reported in energy units. The main calculations are to convert biogas production into methane production and then convert that into energy production (in MJ). The methane content of biogas should be about 65% and 1 m^3 of methane contains 34 MJ of energy, so 1 m^3 of biogas should contain about 22 MJ of energy.

CONVERSION FACTORS

- 1 m^3 of biogas = 0.65 m^3 of methane
- 1 m^3 of methane = 34 MJ of energy
- 1 m^3 of biogas = 22 MJ of energy
- 1 m^3/day of biogas = 8,060 MJ/year

A summary of the advantages and disadvantages of the different estimation methodologies is given in Table 3. The more complicated methodologies will give more detailed and accurate estimates of biogas production, but will be more difficult and expensive to implement. Therefore, the choice of methodology should be based on the purpose of the survey and availability of resources.

Table 3: Summary of the different methods to estimate biogas production

Estimation methodology	Advantages	Disadvantages
Plant capacity: Estimate production from capacity data using a capacity utilisation figure.	Useful to make estimates from administrative data or simple surveys of plant capacity. Can be used to produce annual estimates of production in between biogas surveys.	The accuracy of estimates will depend on how much is known about capacity utilisation. This method may be difficult to use if many different types and sizes of biogas plants exist.
Appliance use: Collect data on appliance use (hours per day and gas per hour) and use this to estimate consumption.	This requires a small number of questions that can be integrated into existing household surveys. It can be used to produce detailed estimates of consumption as part of larger surveys or as a relatively small energy survey.	Biogas users may not know how much they use biogas appliances. There may be a difference between biogas consumption and production.
Feedstock use: Collect data on digester size, technology and feedstock use and calculate the expected level of gas production.	This method calculates production based on feedstock use rather than assumptions about capacity utilisation. It is most suitable for including in detailed household energy surveys. Results can also be used to calculate capacity utilisation figures.	Data collection requires a detailed set of questions and more complex calculations to produce results. Estimates of feedstock inputs may not be accurate, but errors may be lower than in other methods.
Fuel substitution: Collect data on fuel use in households with/without or before/after connection to biogas and estimate consumption from the use of other fuels.	This requires a small number of questions that can be integrated into existing household surveys. This approach is particularly useful for project monitoring and for examining socio-economic and environmental aspects of fuel switching.	More complex analysis is required to adjust for household characteristics in the comparison of fuel use. Total energy use may also differ between households using or not using biogas.
Direct measurement: Biogas production is recorded over a period of time by mechanical devices (flow meters).	This method will give the most accurate and detailed measurements of biogas production. It is only likely to be cost-effective for large-scale production or for detailed research into the design and operation of biogas plants.	Measuring devices are expensive and may require specialised training to use. It may also still be necessary to estimate annual production from measurements taken over a short time period.

Plant capacity

The simplest way to estimate annual biogas production is to calculate the theoretical level of production from plant capacity data and adjust this for capacity utilisation (where possible).

Measurement: For this method, plant capacity can be taken from administrative data or the results of capacity surveys.

Calculation: If biogas capacity is recorded as the rated daily gas production of biogas plants (see Section 3) then the maximum potential biogas production in a country is calculated as total plant capacity multiplied by 8,060 (i.e. to convert from daily biogas production in m^3/day to biogas energy production in MJ/year).

If capacity is recorded as total plant volume (in m^3), then it should be converted to estimated daily gas production using figures such as those shown in Table 2. For example, Table 2 shows that the total plant volume of fixed dome plants should be about twice the daily volume of biogas production, so total plant volume (in m^3) divided by two will give an estimate of total daily gas production (in m^3/day). This can then be multiplied by 8,060 to get a figure for biogas energy in MJ/year.

The result of these calculations is the maximum theoretical or potential level of gas production in a country, but this assumes that all biogas plants are operated under optimal conditions (e.g. with the correct preparation of feedstocks, ideal operating temperatures, etc.). Real operating conditions are unlikely to be ideal, so this figure should be multiplied by a capacity utilisation factor (%) to take this into account.

The main advantage of this methodology is that plant capacity data can be converted into estimates of biogas production with simple calculations. The main problem is that the results of these calculations should be adjusted for capacity utilisation, which will often be unknown and could be as low as 40-60% (NDBMP, 2013).

To solve this problem, capacity utilisation may be estimated from local expert knowledge or from a more detailed survey of sample of biogas plant owners (comparing rated and actual production levels). This information may also be obtained gradually over time as more biogas data is collected in a country.

Appliance use

A second method to estimate biogas production is to collect information about the use of biogas-powered appliances (e.g. lamps and stoves). This can then be used to calculate the annual biogas consumption of households.

Measurement: Survey questions should collect information about the types of household appliances using biogas, the amount of biogas used in each appliance (its power rating) and the average number of hours each appliance is used every day.

An example of the questions that could be used is shown in questionnaire Module M3. Questions 1-3 ask about the power rating and use of biogas lamps, questions 4-5 ask about biogas used for cooking and questions 6-7 ask if the household has to burn excess biogas (biogas flaring).[5]

Data should be collected about the average power rating of each biogas lamp and each burner on a biogas stove. So for example, if a household has one lamp that uses 60 litres of biogas an hour and another that uses 100 litres/hour, the average power rating of the biogas lamps would be 80 litres/hour. Similarly, if a biogas stove has two burners and a total power rating of 5,000 watts, the power rating of each burner would be 2,500 watts.

Data collectors should ask about these power ratings, but should also check the answers to these questions by looking at technical manuals or on any labels on appliances (if available). They should also be very careful to record the power rating of each lamp and burner and not the total power rating of all lamps and burners.

In countries where the power ratings of biogas lamps and stoves are standardised, it may also be possible to collect this data using a limited choice of answers (e.g. lamps of 100 W, 200 W and 300 W) rather than asking about the exact power rating of appliances.

Calculation: Biogas energy consumption can be calculated in four steps.

Step 1: All of the measurements of the power rating of appliances should be converted into a common unit of m^3/hour. For data recorded in litres per hour, the measurements should be divided by 1,000. For data recorded in watts, the measurements should be divided by 6,100 (i.e. 1 m^3 of biogas contains 22 MJ, which is the same as 6,100 watt-hours).

[5] If a household has a biogas plant that produces more biogas than they can use, then they may have to burn the excess biogas for safety reasons. This can occur if an over-sized biogas plant has been built by mistake or if it has been designed to manage a waste problem.

