BIOENERGY AND FOOD SECURITY RAPID APPRAISAL (BEFS RA)

User Manual

BIOGAS COMMUNITY

BEFS Rapid Appraisal

Energy End Use Options Module

Heating and Cooking Sub-Module

Biogas Community

User Manual

Acknowledgements

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3 The National Biofuels Board is chaired by the Secretary of Department of Energy and includes the following members: Department of Trade and Industry, Department of Science and Technology, Department of Agriculture, Department of Finance, Department of Labor and Employment, Philippine Coconut Authority, Sugar Regulatory Administration.

BEFS RA User Manual Volumes

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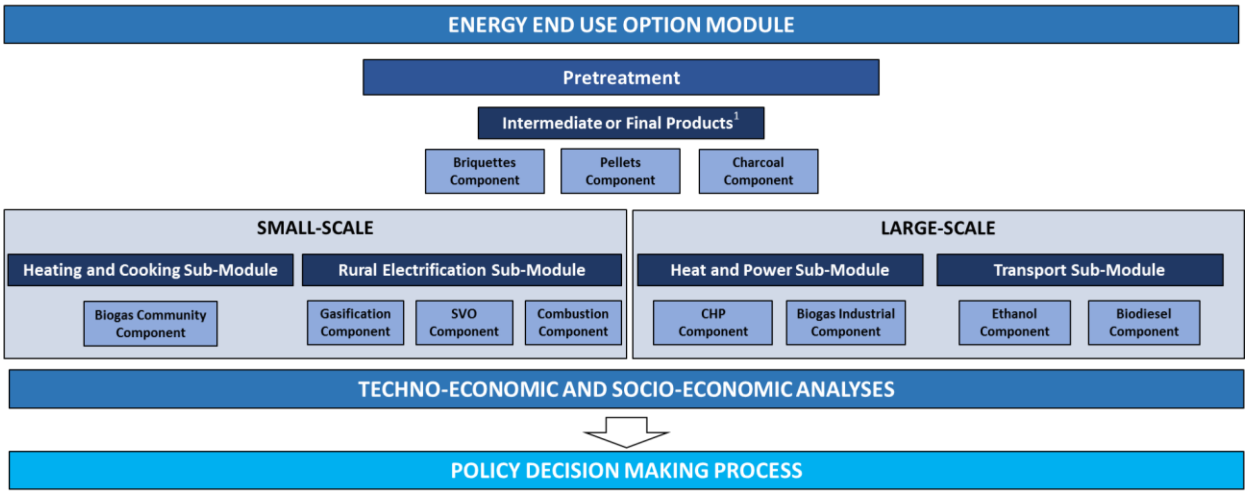
1 Overview of the Energy End Use Option (End Use) Module

As explained in the general introduction of the BEFS RA training manual, the *Energy End Use Option* module is used to assess the techno-economic and socio-economic viability of different bioenergy production pathways. The module is divided into five sections, these are: Intermediate or Final Products, Heating and Cooking, Rural Electrification, Heat and Power and Transport. Each of the sub- modules includes a choice of components of analysis to assess the production of specific biofuels based on particular processing technologies, as depicted in Figure 1. This module builds up from the information generated in the *Natural Resources* modules in relation to feedstock. For a more detailed description of the module, refer to the general introduction of the training manual.



[1]These products may be used either as final products for heating and cooking or as intermediate products in the rural electrification options of gasification and combustion.

Figure 1: The Structure of the Energy End Use Option Module

A general description of each of the sub-modules and their respective components of analysis are presented below. A more detailed discussion on each of the components of analysis will be provided in the respective user manual.

The **Intermediate or Final Products** sub-module is used to assess the viability of producing briquettes, pellets and charcoal. The **Briquettes/Pellets** components are used to evaluate the potential to develop the production of biomass briquettes/pellets to supply energy for heating and cooking in rural and urban households. The objective of the analysis is to generate information on production cost, biomass requirements and financial viability and social parameters to help users in their decision to promote briquette/pellet production in the country. The **Charcoal** component is used to compare existing charcoal production technologies with improved and more efficient technologies. The aim of the analysis is to assess the required upfront capital cost of the improved technologies, the financial viability from the standpoint of charcoal producers and the social and environmental benefits that improved technologies can trigger when compared to existing charcoal production technologies. The results generated by the analysis inform on potential barriers for the uptake of the improved charcoal technologies by producers and help define how to effectively disseminate their introduction.

The **Heating and Cooking** sub-module is used to assess the viability of producing biogas at the community level. The **Biogas Community** component is used to evaluate the potential to develop biogas production from livestock manures at the household and community levels and compares three different types of technologies. The component generates information on: 1) the amount of biogas that can be produced based on manure availability, 2) the size of biodigester needed to harness the energy, 3) the installation cost of three types of biodigester technologies. The component also provides financial social and economic parameters to help the user understand the potential opportunities and the requirements needed for deploying biogas technology in their countries.

The **Rural Electrification** sub-module is used to assess the viability of supplying electricity from local biomass resources in remote areas without access to the electric grid. The sub-module is comprised of three decentralized-based technology pathways for electrification, these are: gasification, use of straight vegetable oil (SVO) and combustion. The results from this sub-module generate estimates of the cost of electricity generation and distribution, calculates the financial viability of electrification and informs on the associated social and economic outcomes for each alternative technology pathway. The **Gasification** component analyses the partial burning of biomass to generate a gas mixture that is subsequently combusted in gas engines to produce electricity. The **Straight Vegetable Oil (SVO)** component builds on from the Crops component in the Natural Resources module. It assesses the potential to substitute diesel with SVO in generators to produce electricity. The **Combustion** component assesses the burning of biomass to produce steam which drives a turbine to produce electricity.

The **Heat and Power** sub-module is used to assess the viability of the production of electricity and heat from local biomass resources. The sub-module is comprised of two decentralized-based technology pathways for electrification and heat, these are: CHP (cogeneration) and biogas industrial. The results from this sub-module generate estimates of the cost of electricity/heat generation and distribution, calculates the financial viability of electrification/heat and informs on the associated social and economic outcomes for each alternative technology pathway. The **CHP (cogeneration)** component examines the potential for the simultaneous production of electricity and heat from a biomass source, allowing the user to analyse a factory integrated production or a standalone operation for pure grid electricity generation. The **Biogas Industrial** component evaluates the potential to develop a biogas-based industry for electricity, heat, CHP or upgraded biogas. This is done by using waste water, high moisture solids, low moisture solids or a combination of these. All technology pathways are based on simple and readily available technologies that can be easily adaptable to remote rural areas.

The **Transport** sub-module is used to assess the viability of producing liquid biofuels for transport, namely ethanol and biodiesel. The analysis builds on the results generated from the Natural Resources' components in terms of feedstock availability and the crop budget. The tool covers ethanol and biodiesel. In the ethanol sections the users can assess the potential for developing the ethanol industry in the country. Likewise in the biodiesel section, the potential for developing the biodiesel industry is assessed. The analyses generates results on the cost estimates for the production of the selected biofuel based on feedstock origin, i.e. smallholder, combination smallholder/commercial or commercial, and according to four predefined plant capacities, namely 5, 25, 50 and 100 million litres/year[4]. The results also consist of information on economic feasibility and socio-economic parameters. In this component, the user has the

[4] The selection of the predefined plant capacities is based on a review of relevant literature; please see the Transport manual for further details.

option to include into the assessment a GHG emissions analysis that covers the whole supply chain of the selected biofuels.

Another option for the user is to utilise the **Pretreatment Calculator** prior to using the Energy End Use tools[5]. This allows the user to calculate the additional costs of pre-processing the biomass selected in order to obtain the specific conditions required for the final biomass conversion for energy end use.

2 The *Biogas Community Component*

The biogas assessment tool is designed to assist the user in evaluating the potential to develop the production of biogas to supply energy for space heating and cooking in rural and urban households. The main objective of the tool is to generate information that allows the user to understand if the adoption of biogas can be an alternative energy source which can be promoted in rural communities. The tool assesses the potential to produce biogas from buffalo, dairy cattle, poultry and swine. It analyses four different sizes of biodigesters at a time depending on the number of livestock animals and their respective manure availability. It can be used to evaluate the production cost of biogas for three types of household-scale biodigester reactors, these are: fixed-dome, floating drum and polyethylene bag (tubular). The boundary of the biogas production system that can be analysed by this tool is shown in Figure 2.

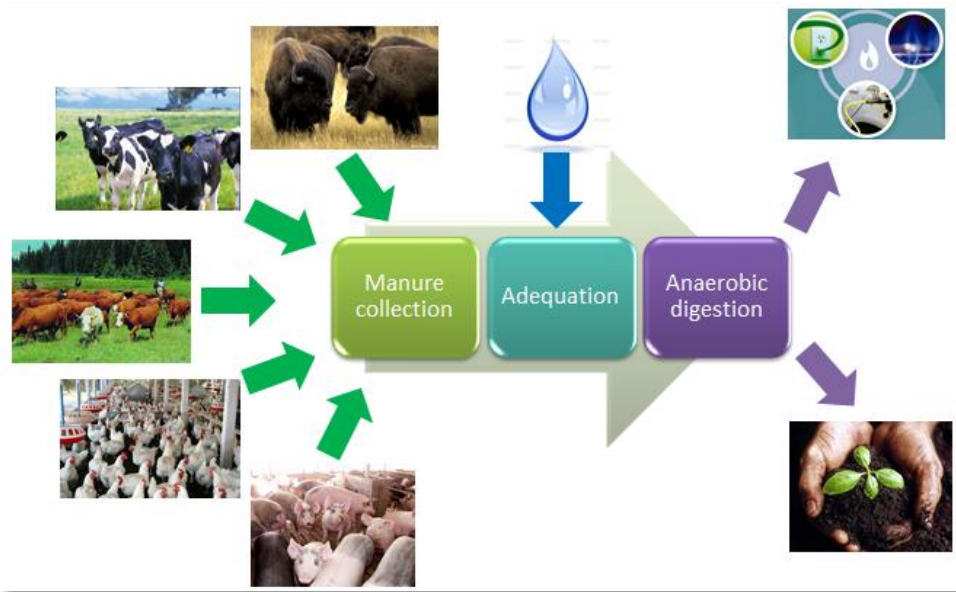


Figure 2: Biogas Production System for Rural Energetic Generation

After completing the analysis, the user will be able to obtain information on the potential volume of biogas that can be produced per day as well as the most appropriate bioreactor size. Moreover, the user will get a comparison on the investment cost for three different types of biodigester technologies, namely fixed dome, floating drum and tubular bag. More specifically, the results as shown in Figure 3, will provide an indication on: 1) the recommended biodigester size depending on the amount of biogas that can be produced, which is based on the specific type and quantity of manure available; 2) the investment cost associated with the construction of each of the biodigester technologies and the cost of production per

[5] The Pretreatment Calculator can be used prior to utilising the Energy End Use Tools. The exceptions are the *Biogas Community and Transport Tools*, as these tools already include pretreatment.

cubic metre of biogas generated; 3) the potential number of households that can be supplied with biogas to meet their energy needs for heating and cooking; and 4) the quantity of jobs that can be created and the potential fuel, money and time savings that can be obtained by using biogas when compared to current sources of energy used at the household level. Financial indicators on Net Present Value (NPV) and Internal Rate of Return (IRR) of biogas production are also generated to help the user assess the financial viability for the different biodigester technologies.