M3: Appliance use

1. Do you use any biogas lamps? *(tick one)*

Yes	
No (go to Q4)	

2. What is the average power rating of each lamp? *(tick don't know or write in number in* *<u>either</u>* *litres/hour or watts)*

Don't know	
Gas use in litres/hour	
Power in watts	

3. On average, how many hours per day do you use each lamp? *(write in no. of hours)*

	hrs/day
Gas lamp 1	
Gas lamp 2	
Gas lamp 3	

4. What is the power rating of each burner on your biogas stove? *(tick don't know or write in number in* *<u>either</u>* *litres/hour or watts)*

Don't know	
Gas use in litres/hour	
Power in watts	

5. On average, how many hours per day do you use each burner for cooking and boiling water? *(write in no. of hours)*

	hrs/day
Burner 1	
Burner 2	
Burner 3	

6. Do you also burn excess biogas? *(tick one)*

Yes	
No (go to......)	

7. On average, how many hours per day do you use each burner to burn excess biogas? *(write in no. of hours)*

	hrs/day
Burner 1	
Burner 2	
Burner 3	

Step 2: The second stage is to complete the set of power rating measurements by using estimates in cases where the household did not know this information or it could not be obtained from manuals or labels on appliances.

There are many ways of replacing missing data with substituted values (imputation). The simplest is to calculate the average of all recorded measurements and use that value for all missing data. Alternatively, national minimum standards for appliances can be used or average values may be taken from other studies and used. Some examples of minimum standards for biogas burners and estimates of biogas use in lamps are shown in Table 4.

Table 4: Examples of appliance power ratings

Biogas lamps (averages)	
Cambodia	0.049 m^3/hr
Ethiopia	0.048 m^3/hr
India	0.093 m^3/hr
Biogas stove burners (minimum standards)	
China	0.380 m^3/hr
India	0.450 m^3/hr
Kenya	0.500 m^3/hr

Sources: Khandelwal and Gupta (2009); KBS (2013).

Step 3: The third stage is to calculate the average daily biogas consumption of each household by multiplying the average power rating of biogas lamps (m^3/hr) by the total number of hours they are used and the power rating of burners by the total number of hours they are used for cooking and flaring. This should give the daily biogas consumption (in m^3) for lighting, cooking and flaring in each household.

Step 4: The last stage in the calculation is to multiply these results by 8,060 to convert the figures into MJ/year per household. These figures can then be used to produce regional and national estimates, using the appropriate multiplication factors to convert the sample results to population estimates.

When this is done, the biogas consumption for lighting and cooking should be recorded as final consumption in the appropriate end-use sectors in the energy balance, any biogas used for flaring should be recorded as losses and the total of all three uses can be recorded as primary energy supply.

FEEDSTOCK USE

Biogas production can also be estimated from information about the amount and type of feedstocks used in digesters. The amount of data required is similar to other methodologies, but the calculation of biogas production is slightly more complicated. However, these calculations can also provide useful information about the operation of biogas digesters in a country.

Measurement: Digester volume is used to calculate biogas production, so this must be measured or estimated (see previous section). In addition, data also needs to be collected about the weight and volume of different feedstocks added to the digester each day. Questionnaire Module M4 shows some questions that could be used.

The first question asks about animal waste. Rather than asking about the amount of waste added to the digester, this asks about the number of animals that provide waste for the digester. Various studies have reported the weight of waste produced by different animals and these figures can be used in the calculations (see Table 5).

The second question asks more directly about the weight of other materials added to the digester (in kg/day). This should not include any water added to the waste (this is a separate question).

Cereals/grains are high value inputs with a lot of energy content that may only be added if respondents are deliberately trying to increase gas production. The other inputs are all wastes. If respondents cannot divide their waste inputs by type, then these inputs can be recorded as mixed food waste or mixed organic waste.

If biogas plant owners are unable to answer this question, then it may be possible to estimate the inputs by asking about the container used to collect the waste (probably a large bucket) and then by weighing one bucket full of waste and asking them how many bucket loads they add a day. Another alternative is to ask about (or calculate) the volume of the bucket and assume that 1 litre = 1 kg, then calculate the weight added from the number of bucket loads per day (as described above).

The last question asks about how much water is added to the digester. Wastes are usually mixed with water when they are added to a digester, so the easiest way to ask about this is to ask about how much water is added compared to the amount of waste added. (Note, this should include the water added to both animal and other wastes).

M4: Feedstock use

1. Do you feed the digester with waste from any of the following animals? *(write in no. of animals providing waste for digester)*

	No.
Buffalo	
Cows	
Calves	
Sheep/goats	
Pigs	
Hens	
Horses	
Humans	

2. How much of the following types of waste do you usually add to the digester each day? *(write in amount in kg)*

	Kg/day
Cereals/grains	
Rice straw	
Wheat straw	
Grass	
Corn stalk	
Fruit waste	
Vegetable waste	
Fats	
Mixed food waste	
Mixed organic waste	

3. When you feed the digester, how much water do you add compared to the amount of waste? *(tick one, check that this includes the water added to animal wastes)*

Half as much water	
An equal amount of water	
Twice as much water	
Three times as much water	
Over three times as much water	
Don't know	

Calculation: For any one feedstock, daily biogas production can be estimated using the following equation (Fulford, 2015):

$$G = C \times V_d \times S \times \left(\frac{k}{1 + kR}\right)$$

Where:

- G is the biogas production (in m^3/day)
- C is the biogas potential, which is the maximum amount of gas that can be produced from 1 kg of volatile solids in a feedstock (in m^3/kg)
- V_d is the digester volume (in m^3)

- S is the initial concentration of volatile solids in the slurry (in kg/m^3)
- R is the feedstock retention time (in days)
- k is a constant indicating the rate of gas production at a given temperature

To simplify this equation, IRENA has calculated gas production across a wide range of temperatures and retention times, so that biogas production can be calculated as follows:

$$G = \frac{Y \times V_d \times S}{1000}$$

Where G, V_d and S are the same as before and Y is a yield factor based on temperature and the feedstock retention time (see Table 7).[6]

Assuming that the digester volume (V_d) has already been calculated, it is only necessary to calculate the feedstock retention time (R) and initial concentration of volatile solids (S) in order to calculate daily biogas production and this can all be done in the following four steps.

Step 1: First, the total feedstock volume should be calculated. This starts by multiplying the number of animals recorded in the survey by the total waste production per day (from Table 5) and adding to this the total weight of all other feedstocks used. This gives the daily waste input in kg. This figure can be assumed to be about the same as the volumetric input in litres. The answer to question 3 is then used to multiply that value to take into account the added water (e.g. if they add twice as much water then the waste input should be multiplied by three). The final value is divided by 1,000 to convert from litres to m^3.

Step 2: The feedstock retention time is calculated by dividing the digester volume by the total feedstock volume. So, for example, if the digester volume is 5.0 m^3 and the total daily feedstock volume (including water) is 0.08 m^3/day, the feedstock retention time (R) is 5.0/0.08= 62.5 days.

Step 3: The initial concentration of volatile solids (S) is calculated by dividing the weight of volatile solids added each day by the daily waste inputs. The weight of volatile solids from animal waste can be calculated from the figures shown in Table 5 and the numbers of animals providing waste for the digester. The weight of volatile solids from other wastes can be calculated using the figures shown in Table 6.[7] These figures can then be added together to get the total weight of volatile solids added each day, which can be divided by the total feedstock volume.

So, for example, if the weight of volatile solids added each day is 5.6 kg/day and the daily feedstock volume is 0.08 m^3/day, the initial concentration of volatile solids (S) is 5.6/0.08 = 70 kg/m^3.

Table 5: Animal waste feedstock properties

Animal	Total production (kg/day)	Volatile solids (kg/day)
Buffalo	14	1.94
Cow	10	1.42
Calf	5	0.50
Sheep/goat	2	0.44
Pig	5	1.00
100 hens	7.5	2.77
Horse	10	2.24
Human	0.2	0.03

Sources: Kudaravalli (2014); Fulford (2015); Lorimor et al (2004); SEAI (2012).

Table 6: Other feedstocks volatile solid content

Animal	Volatile solids (in %)
Cereals/grains	0.81
Rice straw	0.36
Wheat straw	0.39
Grass	0.51
Corn stalk	0.43
Fruit waste	0.14
Vegetable waste	0.16
Fat	0.83
Mixed food waste	0.08
Mixed organic waste	0.26

Sources: Rajendran et al (2012); Fulford (2015); SEAI (2012).

Step 4: The final step in the calculation is to use the feedstock retention time and temperature in the

6 These yield factors have been derived by calculating gas production for different combinations of temperature and feedstock retention time, using values of C and k that are typical for the feedstocks used in small-scale digesters. This is a simplification of the first equation, which would require calculating daily gas production for each and every feedstock used in the digester.

7 This proportion is calculated from the total solid content in a feedstock (in percent) multiplied by its volatile solid content (measured as a percentage of solid content). For feedstocks not shown in Tables 6 and 5, estimates of these values can be found in many different biogas studies.

country to find the yield factor and use this to calculate daily gas production and annual energy production in MJ.

So, for example, if the feedstock retention time of a biogas plant is 62.5 days and the average temperature in a country is 23 °C, the yield factor (Y) would be 3.33.

A table of average annual temperatures in different countries and areas is given in Table 15 in Appendix 1. If a biogas digester is buried underground, an additional 2 °C should be added to the average temperature to account for this.

With a yield factor (Y) of 3.33, digester volume (V_d) of 5.0 m^3 and initial concentration of solids (S) of 70 kg/m^3, daily gas production would be calculated as follows:

$$G = \frac{3.33 \times 5 \times 70}{1000} = 1.17\ m^3/day$$

The figure for daily gas production can then be converted into annual energy production in megajoules by multiplying by 8,060, as before (i.e. 1.17 m^3/day x 8,060 = 9,430 MJ/year).

Table 7: Yield factors for biogas production, by temperature and feedstock retention time

Feedstock retention time (in days)	Temperature (°C)					
	16-18	19-21	22-24	25-27	28-30	31-33
6-10	5.41	7.98	10.83	13.59	15.91	18.33
11-15	4.73	6.79	8.99	11.09	12.88	14.74
16-20	4.21	5.90	7.68	9.37	10.82	12.32
21-25	3.79	5.22	6.70	8.11	9.33	10.59
26-30	3.44	4.69	5.95	7.15	8.20	9.28
31-35	3.16	4.25	5.35	6.39	7.32	8.26
36-40	2.91	3.88	4.86	5.78	6.60	7.44
41-45	2.71	3.58	4.45	5.27	6.02	6.77
46-50	2.53	3.32	4.10	4.85	5.53	6.21
51-55	2.37	3.09	3.81	4.49	5.11	5.74
56-60	2.23	2.89	3.55	4.18	4.75	5.33
61-65	2.10	2.72	3.33	3.91	4.44	4.98
66-70	1.99	2.57	3.13	3.67	4.17	4.67
71-75	1.89	2.43	2.95	3.46	3.93	4.40
76-80	1.80	2.30	2.80	3.27	3.71	4.15
81-85	1.72	2.19	2.66	3.10	3.52	3.94
86-90	1.65	2.09	2.53	2.95	3.34	3.74
91-95	1.58	2.00	2.41	2.81	3.19	3.56
96-100	1.52	1.92	2.31	2.69	3.04	3.40

FUEL SUBSTITUTION

Given that biogas replaces other fuels, biogas consumption can be estimated by looking at the quantity of other fuels consumed by households with and without biogas plants. This approach is often used as part of biogas projects, where fuel consumption is compared before and after a household is connected to a biogas plant. Alternatively, fuel consumption can be compared across a sample of households with and without biogas plants, after correcting for other factors such as household size and location.

For example, a biogas survey in Bangladesh found that households were saving 249 kg/month of fuelwood on average after switching to biogas, ranging from 186 kg/month for households with a 1.6m^3 plant to 394 kg/month for those with a 4.8m^3 plant (iDE, 2011). Another analysis in Nepal estimated that fuelwood use in households with biogas plants was 1,100 kg/year less than the 2,400 kg/year used in households without biogas plants (Somanathan and Bluffstone, 2015).

The two main disadvantages of this approach are the difficulties of measuring accurately the use of other fuels by households and the possibility that total energy use in a household may change if they have a biogas plant. For example, houses switching from fuelwood to biogas may use more total energy if their biogas plant produces a lot of biogas.

Measurement: Information about the amounts of different fuels used in a household can be collected using a very simple question, such as that shown in Questionnaire Module M5. Households with a biogas plant could be asked in one survey how much they were using before it was installed and now, but their answers about fuel use before the plant was installed could be unreliable. Thus, this question should be asked in two surveys, before and after a biogas plant is installed (e.g. as part of project monitoring); otherwise, a sample of households with and without biogas plants can be asked this question in one survey.

These questions can be asked using a variety of different units. However, it is advisable to record responses in kg or litres per day. So, for example, if a household buys kerosene in 1 litre bottles and they last about 4-5 days on average, then the daily consumption would be 1/4.5 = 0.22 litres/day.

Calculation: To calculate the energy provided by biogas, it is necessary to compare the consumption of fuels in households with and without biogas (or before and after a biogas connection) and correct for the efficiencies of the different devices typically used for cooking with different fuels.