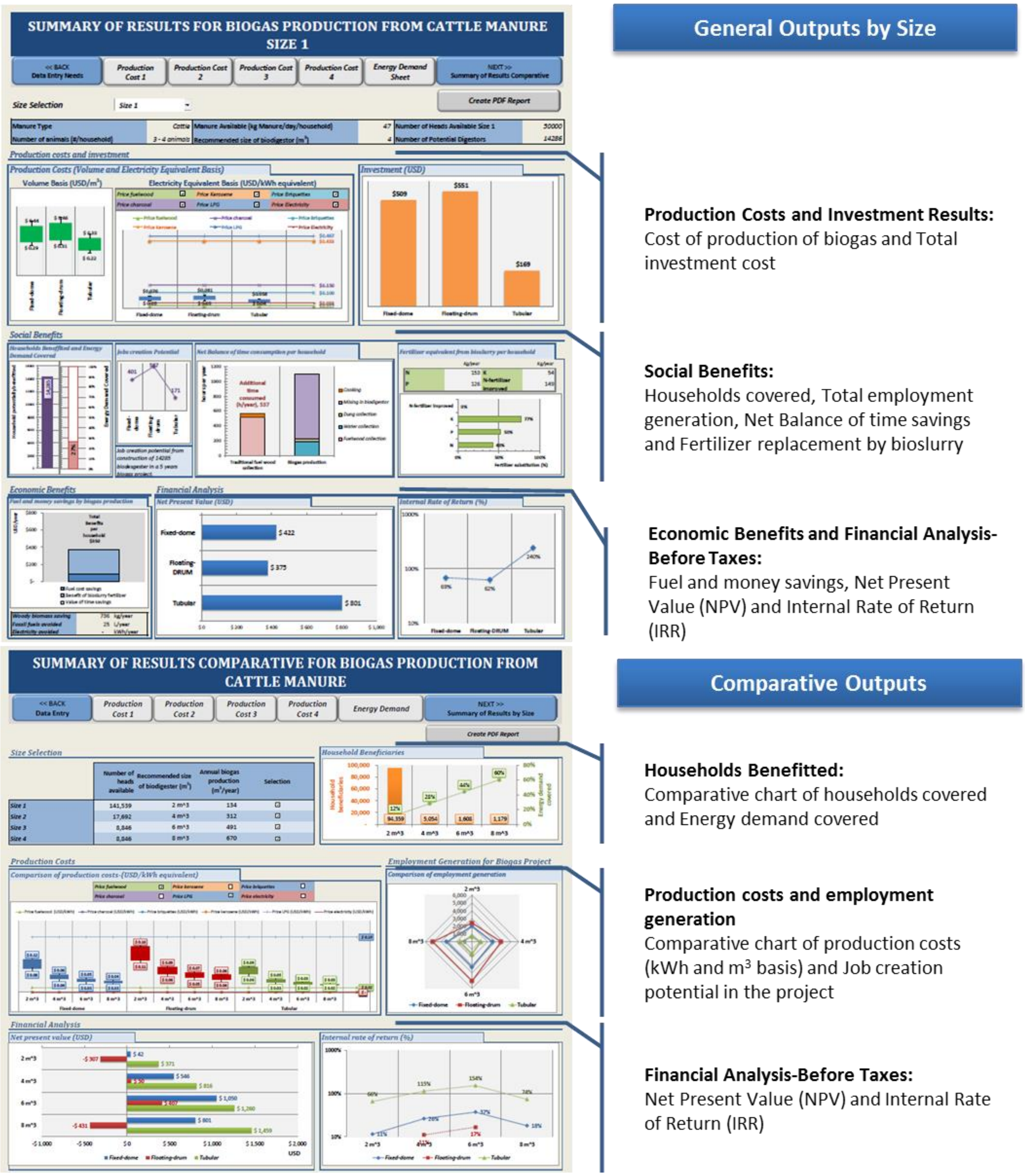


Figure 3: Layout of the Biogas Community Results Sheets

3 Terms and Definitions in the *Biogas Community Component*

This section includes the definitions of specific terms used in the *Biogas Community Component*. It is important to anticipate these definitions and consider them throughout the analysis, as to be able to interpret the results correctly.

- **Biogas** is a clean, efficient and renewable source of energy produced from organic materials that can be used particularly as an alternative fuel. Biogas is generated when bacteria degrade the organic material in the absence of oxygen, in a process known as anaerobic digestion. Biogas can be effectively used in simple gas stoves for cooking and in lamps used for lighting in rural areas. It can substitute the use of fuelwood, charcoal or kerosene. The development of household-scale biogas production systems in rural areas in developing countries is an attractive alternative given the availability of organic matter (i.e. manures) in these areas and considering conditions on the scarcity of fuelwood or lack of access to fossil fuel in these communities. The deployment of biogas production systems requires an understanding on the technical, financial and non-financial benefits that these systems can generate at the household and the country level.
- **Fixed dome** consists of a digester with a fixed, non-movable gas holder, which sits on top of the digester. When gas production starts, the slurry is displaced into the compensation tank. Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the compensation tank. There are also no rusting steel parts and hence the life of the plant is considered to be 20 years. The plant is constructed underground, protecting it from physical damage and saving space.
- **Floating drum** consists of an underground digester and a moving gas-holder. The gas-holder floats either directly on the fermentation slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored. There are rusting steel parts that need to be removed and re-painted. The life-time of the drum is considered to be 20 years.
- **Tubular or polyethylene bag** consists of digesters built from two layers of polyethylene plastic in a tubular form. A tubular digester is placed into a trench with a slope to facilitate gravity flow. It is the least expensive and the easiest to construct; however, the lifetime is only about 10 years.
- **Semi-Skilled worker** consists of personnel with particular skill or specialized experience, such as masonry and technicians.
- **Unskilled worker** consists of personnel with no special skill who support operations. Such workers could be helpers or personnel carrying out tasks that can be learned easily, with a few days of training.

4 Scope and Objective of the *Biogas Community Component*

In this section of the BEFS RA, the user will be able to evaluate the potential to develop household-scale biogas production from livestock manures to supply alternative sources of heat and cooking fuels in rural areas. The results of the analysis can be used to identify the viability of biogas production in terms of the most appropriate size, the financial viability of the different digester types, the optimum size and type of digester in the country, and the socio and economic benefits that can be attained from the production of biogas. The tool has been developed based on extensive literature reviews on the subject. The detailed assumptions and calculations used to develop the tool are presented in the Annex.

Figure 4: Rapid Appraisal Tool for Biogas Production

5 Running the *Biogas Community Component*

The flow of analysis within the *Biogas Community Component* and the inter-linkages it has with other components is depicted in Figure 5. The user has the choice to select the components of analysis in a different order or even omit some components. It is, however, strongly recommended that the user follows the order and flow of analysis as described below, given that the *Biogas Community Component* relies on the information generated in the *Natural Resources* module and information can be cross-referenced with other modules to contextualize the results of the analysis. The results of this component are essential for the comprehensiveness of the analysis. When interpreting the results, the user should take into account all relevant factors, even when some components of analysis that are omitted (e.g. aspects related to the food security, agricultural trade, sustainable use of natural resources, etc.).

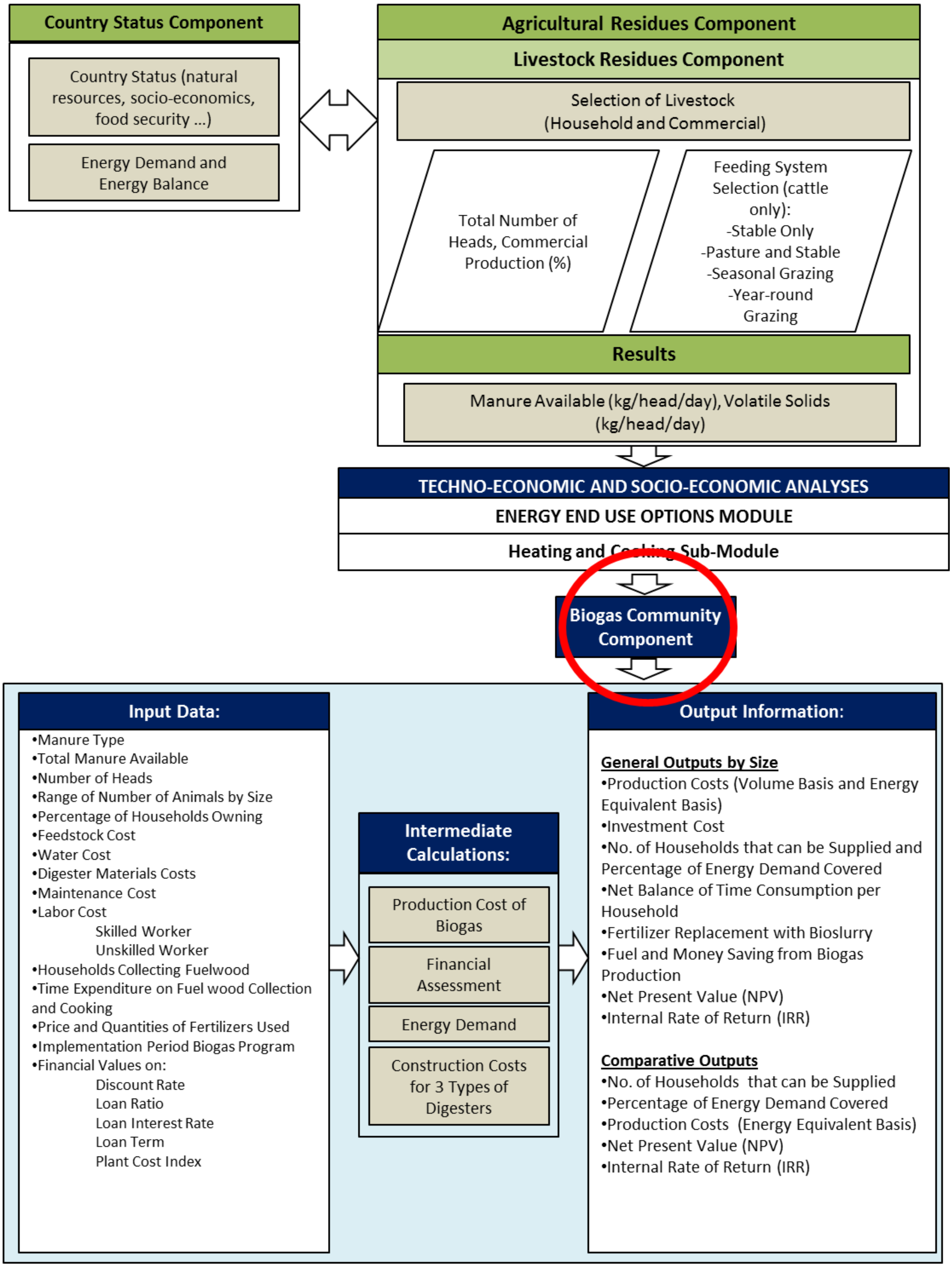


Figure 5: *Biogas Community Component*: Flow of Analysis and Inter-linkages with BEFS RA Modules and Components

The user navigates step by step through the options and is asked to input the necessary data to obtain the final results. When the required data are limited or unavailable, then the default values provided by the tool can be utilised. The navigation buttons are placed on the top and bottom of each sheet, indicating the next step with the button "NEXT>>"and allowing the user to return to a previous section with the "<<BACK" button.