M5: Fuel use

1. How much of the following types of fuel do you use for cooking each day? *(write in amount in kg or litres)*

Fuelwood		Kg/day
Charcoal		Kg/day
Kerosene		Litre/day
Bottled gas (LPG)		Litre/day

Table 8: Biogas energy content comparisons

Amount and type of fuel	Volume of biogas with same energy content (m^3)	
	Unadjusted	Adjusted
1 kg fuelwood	0.70	0.25
1 kg charcoal	1.40	0.65
1 litre kerosene	1.60	1.60
1 litre LPG	1.05	1.05
1 kg LPG	2.10	2.10

Note: Energy content of liquid propane gas (LPG) is given in kilograms and litres, in case it is recorded in kg.

The latter adjustment is important because some fuels are used in much less efficient cooking stoves. For example, biogas stoves are usually about three times more efficient than fuelwood stoves, so if the use of biogas in a household reduces the consumption of fuelwood for cooking by 6 kg/day, the biogas energy required to replace this is only equivalent to the energy content of 2 kg/day of fuelwood.

A more complex questionnaire format could ask about the different devices used for cooking and make more detailed adjustments for stove efficiency (for further information about stove efficiencies, see: Berkley Air Monitoring Group, 2012).

Table 8 shows the equivalent amount of biogas that would be required to replace one unit of fuel consumption used for cooking, with the adjusted column showing the figure after adjusting for stove efficiency. The adjusted figures can then be used with the survey data to estimate the energy provided by biogas.

For example, if connection to a biogas plant reduces the average fuelwood consumption of households by 6 kg/day, this suggests that the fuelwood energy used for cooking has been replaced by 1.5 m^3/day of biogas (i.e. 6 x 0.25 = 1.5). This can then be multiplied by 8,060 to calculate the annual energy consumption in MJ (1.5 x 8,060 = 12,090 MJ/year).

Direct measurement

An audit of biogas plants in Bangladesh found that in general only 40-60% of the expected daily gas production was available for use, due to factors such as construction failures as well as incorrect sizing and feeding (NDBMP, 2013). The low efficiency was also compounded by regular gas leakages and clogging of pipelines and appliances. Due to problems such as these, the most accurate way to measure biogas consumption is directly through the use of flow meters.

However, the use of flow meters also presents its own set of challenges including: the variable composition of biogas due to differing waste inputs; the relatively low gas pressures; and the high moisture and particulate content (Rouse, 2013).

Thermal mass flow meters are often used to measure biogas flow rates in industrial settings due to their ability to operate at low pressures and flow rates. However these devices tend to be built into the system limiting their application for portable and small scale use.

There are also a number of portable ultrasonic devices available on the market, some of which are developed specifically for household plant use. Such instruments are calibrated for low flow rates (e.g. between 0-4 m^3/hr) and take both gas flow measurements as well as cumulative flow. In addition, these flow meters are also often able to measure methane concentration.

Measurement: The measurement of biogas flow will require the attachment of a flow meter somewhere along the gas pipe, so that the cumulative flow can be measured over a period of time (e.g. several days). The meter can then be read and removed at the end of this period.

Calculation: The daily gas consumption can then be calculated by dividing the cumulative gas flow by the number of days that the meter was in place. This can then be converted into MJ/year as described previously.

While this approach will give very accurate measurements, it is likely to require technical expertise to attach these devices and the cost of flow meters may make this a very expensive exercise. Therefore, it is only likely to be justified for the measurement of gas production in large communal digesters or in situations where very detailed data is required for analysis.

5. OTHER INFORMATION ABOUT BIOGAS PRODUCTION

In addition to monitoring biogas production and consumption, biogas surveys also often ask a number of additional questions about the condition of biogas plants and the environmental and socio-economic impacts of biogas use.

This chapter provides examples of survey questions that can be used to measure other aspects of biogas production in the following areas:

- Financial and technical performance;
- Emissions reductions;
- Energy access and socio-economic impact.

Further information about the types of questions often asked in biogas surveys can be found in some of the project and programme evaluations implemented in countries such as Bangladesh, Nepal and Viet Nam (see references).

Financial and technical performance

Many surveys are implemented with the aim of monitoring the operational status of biogas plants installed under national programmes. Potential issues include construction defects in the inlet and outlet tanks, mixing devices and digesters, as well as biogas leakages due to cracks.

For example, in a biogas survey in Bangladesh, it was found that 18% of plants were either partially functioning or not functioning at all (NDBMP, 2013). Given some of the difficulties with maintaining biogas plants, regular surveys must be carried out to determine the proportion of plants that are functioning and to update statistics accordingly.

Related to this, surveys may also collect information about the maintenance support provided to households by biogas installers, both during the guarantee period and after this, as well as any training provided about how to use and maintain a digester. This can include collecting information about how the slurry from digesters are used, if manure management is an objective of the biogas programme.

Surveys may also collect information about financing, including the sources of finance used by households to pay for their digesters and any subsidies received.

The questions asked in a survey will depend on what needs to be monitored, but are likely to include a number of multiple choice questions. Some examples of the questions that may be useful are given in Questionnaire Module M5.

M6: Financial and technical performance

1. How did you finance the construction of your biogas plant? *(tick one)*

   Self-financed ☐
   Loan ☐
   Micro credit scheme/cooperative ☐
   Other ☐

2. Did you receive a subsidy? *(tick one)*

   Yes ☐
   No (go to Q4) ☐

3. Who provided the subsidy? (*write in name of the scheme*)

   [ ]

4. Does your biogas digester currently work? *(tick one)*

   Yes (go to Q7) ☐
   Partially ☐
   No ☐

5. Why is it not working properly? *(tick one)*

   Poor construction ☐
   Inadequate maintenance ☐
   Not enough waste and/or water ☐
   Blocked inlet/outlet/gas pipes ☐
   Other ☐

6. Briefly describe the problem? (*write in*)

   [ ]

7. Were you trained about how to maintain and operate the digester? *(tick one)*

   Yes ☐
   Yes, but did not attend ☐
   No ☐

8. What is the quality of repair and maintenance services available? *(tick one)*

   Good, repairs are carried out quickly ☐
   Adequate, repairs take some time ☐
   Poor, services are not available ☐

EMISSIONS REDUCTIONS

One of the main environmental benefits of biogas use is the reduction in greenhouse gas emissions that can occur if households switch to biogas from other types of fuel. For example, in Nepal biogas was the first renewable energy technology to receive support under the Clean Development Mechanism (CDM), with a total of around 60,000 plants registered under Project Activity 1-4 by December 2011 (Motherland Energy Group, 2013).

Biogas surveys are required to measure the emissions reductions from biogas installations for preparing and monitoring the performance of CDM projects and may also contribute to national greenhouse gas inventories.

Households switching to biogas may reduce emissions in three ways:

1. By reducing emissions from fuel use.
2. By reducing methane emissions from animal waste used in the digester.
3. By using slurry from the digester as fertiliser (replacing commercial fertiliser produced with high energy inputs).

The methodologies for estimating emissions reductions from animal waste and fertiliser use are complicated and will not be covered here. The following text will briefly describe how biogas data can be used to calculate emissions reductions directly associated with changes in fuel use. More detailed guidance on how to calculate emissions from fuel, animal waste and fertiliser use are given in IPCC (2006).

Measurement: The information required to calculate fuel emissions reductions can be collected using the fuel substitution method described in the previous section. In this case, the main difference in the analysis is that the unadjusted figures for fuel substitution (shown in Table 8) are used to calculate emissions reductions.

Calculation: Emissions from biogas use are zero,[8] so emissions reductions are calculated by multiplying the reduction in fuel use (after switching to biogas) by the amount of carbon dioxide that would have been emitted from burning those fuels.

The emissions from different fuels are calculated by multiplying the kilograms of CO_2 emitted per MJ of energy (from IPCC, 2006) by the energy content of each type of fuel. Table 9 shows the results of these calculations as emissions per kg or litre of fuel used.

Table 9: Emissions from burning different fuels

Amount and type of fuel	Emissions from fuel use (kg CO_2)
1 kg fuelwood	1.70
1 kg charcoal	3.45
1 litre kerosene	2.50
1 litre LPG	1.45
1 kg LPG	1.90

Source: Derived from IPCC (2006).

The figures in Table 9 above can then be used directly with the results of fuel substitution surveys to calculate the total emissions reductions from the use of biogas. For example, if connection to a biogas plant reduces the average fuelwood consumption of households by 6 kg/day, the CO_2 emissions reduction would be calculated as 6 x 1.7 = 10.2 kg/day or 3,725 kg/year.

For fuelwood and charcoal, emissions are usually adjusted by a factor that takes into account how much of that wood was produced from non-renewable sources (e.g. if the non-renewable supply of fuelwood is about 40% of total fuelwood supply, then the above figure would be multiplied by 0.4). However, for kerosene and LPG, the total amount of emissions would always be counted in the calculation.

ENERGY ACCESS AND SOCIOECONOMIC IMPACTS

The Sustainable Development Goal for energy (SDG 7) is to ensure access to affordable, reliable, sustainable and modern energy for all.

In order to track progress towards this goal, a number of indicators have been developed, one of which is: The proportion of the population with primary reliance on clean fuels and technology (Indicator 7.1.2).

Biogas used for cooking would be considered a clean fuel compared to alternatives such as kerosene used for lighting or fuelwood used for cooking (without an improved cook stove).

To monitor progress towards this goal, data should be collected about the different types of fuels and technologies used by households to meet their energy needs. Ideally this should be collected as part of national censuses, living conditions surveys and energy surveys, but a biogas survey could provide partial information in terms of the numbers of households using biogas. Administrative data may

8 Biogas is mostly methane, which has a high global warming potential, so any biogas leaks could result in more harmful emissions than the use of other fuels. This is why it is so important to monitor the condition of biogas plants in a country.

also be useful for monitoring in between large-scale surveys (see, for example, the approach used in China described in Appendix 2).

Energy access: In addition to very basic questions about energy use, biogas surveys can also collect more detailed information about energy access and biogas surveys often ask about whether the amount of biogas produced is sufficient to meet needs.

For example, a biogas user survey in Nepal found that biogas plants only supplied sufficient energy for cooking in about 58% of households in one region (Motherland Energy Group, 2013).

Questions about biogas use can even ask for more details about the times of year when supply is inadequate (e.g. when it is colder and digesters produce less gas) or the ways that households cope with energy shortages.

Health impacts: Switching from traditional biomass stoves to biogas should reduce the amount of indoor air pollution associated with cooking, which has a negative effect on health. The use of kerosene for lighting is also known to cause many accidents, especially involving children.

Biogas surveys can ask questions directly about any changes in health that have been noticed after switching to biogas, but as this amounts to another type of fuel-substitution effect, such data is probably best collected before and after plants are installed, or by comparing households with and without biogas plants.

It can also be useful to collect information about the types of energy used by households as part of health monitoring surveys, so that the impacts of fuel switching on health can be measured more accurately.

Time savings: Similarly, fuel switching studies or general household surveys should also ask about the time spent collecting and preparing fuel (including any time spent maintaining and operating biogas plants).

Biogas plants will require some time for daily maintenance and operation, but they are likely to reduce significantly the amount of time spent on fuel collection and preparation activities. As women and children often perform most of these tasks, it is very important to collect this information disaggregated by household members (e.g. average time spent in minutes per day by men, women and children).

REFERENCES

AIDG, (2009), *Build manual: ARTI floating dome biodigester*, Appropriate Infrastructure Development Group (AIDG), Boston.

Berkley Air Monitoring Group (2012), *Stove performance inventory report - Prepared for the Global Alliance for Clean Cookstoves*, United Nations Foundation, New York.

Bunny, H. and I. Besselink (2006), *The national biodigester programme in Cambodia in relation to the clean development mechanism*, Cambodia National Biodigester Programme, Phnom Penh.

Dung, T.V. et al. (2009), *Biogas user survey 2007-2008*, Biogas development programme for livestock sector in Vietnam 2007-2011, Hanoi.

Fulford, D. (2015), *Small-scale rural biogas programmes: A handbook*, Practical Action Publishing, Rugby.

Heegde, F. (2010), *Domestic biogas plants: sizes and dimensions*, SNV, The Hague.

iDE (2011), *Annual Biogas Users Survey 2010* , National Domestic Biogas and Manure Programme, Dhaka.

INFORSE South Asia, (2007), *Manual on sustainable energy technologies solutions for poverty reduction in South Asia*, International Network for Sustainable Energy (INFORSE) – South Asia, New Delhi.

IPCC (2006), *2006 IPCC Guidelines for national greenhouse gas inventories*, Intergovernmental Panel on Climate Change, Geneva.

KBS (2013), *Domestic biogas stoves - Specification (Public Review Draft, December 2013)*, Kenya Bureau of Standards, Nairobi.

Khandelwal, D.K.C. and D.V.K. Gupta (2009), *Popular summary of the test reports on biogas stoves and lamps prepared by testing institutes in China, India and the Netherlands*, SNV, The Hague.