In this section, an example is used to illustrate the detailed steps in the analysis. The example is based on the use of cow manure for producing biogas in isolated areas, where the majority of domestic energy is provided by firewood. All input parameters are based on Tanzania case studies reviewed by Ratamu (1999) and Schmitz (2007).

At the beginning of the analysis, the user must select the language of preference in order to view the tool in that language (Figure 4, label 1). The language choices are: English (EN), French (FR) and Spanish (ES). Next, the user has three options, with the following navigation buttons: "Data Entry Sheet", "Biogas Process Description" and "Energy Demand" as shown in Figure 4.

Note: This is not a compulsory step. This section presents the user with a quick overview of the boundaries of the analysis.

1. **Biogas Process Description**: the user will be taken to a schematic representation of the boundaries of the analysis carried out in this section, as shown in Figure 6.

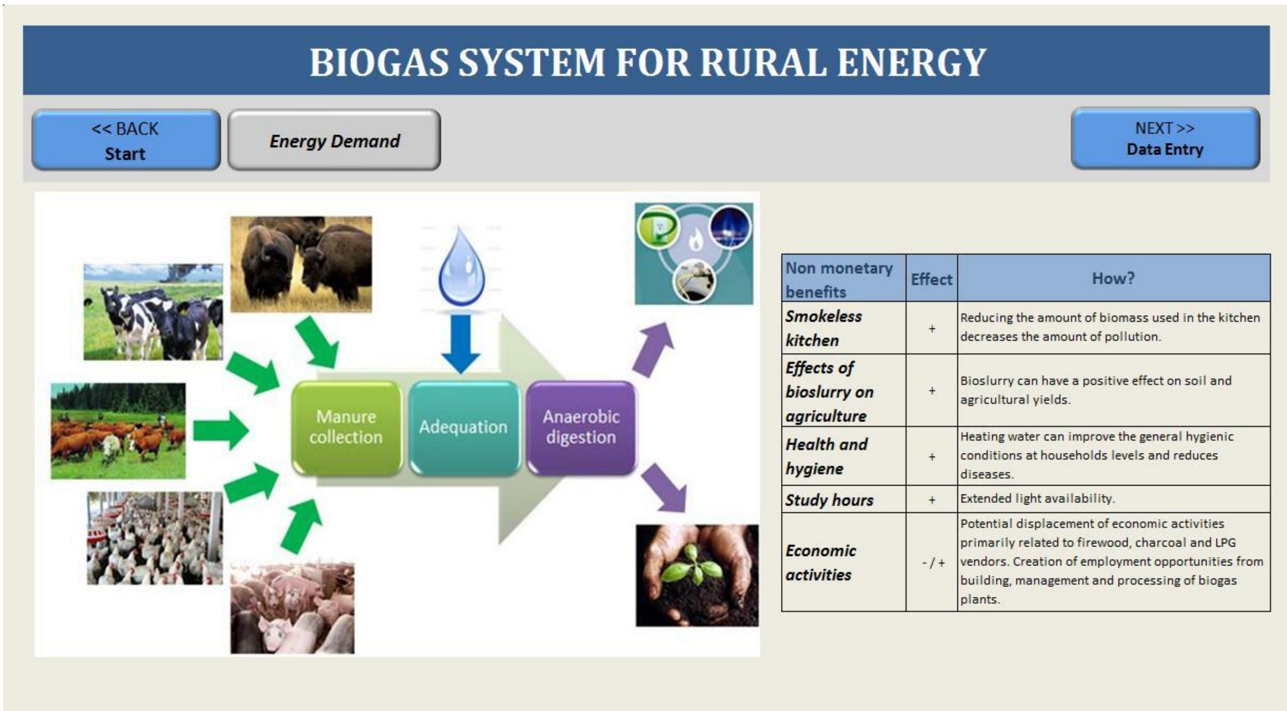
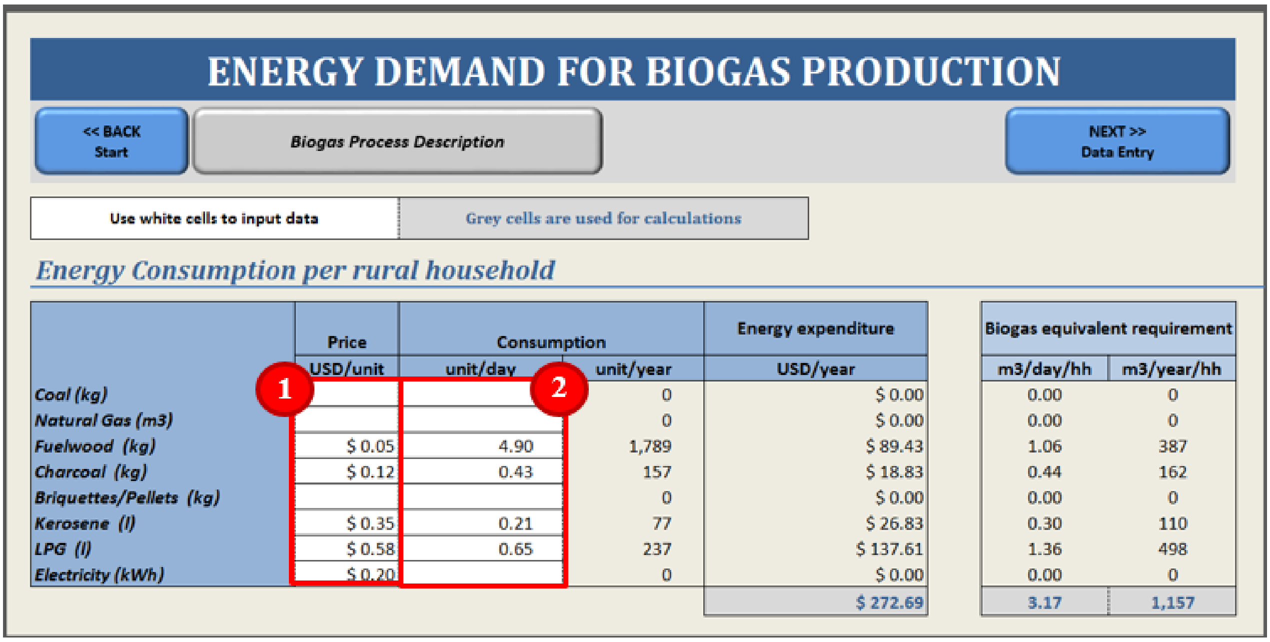


Figure 6: Biogas Process Description

2. **Energy Demand:** this is the first section the user must go to in order to fill out the data needed to continue the analysis.
3. **Data Entry Sheet:** the user will then proceed to this section to enter the data required to carry out the next parts of the analysis. The detailed steps for performing the analysis are presented below.

5.1 Step 1: Energy demand

The user needs to enter the market price of current fuels used in the household and their respective consumption volumes. These values are used to estimate the energy expenditure and the biogas equivalent requirement in the households (Figure 7).



	Price	Consumption		Energy expenditure	Biogas equivalent requirement	
	USD/unit	unit/day	unit/year	USD/year	m3/day/hh	m3/year/hh
Coal (kg)			0	$ 0.00	0.00	0
Natural Gas (m3)			0	$ 0.00	0.00	0
Fuelwood (kg)	$ 0.05	4.90	1,789	$ 89.43	1.06	387
Charcoal (kg)	$ 0.12	0.43	157	$ 18.83	0.44	162
Briquettes/Pellets (kg)			0	$ 0.00	0.00	0
Kerosene (l)	$ 0.35	0.21	77	$ 26.83	0.30	110
LPG (l)	$ 0.58	0.65	237	$ 137.61	1.36	498
Electricity (kWh)	$ 0.20		0	$ 0.00	0.00	0
				$ 272.69	3.17	1,157

Figure 7: Energy Demand

To run this analysis, the user has to enter the following data:

- Market price of each energy type used in the household (Figure 7, label 1)
- Energy consumption of each energy type used in the household (Figure 7, label 2)

Guide: If fuelwood is collected and therefore does not have a price, then it is recommended that the user inputs a proxy price. For example, this can be calculated by using the number of hours for collection times the price of labour in rural areas.

5.2 Step 2: Input data

Next, the user needs click on "NEXT>>Data Entry" to enter the necessary information. The white cells correspond to information that should be provided by the user. In some cases, the value is limited to a dropdown menu where the user can choose one of the given options. Results are shown in the grey cells.

The tool provides default values for some of the parameters (Figure 8, label A).

These default values are based on global data, therefore the user should keep that in mind when choosing this option as results may not be accurate.