Kudaravelli, K. (2013), *Biogas plant construction manual - fixed dome Deenbandhu model digester: 2 to 6 cubic meter size*, Egyptian Environmental Affairs Agency, Cairo.

Kudaravelli, K. (2014), *Education manual*, SKG Sangha Foundation, Kolar.

LGED, (2002), *Design of a biogas plant*, Local Government Engineering Department (LGED), Dhaka.

Lorimor, J. et al. (2004), “Manure characteristics”, *Manure Management Systems Series MWPS-18 Section 1*, Iowa State University, Ames.

Motherland Energy Group (2013), *Biogas users' survey 2012/13 - Final Report*, Ministry of Science, Technology and Environment, Alternative Energy and Promotion Centre (AEPC), Kathmandu.

NDBMP, (2013), *Biogas audit Bangladesh 2011-2013*, National Domestic Biogas and Manure Programme, Dhaka.

Rajendran, K., et al. (2012), *Household Biogas Digesters- A Review,* Energies 5, no. 8: 2911-2942.

Rouse, S. (2013), *Precise biogas flow measurement: Overcoming the challenges of changing gas composition*, Sierra Instruments, Monterey.

Sasse, L. et al. (1991), *Improved biogas unit for developing countries*, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Eschborn.

SEAI (2012), *Gas yields table*, Sustainable Energy Authority of Ireland, Dublin.

Somanathan, E. and R. Bluffstone (2015), “Biogas: Clean energy access with low-cost mitigation of climate change”, *Policy Research Working Paper 7349,* World Bank, Washington DC.

Vögeli Y. et al. (2014), *Anaerobic digestion of biowaste in developing countries: Practical information and case studies*, Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf.

World Bank (2011), *Climate change knowledge portal: Historical data*, available at: http://data.worldbank.org.

APPENDIX 1: BIOGAS PLANT CALCULATION TABLES

Table 10: Estimated volume of a fixed dome plant (hemisphere design) by plant diameter

Diameter (m)	Total plant volume (m^3)	Digester volume (m^3)	Gas storage volume (m^3)	Rated daily gas production (m^3/day)
2.0	2.09	1.68	0.42	0.70
2.2	2.79	2.23	0.56	0.93
2.4	3.62	2.90	0.72	1.21
2.6	4.60	3.68	0.92	1.53
2.8	5.75	4.60	1.15	1.92
3.0	7.07	5.65	1.41	2.36
3.2	8.58	6.86	1.72	2.86
3.4	10.29	8.23	2.06	3.43
3.6	12.21	9.77	2.44	4.07
3.8	14.37	11.49	2.87	4.79
4.0	16.76	13.40	3.35	5.59
4.2	19.40	15.52	3.88	6.47
4.4	22.30	17.84	4.46	7.43
4.6	25.48	20.39	5.10	8.49
4.8	28.95	23.16	5.79	9.65
5.0	32.72	26.18	6.54	10.91

Note: these figures assume that the gas storage volume is 20% of total volume and that it can hold 60% of daily production.

Table 11: Estimated volume of a fixed dome plant (Deenbandhu design) by plant diameter

Diameter (m)	Total plant volume (m^3)	Digester volume (m^3)	Gas storage volume (m^3)	Rated daily gas production (m^3/day)
2.0	2.76	2.20	0.55	0.92
2.2	3.67	2.93	0.73	1.22
2.4	4.76	3.81	0.95	1.59
2.6	6.06	4.84	1.21	2.02
2.8	7.56	6.05	1.51	2.52
3.0	9.30	7.44	1.86	3.10
3.2	11.29	9.03	2.26	3.76
3.4	13.54	10.83	2.71	4.51
3.6	16.07	12.86	3.21	5.36
3.8	18.90	15.12	3.78	6.30
4.0	22.05	17.64	4.41	7.35
4.2	25.53	20.42	5.11	8.51
4.4	29.35	23.48	5.87	9.78
4.6	33.53	26.83	6.71	11.18
4.8	38.10	30.48	7.62	12.70
5.0	43.07	34.45	8.61	14.36

Note: these figures assume that the gas storage volume is 20% of total volume and that it can hold 60% of daily production.

Table 12: Estimated volume of a fixed dome plant (Chinese design) by plant diameter

Diameter (m)	Total plant volume (m^3)	Digester volume (m^3)	Gas storage volume (m^3)	Rated daily gas production (m^3/day)
2.0	3.58	2.86	0.72	1.19
2.2	4.76	3.81	0.95	1.59
2.4	6.18	4.94	1.24	2.06
2.6	7.86	6.29	1.57	2.62
2.8	9.81	7.85	1.96	3.27
3.0	12.07	9.66	2.41	4.02
3.2	14.65	11.72	2.93	4.88
3.4	17.57	14.06	3.51	5.86
3.6	20.86	16.69	4.17	6.95
3.8	24.53	19.63	4.91	8.18
4.0	28.61	22.89	5.72	9.54
4.2	33.12	26.50	6.62	11.04
4.4	38.08	30.47	7.62	12.69
4.6	43.52	34.81	8.70	14.51
4.8	49.44	39.55	9.89	16.48
5.0	55.88	44.71	11.18	18.63

Note: these figures assume that the gas storage volume is 20% of total volume and that it can hold 60% of daily production.