Step 2.A Manure type selection and defining the number of heads

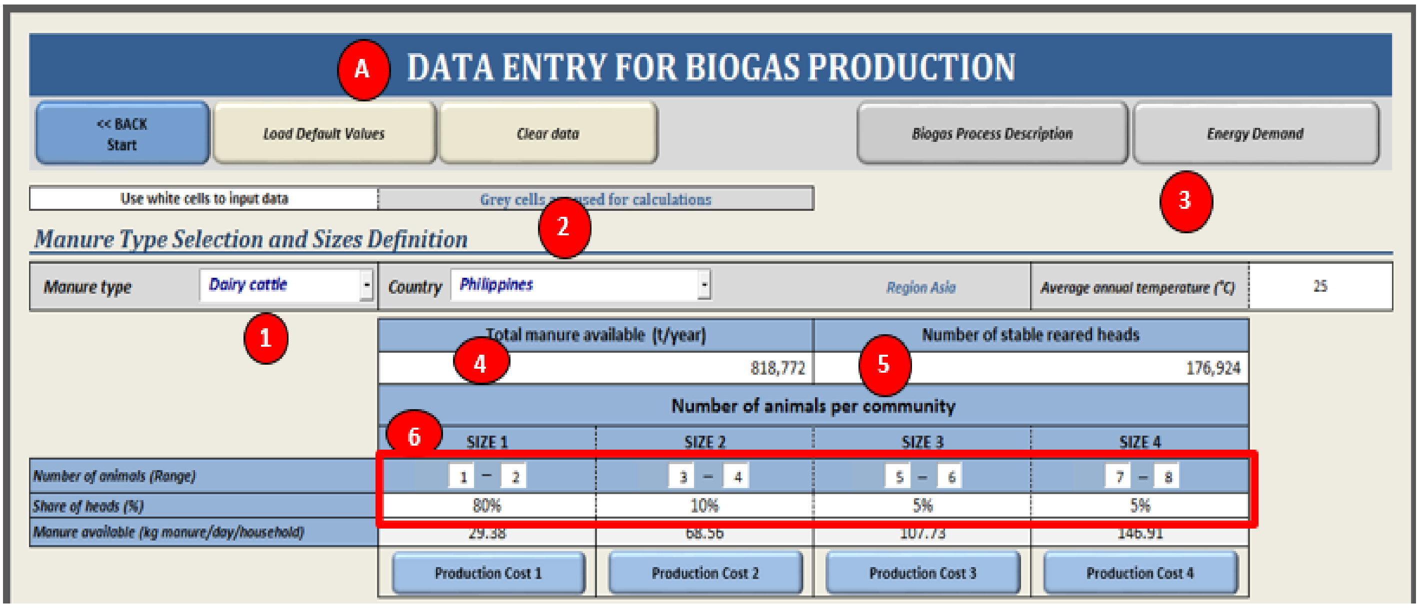


Figure 8: Manure Type and Sizes Definition

1. **Manure type:** There are three manure options to choose from the dropdown menu (Figure 8, label 1):
   - Dairy Cattle
   - Buffalo
   - Swine
2. **Country:** The user chooses menu the country where the analysis is taking place from the dropdown and inputs the average environmental temperature in the country in degrees Celsius (Figure 8, labels 2 and 3).
3. **Total manure available (t/year):** The user inputs the total manure available in the country as calculated in the *Livestock Residues Tool* of the *Natural Resources* module (Figure 8, label 4).
4. **Number of stable reared heads:** The user inputs the total number of animal stable reared heads in the country as defined in the *Livestock Residues Tool* of the *Natural Resources* module (Figure 8, label 5).
5. **Size definition:** The user defines the range of number of animals available per household by inputting the upper and lower limits in each cell (Figure 8, label 6).
6. **Share of households owning (%):** The user then enters the percentages of households owning animals. *This value is used later on to estimate the potential number of households that can be benefitted* (Figure 8, label 6).

Based on this information, the tool automatically calculates the manure availability in kg of manure per day per household.

For this example, manure from cattle in the Philippines was selected. The environmental temperature was defined as 25°C and all other values shown in Figure 8 are used in the analysis.

Step 2.B General inputs

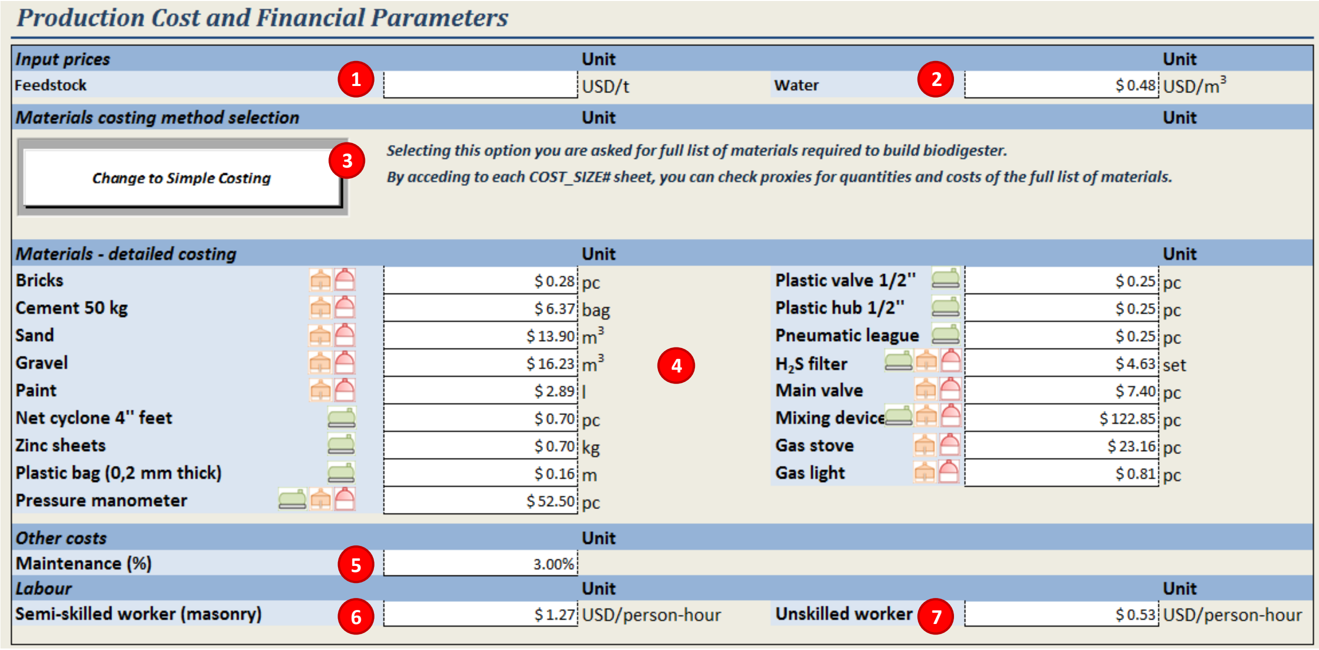


Figure 9a: General Inputs

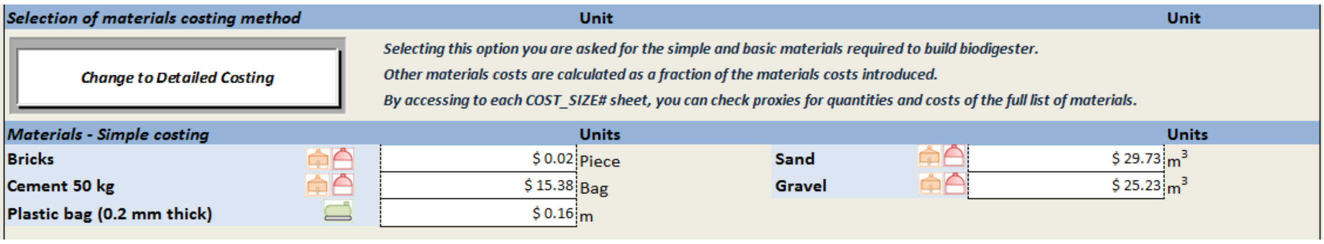


Figure 9b: General Inputs

Assumption: By default, the analysis assumes that there are no monetary costs for manure and water. Rather, this will require time to collect and mix the manure and water/urine.

1. **Input prices:**
   - **Feedstock (USD/t):** When manure is not free, the user must enter the price paid for the manure as the feedstock. If there is no monetary price associated with the manure, then the user must enter -0- (Figure 9a, label 1).
   - **Water (USD/m^3):** Similarly, the user must enter the price paid for water if needed. However, if water is collected and there is no monetary price associated with it, then the user must enter -0- (Figure 9a, label 2).

For this example, the feedstock is free of charge and the price of water is 0.48 USD per cubic meter.

2. **Selection of materials costing method:** The user has the option to select a simple or detailed method to carry out the construction costs for the biodigesters (Figure 9a, label 3).
   - **Simple costing method:** This method requires price inputs of the items that represent the largest cost. The items that are only a small portion of the cost are then estimated as a percentage of the cost of the higher cost inputs (Figure 9b).
   - **Detailed costing method:** This method requires the user to enter the price for all items required to build the biodigesters.

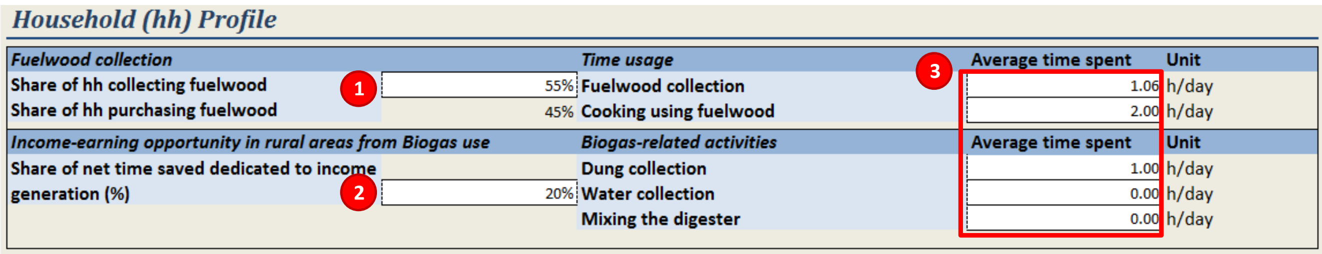
3. **Construction material prices:** In this step, the user enters the current prices of construction material needed to build the digesters (Figure 9a, label 4).

4. **Maintenance (%):** The user has to enter the percentage of the maintenance of the biodigester, with respect to the cost of the construction price. For example, the suggested percentage for Tanzania is 1.5% (GTZ 2007) (Figure 9a, label 5).

5. **Labour prices (USD/person-hour):** The user enters the price of labour for semi-skilled (masonry) and unskilled workers (Figure 9a, labels 6 and 7).

For this example, the values shown in Figure 9 were used to carry out the analysis.

Step 2.C Household profile



Household (hh) Profile

Fuelwood collection		*Time usage*	Average time spent	Unit
Share of hh collecting fuelwood	55%	Fuelwood collection	1.06	h/day
Share of hh purchasing fuelwood	45%	Cooking using fuelwood	2.00	h/day
Income-earning opportunity in rural areas from Biogas use		*Biogas-related activities*	Average time spent	Unit
Share of net time saved dedicated to income generation (%)	20%	Dung collection	1.00	h/day
		Water collection	0.00	h/day
		Mixing the digester	0.00	h/day

Figure 10: Energy Demand and Household Profile

The user will define key aspects of the energy consumption pattern of a typical rural household by providing information on the following variables:

Note: This information is used to estimate the potential benefits obtained from developing biogas systems at the household level. Default values are available.

1. **Households' collection of fuelwood (%):** Percentage of rural households collecting fuelwood in the country (Figure 10, label 1).
2. **Time dedicated to fuelwood collection and cooking:** Average daily hours spent by a household member in (Figure 10, label 3):
   - Fuelwood collection (h/day)
   - Cooking using fuelwood (h/day)
3. **Time dedicated to operate the biodigester**: Average daily hours spent by a household member in (Figure 10, label 3):
   - Dung collection (h/day)

- Water collection (h/day)
- Filling the biodigester with dung –the straws have been removed- and mixing dung and water to load the biodigester (h/day)

4. **Income-earning opportunity in rural areas with time savings from biogas use (%)**: The user will need to enter a percentage of the time saved using biogas that can be potentially used for income-generation activities (Figure 10, label 2). For example, in Sub-Sahara Africa 20% of the saved time could be used for income-generating activities (Winrock International, 2007).

> **Guidance:** It is assumed that only a portion of the time savings from using biogas can be used for income-generating activities, considering the limited-earning opportunities that may be available in rural areas.

For this example, the values shown in Figure 10 were used to carry out the analysis.

Step 2.D Social benefits

1. The user needs to enter data on fertilizers, namely the prices (USD/kg) and consumption (kg/year) for (Figure 11, label 1):
   - Nitrogen
   - Phosphorous
   - Potassium
2. The user will also need to identify if the manure is used directly as fertilizer. If "yes", then the manure consumption (kg/year) has to be entered (Figure 11, label 2).

Social Benefits

Consumption fertilizer per household	Unit Price USD/kg	Consumption kg/year
Nitrogen	$ 0.49	1.00
Phosphorous	$ 0.45	2.00
Potassium	$ 0.12	3.00
Do you use manure as fertilizer?	*no*	

Implementation of Biogas Programme	
Implementation of Biogas Programme (years)	5.0

Financial variables	
Loan interest rate (%)	12%
Loan term (years)	15
Discount rate (%)	10%
Loan ratio (%)	60%

Figure 11: Social Benefits

3. The user must input the values for the following financial parameters (Figure 11, label 4):
   - Loan interest rate (%)
   - Loan term (years)
   - Discount rate (%)
   - Loan ratio (%)

> **Guidance:** Data can come from the Central Bank in the country or from typical agricultural credits given to farmers in the country.

Guidance: This data will be used to calculate the labour generation from the construction of the biodigesters in the country. Typical programs run for 5 years.

4. The user must enter the implementation time of the programme. This is the period during which biodigesters will be constructed in the country (Figure 11, label 3).

For this example, the values shown in Figure 11 were used to carry out the analysis.

5.3 Step 3: Calculation of biogas production cost

After entering the data in Steps 1 and 2, the user can click on any of the "Production Cost" buttons (Figure 12, label 1).

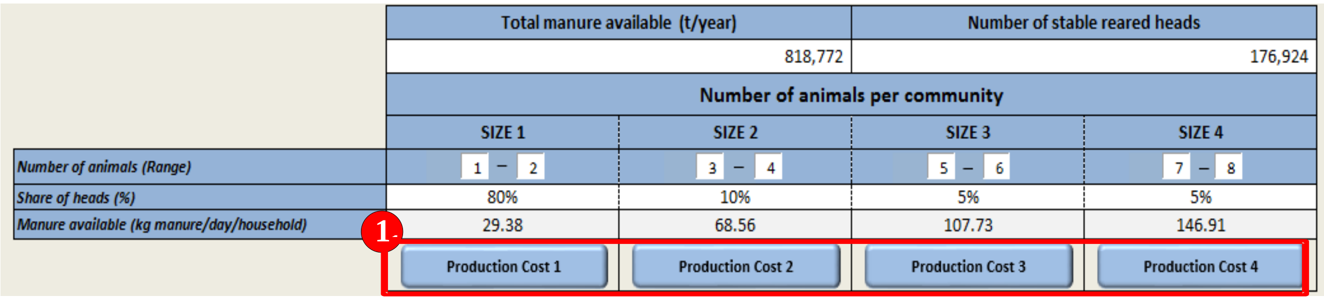


Figure 12: Production Cost Evaluation

This will take the user to the budget processing section for the selected production size (Figure 13).

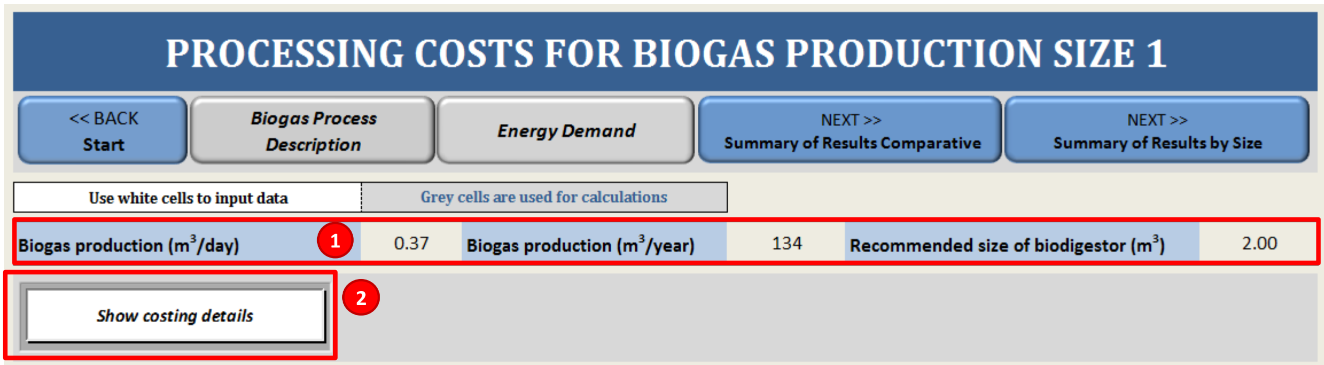


Figure 13: Processing Cost of Biogas

In this sheet, the user will find information about the amount of biogas that can be produced in cubic metres per day and cubic metres per year and the recommended size of the biodigester that can be built (Figure 13, label 1).

The user can also look at the detailed calculations of the construction cost of the biodigester (Figure 13, label 2). This aspect is further discussed in the results section.

For this example, the Size 1 biogas production is estimated at 0.37 m^3 per day. The recommended size of biodigester is 2 m^3 (Figure 13).

6 Assumptions and Limitations of the *Biogas Community Component*

Before starting the analysis, the user should become familiar with the assumptions and limitations of the tool and take them into consideration during the analysis and most especially when interpreting the results.

The limitations of the *Biogas Community Component* are:

1. <u>*Only*</u> buffalo, dairy cattle, and swine manures are considered.
2. Volatile solids (VS) content in raw material must be lesser than 100 kg/m^3.
3. The model cannot carry out an analysis using co-digestion or mixtures of more than one type of manure.
4. The model operates in the range of temperatures between 5 – 60 °C.
5. The analysis can <u>*only*</u> be run for one type of manure at a time. The user has the option to save the results of the first analysis and run a successive analysis for other type of manures.
6. The tool can analyse 4 sizes of biodigester reactors for a specific livestock type and the respective available manure.
7. The user can choose to analyse from three types of biodigesters: Fixed dome, Floating drum and Tubular (polyethylene bag).
8. For both fixed dome and floating drum reactors, the lifetime is 20 years and for the tubular reactor it is 10 years. Consequently, the financial analysis for fixed dome and floating drum reactors is 20 years and for the tubular reactor is 10 years.
9. The calculations for determining the size and for carrying out the costing of the construction of the biodigester reactors are based on the volatile solids (VS) available in manure, according to regions in the world and based on the quantification done in the *Natural Resources* module.

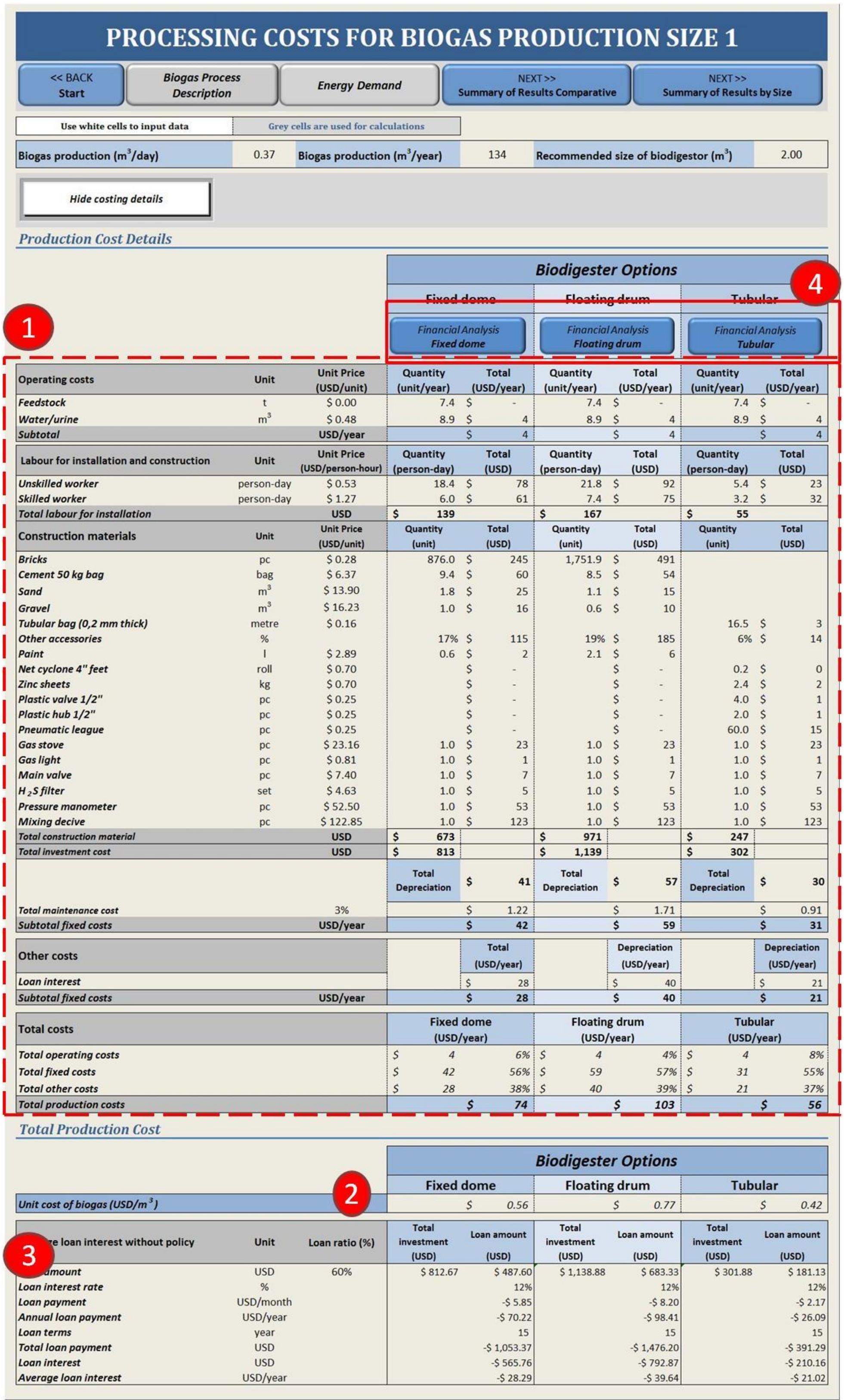
7 Results of the *Biogas Community Component*

7.1 Overview of the production cost calculations (optional)

After the user inputs all required data (Steps 1 to 3), then the user has the option to review the detailed production cost by selecting the “Show costing details” button (Figure 13, label 2). There are four main sections in this worksheet as explained below (Figure 14).