Table 13: Estimated volume of a floating drum plant by plant height and diameter

Diameter (m)	Height = 1.0 metres			Height = 1.5 metres			Height = 2.0 metres		
	Digester volume (m^3)	Gas storage vol. (m^3)	Daily gas product (m^3/day)	Digester volume (m^3)	Gas storage vol. (m^3)	Daily gas product (m^3/day)	Digester volume (m^3)	Gas storage vol. (m^3)	Daily gas product (m^3/day)
1.0	0.55	0.24	0.39	0.82	0.35	0.59	1.10	0.47	0.79
1.2	0.79	0.34	0.57	1.19	0.51	0.85	1.58	0.68	1.13
1.4	1.08	0.46	0.77	1.62	0.69	1.15	2.16	0.92	1.54
1.6	1.41	0.60	1.01	2.11	0.90	1.51	2.81	1.21	2.01
1.8	1.78	0.76	1.27	2.67	1.15	1.91	3.56	1.53	2.54
2.0	2.20	0.94	1.57	3.30	1.41	2.36	4.40	1.88	3.14
2.2	2.66	1.14	1.90	3.99	1.71	2.85	5.32	2.28	3.80
2.4	3.17	1.36	2.26	4.75	2.04	3.39	6.33	2.71	4.52
2.6	3.72	1.59	2.65	5.57	2.39	3.98	7.43	3.19	5.31
2.8	4.31	1.85	3.08	6.47	2.77	4.62	8.62	3.69	6.16
3.0	4.95	2.12	3.53	7.42	3.18	5.30	9.90	4.24	7.07
3.2	5.63	2.41	4.02	8.44	3.62	6.03	11.26	4.83	8.04
3.4	6.36	2.72	4.54	9.53	4.09	6.81	12.71	5.45	9.08
3.6	7.13	3.05	5.09	10.69	4.58	7.63	14.25	6.11	10.18
3.8	7.94	3.40	5.67	11.91	5.10	8.51	15.88	6.80	11.34
4.0	8.80	3.77	6.28	13.19	5.65	9.42	17.59	7.54	12.57
4.2	9.70	4.16	6.93	14.55	6.23	10.39	19.40	8.31	13.85
4.4	10.64	4.56	7.60	15.97	6.84	11.40	21.29	9.12	15.21
4.6	11.63	4.99	8.31	17.45	7.48	12.46			
4.8	12.67	5.43	9.05	19.00	8.14	13.57			
5.0	13.74	5.89	9.82	20.62	8.84	14.73			

Note: these figures assume that the gas storage volume is 30% of total volume and that it can hold 60% of daily production. For plant heights greater than 2 m, volume can be calculated by multiplying the volumes for a 1 m plant by the measured height.

Table 14: Estimated volume of a balloon digester by length and diameter

Diameter (m)	Length = 1.0 metres			Length = 1.5 metres			Length = 2.0 metres		
	Digester volume (m^3)	Gas storage vol. (m^3)	Daily gas product (m^3/day)	Digester volume (m^3)	Gas storage vol. (m^3)	Daily gas product (m^3/day)	Digester volume (m^3)	Gas storage vol. (m^3)	Daily gas product (m^3/day)
1.0	0.59	0.20	0.33	0.88	0.29	0.49	1.18	0.39	0.65
1.2	0.85	0.28	0.47	1.27	0.42	0.71	1.70	0.57	0.94
1.4	1.15	0.38	0.64	1.73	0.58	0.96	2.31	0.77	1.28
1.6	1.51	0.50	0.84	2.26	0.75	1.26	3.02	1.01	1.68
1.8	1.91	0.64	1.06	2.86	0.95	1.59	3.82	1.27	2.12
2.0	2.36	0.79	1.31	3.53	1.18	1.96	4.71	1.57	2.62
2.2	2.85	0.95	1.58	4.28	1.43	2.38	5.70	1.90	3.17
2.4	3.39	1.13	1.88	5.09	1.70	2.83	6.79	2.26	3.77
2.6	3.98	1.33	2.21	5.97	1.99	3.32	7.96	2.65	4.42
2.8	4.62	1.54	2.57	6.93	2.31	3.85	9.24	3.08	5.13
3.0	5.30	1.77	2.95	7.95	2.65	4.42	10.60	3.53	5.89

Note: these figures assume that the gas storage volume is 25% of total volume and that it can hold 60% of daily production. For digesters longer than 2 m, volume can be calculated by multiplying the volumes shown for a 1 m length by the measured length.

Table 15: Average annual temperature 1961-1999 (in °C)

Region	Country or area
Africa	Algeria (23); Angola (22); Benin (27); Botswana (21); Burkina Faso (28); Burundi (20); Cabo Verde (25); Cameroon (25); Central African Republic (25); Chad (27); Comoros (24); Democratic Republic of the Congo (24); Congo (25); Côte d'Ivoire (26); Djibouti (28); Egypt (22); Equatorial Guinea (24); Eritrea (26); Ethiopia (22); Gabon (25); Gambia (the) (27); Ghana (27); Guinea (26); Guinea-Bissau (27); Kenya (24); Lesotho (20); Liberia (25); Libya (22); Madagascar (22); Malawi (22); Mali (28); Mauritania (28); Mauritius (23); Morocco (17); Mozambique (24); Namibia (20); Niger (27); Nigeria (27); Réunion (21); Rwanda (19); Sao Tome and Principe (26); Senegal (28); Seychelles (27); Sierra Leone (26); Somalia (27); South Africa (18); South Sudan (27); Sudan (27); Swaziland (20); Tanzania (22); Togo (27); Tunisia (19); Uganda (23); Western Sahara (23); Zambia (22); Zimbabwe (21).
Asia	Bangladesh (25); Brunei Darussalam (26); Cambodia (27); India (24); Indonesia (26); Laos (23); Malaysia (25); Myanmar (23); Pakistan (20); Philippines (25); Sri Lanka (27); Thailand (26); Timor-Leste (25); Viet Nam (24).
Central America and the Caribbean	Bahamas (25); Belize (25); Costa Rica (24); Cuba (25); Dominica (24); Dominican Republic (24); El Salvador (25); Guadeloupe (25); Guatemala (23); Haiti (24); Honduras (23); Jamaica (24); Nicaragua (25); Panama (25); Puerto Rico (24); St Vincent and the Grenadines (27); Trinidad and Tobago (26); US Virgin Islands (26).
Middle East	Iran (17); Iraq (22); Israel (20); Jordan (18); Kuwait (25); Lebanon (16); Oman (25); Qatar (27); Saudi Arabia (25); Syrian Arab Republic (18); United Arab Emirates (27); Yemen (23).
North America	Mexico (21).
Oceania	Fiji (23); New Caledonia (22); Papua New Guinea (25); Solomon Islands (26); Vanuatu (24).
South America	Bolivia (21); Brazil (25); Colombia (24); Ecuador (21); French Guiana (26); Guyana (26); Paraguay (23); Peru (19); Suriname (26); Uruguay (18); Venezuela (25).

Source: World Bank (2011). Note: For digesters buried underground add 2°C to the average temperature in order to determine digester temperature. Table excludes countries with low average annual temperatures or where data is unavailable.

APPENDIX 2: BIOGAS DATA COLLECTION IN CHINA

In China, biogas statistics are collected by both the Ministry of Agriculture (through the National Rural Renewable Energy Statistics System) and the National Energy Administration (through the Green County Demonstration Programme Monitoring System). In both cases, statistics are collected at a county level and then reported provincially and finally nationally.