- **PART 1** (Figure 14, label 1) shows the distribution of production cost along the following categories: inputs, labour, operating costs, maintenance, investment and loan interest. The total production costs (USD/year) of the three biodigester types (Fixed dome, Floating drum and Tubular) are also summarized.
- **PART 2** (Figure 14, label 2) shows the unit cost of biogas (USD/m^3) for each of the biodigester types.
- **PART 3** (Figure 14, label 3) summarizes the financial details: loan amount, loan interest, annual loan payment, which is used in the financial analysis.

- **PART 4** (Figure 14, label 4) the “Financial Analysis” buttons will open the worksheet to go into the detailed financial analysis for each biodigester type for the selected size.



PROCESSING COSTS FOR BIOGAS PRODUCTION SIZE 1

<< BACK Start | Biogas Process Description | Energy Demand | NEXT >> Summary of Results Comparative | NEXT >> Summary of Results by Size

Use white cells to input data | Grey cells are used for calculations

Biogas production (m³/day)	0.37	Biogas production (m³/year)	134	Recommended size of biodigestor (m³)	2.00

Hide costing details

Production Cost Details

1

4

			Biodigester Options					
			Fixed dome		Floating drum		Tubular	
			Financial Analysis Fixed dome		Financial Analysis Floating drum		Financial Analysis Tubular	
Operating costs	**Unit**	**Unit Price (USD/unit)**	**Quantity (unit/year)**	**Total (USD/year)**	**Quantity (unit/year)**	**Total (USD/year)**	**Quantity (unit/year)**	**Total (USD/year)**
Feedstock	t	$ 0.00	7.4	$ -	7.4	$ -	7.4	$ -
Water/urine	m³	$ 0.48	8.9	$ 4	8.9	$ 4	8.9	$ 4
Subtotal		USD/year		$ 4		$ 4		$ 4
Labour for installation and construction	**Unit**	**Unit Price (USD/person-hour)**	**Quantity (person-day)**	**Total (USD)**	**Quantity (person-day)**	**Total (USD)**	**Quantity (person-day)**	**Total (USD)**
Unskilled worker	person-day	$ 0.53	18.4	$ 78	21.8	$ 92	5.4	$ 23
Skilled worker	person-day	$ 1.27	6.0	$ 61	7.4	$ 75	3.2	$ 32
Total labour for installation		USD	$ 139		$ 167		$ 55	
Construction materials	**Unit**	**Unit Price (USD/unit)**	**Quantity (unit)**	**Total (USD)**	**Quantity (unit)**	**Total (USD)**	**Quantity (unit)**	**Total (USD)**
Bricks	pc	$ 0.28	876.0	$ 245	1,751.9	$ 491		
Cement 50 kg bag	bag	$ 6.37	9.4	$ 60	8.5	$ 54		
Sand	m³	$ 13.90	1.8	$ 25	1.1	$ 15		
Gravel	m³	$ 16.23	1.0	$ 16	0.6	$ 10		
Tubular bag (0,2 mm thick)	metre	$ 0.16					16.5	$ 3
Other accessories	%		17%	$ 115	19%	$ 185	6%	$ 14
Paint	l	$ 2.89	0.6	$ 2	2.1	$ 6		
Net cyclone 4" feet	roll	$ 0.70		$ -		$ -	0.2	$ 0
Zinc sheets	kg	$ 0.70		$ -		$ -	2.4	$ 2
Plastic valve 1/2"	pc	$ 0.25		$ -		$ -	4.0	$ 1
Plastic hub 1/2"	pc	$ 0.25		$ -		$ -	2.0	$ 1
Pneumatic league	pc	$ 0.25		$ -		$ -	60.0	$ 15
Gas stove	pc	$ 23.16	1.0	$ 23	1.0	$ 23	1.0	$ 23
Gas light	pc	$ 0.81	1.0	$ 1	1.0	$ 1	1.0	$ 1
Main valve	pc	$ 7.40	1.0	$ 7	1.0	$ 7	1.0	$ 7
H_2S filter	set	$ 4.63	1.0	$ 5	1.0	$ 5	1.0	$ 5
Pressure manometer	pc	$ 52.50	1.0	$ 53	1.0	$ 53	1.0	$ 53
Mixing decive	pc	$ 122.85	1.0	$ 123	1.0	$ 123	1.0	$ 123
Total construction material		USD	$ 673		$ 971		$ 247	
Total investment cost		USD	$ 813		$ 1,139		$ 302	
			Total Depreciation	$ 41	Total Depreciation	$ 57	Total Depreciation	$ 30
Total maintenance cost		3%		$ 1.22		$ 1.71		$ 0.91
Subtotal fixed costs		USD/year		$ 42		$ 59		$ 31
Other costs				**Total (USD/year)**		**Depreciation (USD/year)**		**Depreciation (USD/year)**
Loan interest				$ 28		$ 40		$ 21
Subtotal fixed costs		USD/year		$ 28		$ 40		$ 21

Total costs	**Fixed dome (USD/year)**			**Floating drum (USD/year)**			**Tubular (USD/year)**		
Total operating costs	$	4	6%	$	4	4%	$	4	8%
Total fixed costs	$	42	56%	$	59	57%	$	31	55%
Total other costs	$	28	38%	$	40	39%	$	21	37%
Total production costs		$ 74			$ 103			$ 56	

Total Production Cost

2

	Biodigester Options		
	Fixed dome	Floating drum	Tubular
Unit cost of biogas (USD/m³)	$ 0.56	$ 0.77	$ 0.42

3

e loan interest without policy	Unit	Loan ratio (%)	Total investment (USD)	Loan amount (USD)	Total investment (USD)	Loan amount (USD)	Total investment (USD)	Loan amount (USD)
amount	USD	60%	$ 812.67	$ 487.60	$ 1,138.88	$ 683.33	$ 301.88	$ 181.13
Loan interest rate	%			12%		12%		12%
Loan payment	USD/month			-$ 5.85		-$ 8.20		-$ 2.17
Annual loan payment	USD/year			-$ 70.22		-$ 98.41		-$ 26.09
Loan terms	year			15		15		15
Total loan payment	USD			-$ 1,053.37		-$ 1,476.20		-$ 391.29
Loan interest	USD			-$ 565.76		-$ 792.87		-$ 210.16
Average loan interest	USD/year			-$ 28.29		-$ 39.64		-$ 21.02

Figure 14: Production Cost Details in Biogas Production

For this example, the production cost of the fixed dome is 74 USD per year and the unitary cost of the biogas is 0.56 USD per m3. The average loan interest is 28 USD per year. For details on the other biodigesters, refer to Figure 14.

7.2 The summary results by size

Results for the *Biogas Community Component* are presented along four main categories: Production Cost and Investments; Social Benefits; Economic Benefits; and Financial Analysis.

1. The user first selects the biodigester size from the dropdown menu that he/she wants to review (Figure 15, label 1). The results for that specific size will be generated.
2. The production cost and investments results are presented as follows:
   - Cost of production of biogas (USD/m^3) for each bioreactor type (Figure 15, label 2).
   - Electricity equivalent basis (USD/kWh equivalent): The user first chooses the conventional fuels to carry out the comparison analysis by clicking in the boxes of the fuels (Figure 15, label 3).
   - Total investment cost (USD) of biogas for each bioreactor type (Figure 15, label 4).

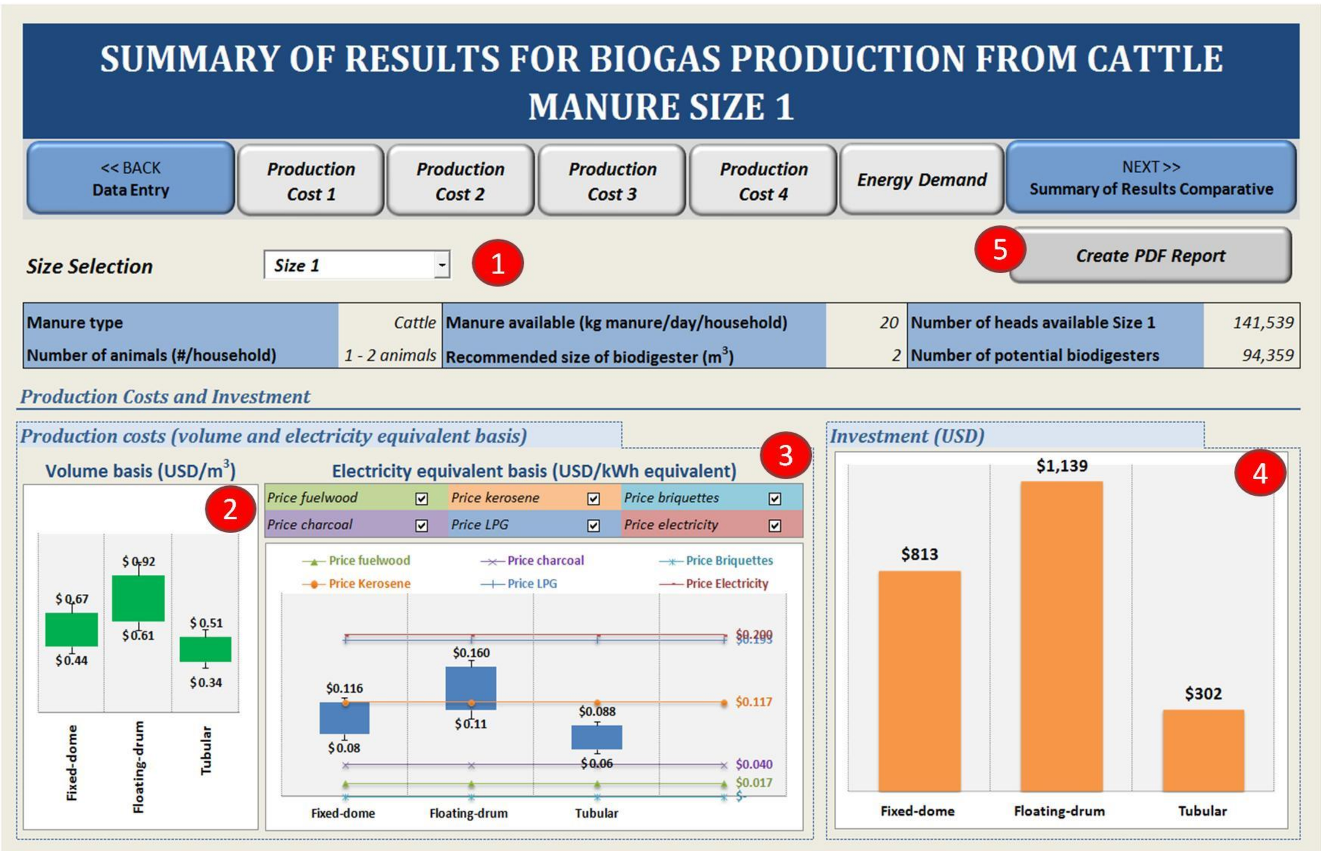


Figure 15: Production Cost and Investment Results

For Size 1, the lowest production cost is for tubular, which is between 0.088 to 0.06 USD per kWh. This production cost is less than the price of charcoal in the country, but higher than the price of fuelwood. The lowest investment cost required is for tubular. However, it is important to keep in mind that the tubular reactor has a lifetime of only 10 years compared to the 20 years of lifetime for the fixed dome and floating drum (Figure 15).

3. The results on social benefits are presented as follows:
   - The number of households that can be supplied with biogas based on national information on biogas availability (Figure 16, label 1).
   - The energy demand that the production of a biodigester can supply at the household level (Figure 16, label 1).
   - Jobs created during the period of implementation of the biogas program at the national level (Figure 16, label 2).
   - Net balance of time consumption per household (Figure 16, label 3). If positive, this means there is time saved from using biogas when compared to current fuels.
   - The quantity of bioslurry in fertilizer equivalent produced by the biogas reactor per household (Figure 16, label 4). The results also calculate the value of bioslurry to pure manure. This is done by attributing a higher nitrogen value to the bioslurry (N-fertilizer improved) as compared to pure manure.

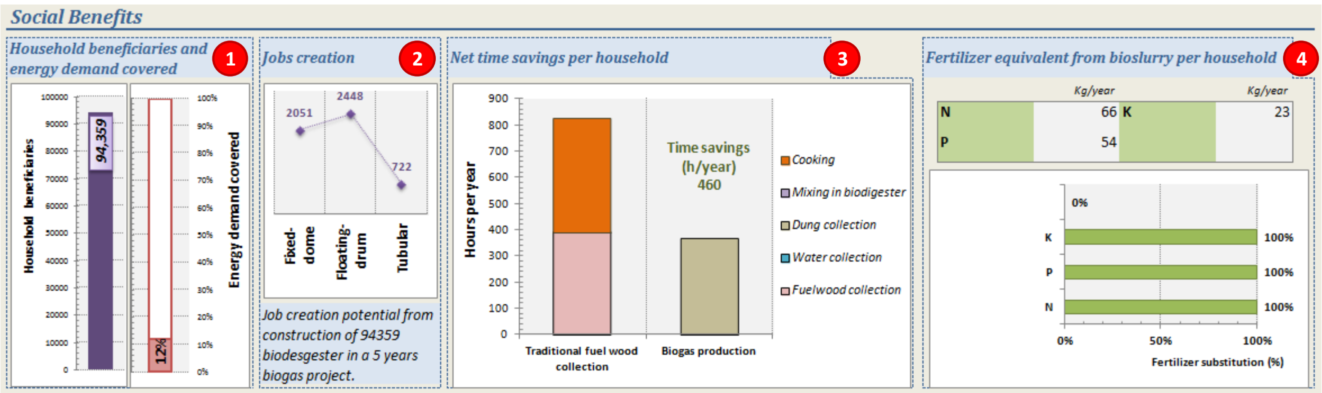
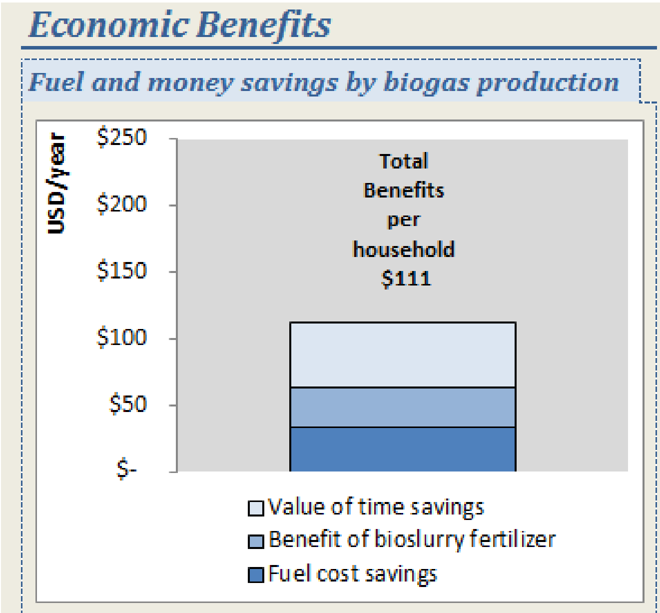


Figure 16: Social Benefits Results

For Size 1, 94,359 households benefitted. The potential number of employment that can be generated to construct the biodigesters in a 5-year program ranges from 722 (tubular) to as much as 2448. Biogas systems can free 500 hours per year for a household compared to if the same household used the traditional fuel option. The bioslurry that is co-generated from biogas is equivalent to 66 kg of nitrogen and can substitute chemical nitrogen fertilizer (Figure 16).

4. The economic benefits results show that fuel and money savings from biogas production include the following (Figure 17):
   - The monetary saving obtained from displacing the use of current biofuels through biogas use, i.e. the purchase of charcoal.
   - The economic benefits embedded associated with bioslurry. This is based on the valuation of the bioslurry as a fertilizer.
   - The valuation of the time saved, assuming that a portion of this time can be used by the household in income generating opportunities.



Woody biomass saving	235	kg/year
Fossil fuels avoided	26	L/year
Electricity avoided	-	kWh/year

Figure 17: Economic Benefits Results

For Size 1, the use of biogas can save about 235 kg per year of biomass. It can avoid the use of 10 litres of fossil fuel equivalents. The substitution of biogas to the current sources of energy, taking into consideration the fuel savings, the benefit from bioslurry as fertilizer and valuing the time saving can save a household about 111 USD per year (Figure 17).

5. The financial analysis (before tax return) provides measures on the feasibility for installing the biodigesters. It also indicates the potential attractiveness of households to install the reactors. If the values are not viable, this indicates the need for government intervention through further analysis, if the country decides to develop a biogas program. The two main financial indicators use in the assessment are:
   - Net Present Value (NPV) (Figure 18, label 1)
   - Internal Rate of Return (IRR) (Figure 18, label 2)

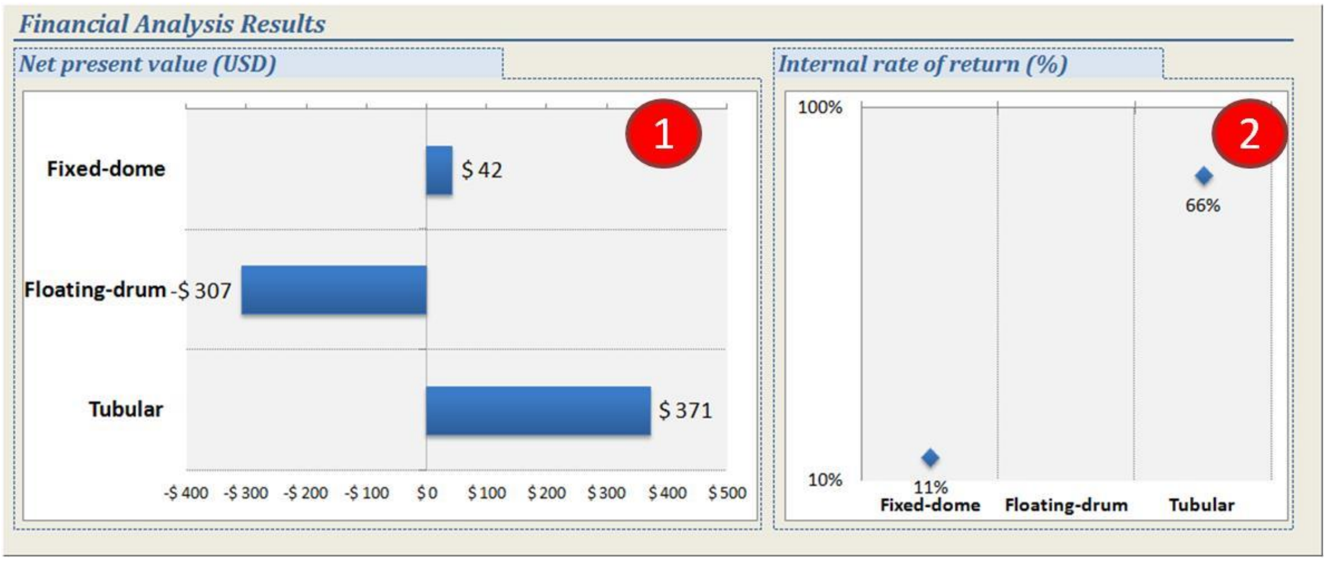


Figure 18: Financial Analysis Results

For Size 1, the financial variables indicate that the tubular digester is the most viable. However, the user should consider that the tubular digester's lifetime is 10 years and will have to be replaced after that. Other considerations should also include if this technology is appropriate for the local context, in terms of environmental and cultural conditions. Moreover, the financial variables should be considered in combination with socio-economic results presented above (Figure 18).

The user can save and print the results in PDF format by using "Create a PDF report" and following the instructions (Figure 15, label 5).

7.3 The summary of comparative results

In this section, the user can compare the results across the various sizes that were evaluated.