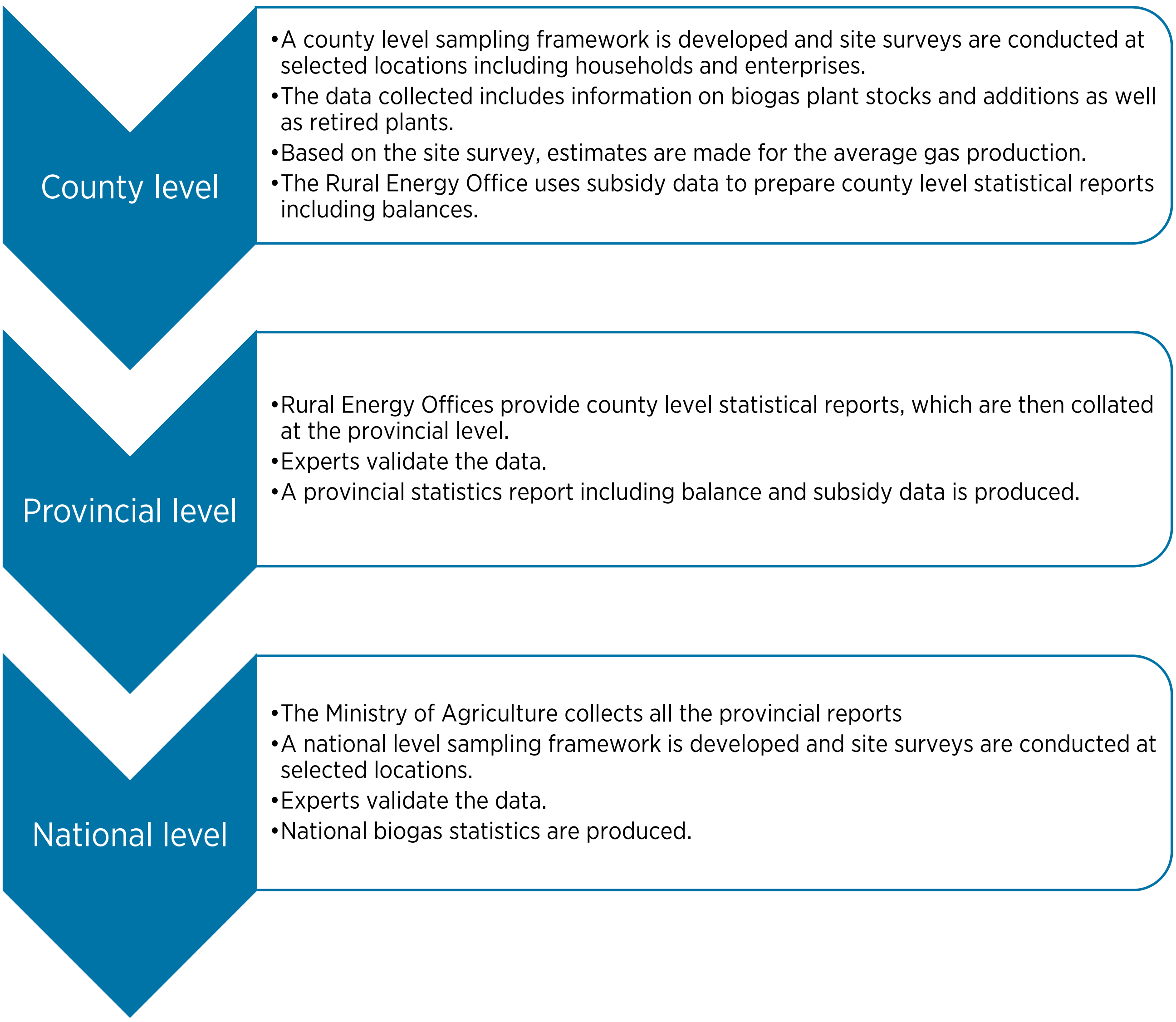
Data gathered in the rural renewable energy statistics system is cross-checked and validated against that of the Green County Demonstration Programme as well as through sample site surveys and expert reviews.

Rural renewable energy statistics system

Biogas statistics are collected by the Ministry of Agriculture using detailed annual surveys of rural households and other relevant enterprises. These surveys collect data from household biogas digesters, as well as biogas plants at sewage purification facilities and agricultural and industrial enterprises.

Statistics are collected on a county level and are then reported to the provincial authority before being collated nationally as illustrated below.

Figure 8: Biogas statistics reporting process



For household plants, data is collected about the number of plants at the start and end of the year, the total biogas production and the average biogas production per household

Table 16: Household biogas data collected in the Rural Renewable Energy Statistics System

Indicator	Unit	Amount
Number at start of year	Household	
Increments this year	Household	
Scrapped this year	Household	
Number at end of year	Household	
- Number of users this year	Household	
Total annual gas production	m^3	
Average annual gas production per household	m^3	

Table 17: Enterprise biogas data collected in the Rural Renewable Energy Statistics System

Indicator	Unit	Amount
Number at start of year		
Increments this year		
Scrapped this year		
Number at end of year		
Engineering numbers		
- Total tank volume	m^3	
- Annual biogas production	m^3	
- Households supply		
- Power capacity	kW	
- Annual power generation	MWh	

kW = kilowatt; MWh = megawatt-hour

For enterprises, additional data is also collected about the capacity of biogas digesters, electricity generating capacity and the amount of any electricity produced from biogas each year. This data is collected for each of the following enterprise categories: industrial waste plants; sewage plants and agricultural processing facilities (large, medium and small-scale).

Green County Monitoring System

The data collected by the Ministry of Agriculture is cross checked against that of the Green County Demonstration Programme Monitoring System.

The Green County programme was set up to increase and centralise biogas production and use in rural areas. The monitoring system includes collecting administrative data (projects under the programme), validating and reviewing the projects, evaluating the current status of projects and reporting the results in a quarterly tracking report submitted to the National Energy Administration.

Data is gathered at the county level and reported to the provincial department and finally to the national administration. Data collected includes details of biogas project planning, implementation, project evaluation and operation management.

The following data form is used to collect data in the Green County Monitoring System.

Table 18: Data collected in the Green County Demonstration Programme Monitoring System

<table>
<tr><td colspan="2">Project name</td><td colspan="2"></td><td>Owner</td><td colspan="2"></td></tr>
<tr><td colspan="2">Location</td><td colspan="2"></td><td>Contact person</td><td colspan="2"></td></tr>
<tr><td>Digester volume (m³)</td><td>Daily biogas production (m³)</td><td>Annual biogas production (m³)</td><td>Households supplied (number)</td><td>Household biogas use (m³/year)</td><td>Gas storage volume (m³)</td><td>Total length of pipelines (km)</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

IRENA
International Renewable Energy Agency

IRENA Headquarters
Masdar City
P.O. Box 236, Abu Dhabi,
United Arab Emirates
www.irena.org