1. Comparison results are presented on:
   - Households that may potentially benefit (Figure 19, label 1)
   - Production cost (USD/m^3) (Figure 19, label 2)
   - Production cost (USD/kWh equivalent) (Figure 19, label 2)
   - Employment generation (Figure 19, label 3)
2. A comparison of financial results before taxes is generated for:
   - Net Present Value (NPV) (USD) (Figure 19, label 4)
   - Internal Rate of Return (IRR) (%) (Figure 19, label 5)

The user can save and print the results in PDF format by using "Create a PDF report" and following the instructions (Figure 19, label 6).

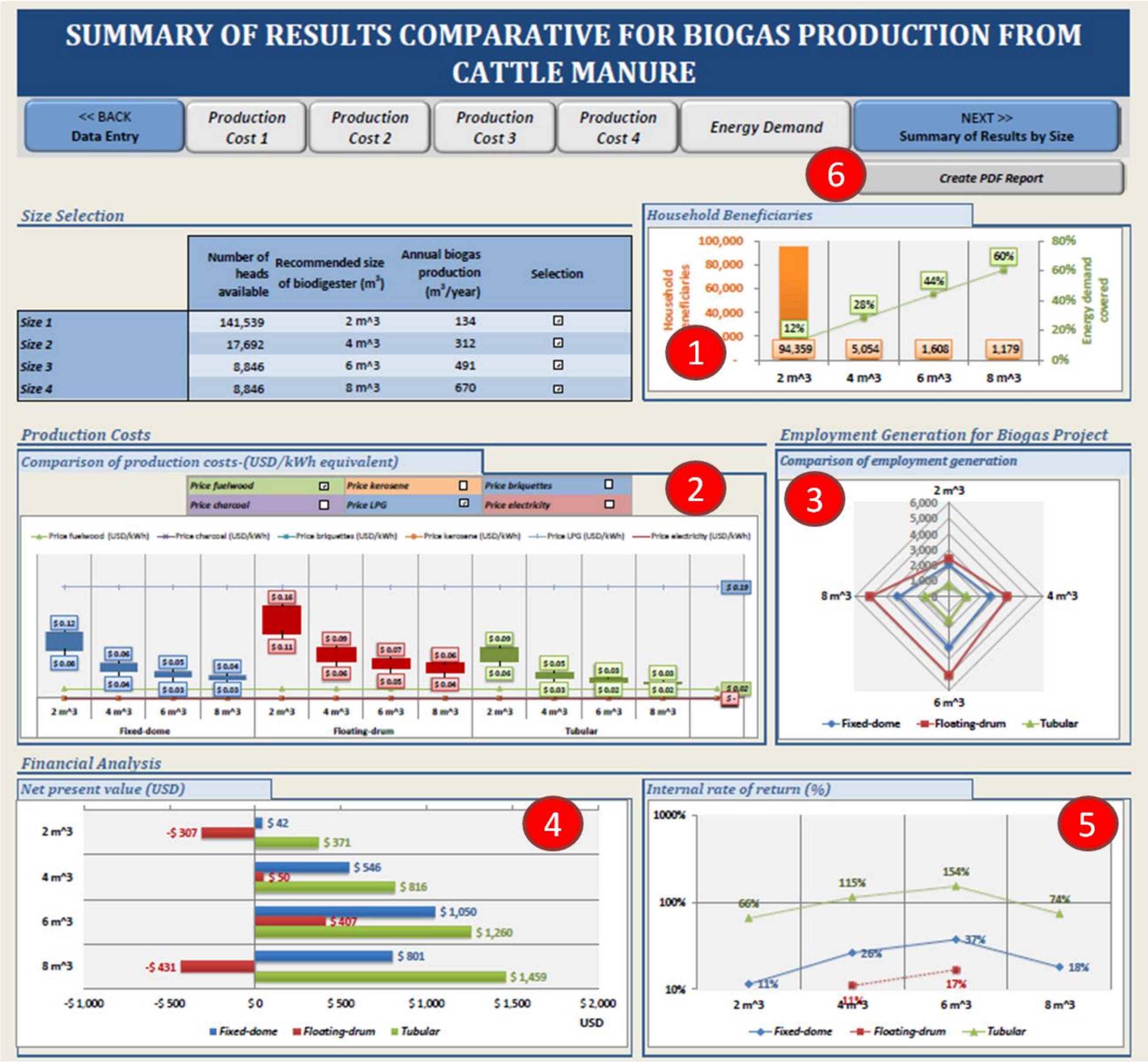


Figure 19: Layout of Comparative Results

For this example, the information generated indicates that for all sizes, the tubular option grants the largest returns given the low investment requirements for this alternative. However, the employment generation potential of this option is the comparative lowest among the considered alternatives, and it might represent a good option to support rural employment generation.

It is also important to analyse that given the significant volume of households that own the lowest range of animals (3-4), the most viable size digesters would fall into the category 4 m^3 (Size 1). This amount of biogas production will only satisfy a 28% of the households' current energy demand. Consequently, to obtain to supply a larger share of the energy demand, it would be advisable to promote associations among householders, in order to increase the manure available to feed a large option, such as the Size 4 at 8 m^3, where the energy supplied can meet 60% of the demand (Figure 19).

The tool aims to help answering the following questions:

- How much biogas can be produced, according to the type and availability of livestock in rural households?
- What biodigester size should be constructed based on the type and availability of manure in rural households?
- What type of biodigester reactor can be considered and how much would it cost to construct different biodigester reactors?
- What quantity of the current energy use in rural households (fuelwood, charcoal, kerosene, etc.) can biogas replace?
- What are the non-economic benefits of biogas from bioslurry use, e.g. time savings and avoidance of fuelwood/charcoal?

8 Annex

8.1 Methodology and outputs

This section describes the methodologies integrated in the *Biogas Community Component*. It also includes a description of the equations which support the analysis. The equations are not visible to the user, but their structure and content might be important for those who will update them and/or work on the improvement of the tool.

8.1.1 Volumetric production of biogas

In order to calculate the volumetric production rate of biogas, the Contoin model was used by using the general equation (Hashimoto, Chen et al. 1981):

$$Y_p = B_0 SV_0 \left[1 - \frac{k}{\theta\mu_m - 1 + k}\right] \times \left[\frac{\dot{m}_{manure}}{\rho_{manure}} + \frac{\dot{m}_{water}}{\rho_{water}}\right]$$

Y_p : Volumetric production rate of methane (m^3 CH_4/d)
B_0 : Ultimate yield of methane (m^3 CH_4/Kg SV)
SV_0 : Initial volatile solid concentration (kd SV/m^3)
k : Kinetic parameter (dimensionless)
θ : Digestion time (d)
μ_m : Maximum specific rate (1/d)
$\dot{m}_{manure}$: Manure rate (kg/d)
ρ_{manure} : Manure density (kg/m^3)
$\dot{m}_{water}$: Water rate (kg/d)
ρ_{water} : Water density (kg/m^3) = 1000 kg/m^3

Specific rate: $\mu_m = 0{,}066[1 + 1100e^{-0{,}187T}]^{-0{,}546}$

μ_m : Maximum specific rate (1/d)
T : Environment temperature (ºC) $5 \leq T \leq 60$

Digestion time: $\theta = 122{,}16e^{-0{,}05T}$

θ : Digestion time (d)
T : Environment temperature (ºC)

Kinetic parameters:
Buffalo: $\mathrm{k} = 0{,}6 + 0{,}021\mathrm{e}^{0{,}05\mathrm{SV}_0}$
Dairy Cattle: $\mathrm{k} = 0{,}8 + 0{,}01\mathrm{e}^{0{,}06\mathrm{SV}_0}$
Swine: If $\mathrm{SV}_0 \leq 58{,}6\ ^{\mathrm{kg}}/_{\mathrm{m}^3}$ $\mathrm{k} = 0;$
If $\mathrm{SV}_0 > 58{,}6\ ^{\mathrm{kg}}/_{\mathrm{m}^3}$ $\mathrm{k} = 0{,}0866\mathrm{SV}_0 + 4{,}2755$

Once the volumetric production rate of methane is known, the biogas volumetric production rate can be calculated by taking into account the percentage of methane in the biogas depending on manure being used.

8.1.2 Construction material

Materials required for the construction of the different digester types at various volumes have been used to assessed the regressions, obtaining linear equations in the form aV + b = c, by using the least square method, where *a* and *b* are the slope and the intercept, respectively; *V* is the digester volume and *c* is the required material quantity. Constants *a* and *b*, are shown in the “Reactor regression materials” sheet for fixed dome, floating drum (Jatinder-Singh and Singh-Sooch 2004; Khandelwal 2007) and tubular (Martí 2008; Filomeno, Bron et al. 2010; Filomeno, Fernández et al. 2010) digesters.

8.1.3 Manure properties

Table 1: Manure Basic Properties

Property	Manure			Reference
	Buffalo	Dairy Cattle	Swine	
Density (kg/m^3)	960	960	1140.9	(Hubbard and R.R. ; Queenland Government ; Tao and Mancl)
Volatile solids	0.1364	0.1325	0.2360	(Alvarez. Villca et al. 2006)

Table 2: Manure Ultimate Analysis

Manure	C (%)	H (%)	N (%)	S (%)	O (%)	C/N	Reference
Buffalo	32.90		1.70			19.00	(Thi Ngo. Rumpel et al. 2011)
Dairy Cattle	50.39	5.77	3.94	1.31	38.58	12.80	(Santoianni. Bingham et al. 2008)
Swine	48.44	7.07	4.90	0.93	38.66	9.89	(O'Palko. Jensen et al. 2003)

Table 3: Manure Proximate Analysis

Manure	Moisture (%)	Volatile matter (%)	Fixed carbon (%)	Ash (%)	Reference
Buffalo	73.49				(Rashad. Saleh et al. 2010; Thi Ngo. Rumpel et al. 2011)
Dairy Cattle	36.60	31.60	6.60	25.20	(Santoianni. Bingham et al. 2008)
Swine	7.22	52.32	11.33	29.13	(O'Palko. Jensen et al. 2003)

Table 4: Properties for the Contoin Model

Bo (m^3/Kg SV)	Manure			Reference
	Buffalo	Dairy Cattle	Swine	
North America	0.10	0.19	0.48	(Hashimoto. Chen et al. 1981)
Western Europe	0.10	0.18	0.45	
Eastern Europe	0.10	0.17	0.45	
Oceania	0.10	0.17	0.45	
Latin America	0.10	0.10	0.29	
Africa	0.10	0.10	0.29	
Middle East	0.10	0.10	0.29	
Asia	0.10	0.10	0.29	
Indian Subcontinent	0.10	0.10	0.29	

8.1.4 Biogas properties

Table 5: Biogas Composition

Composition	Manure		
	Buffalo	Dairy Cattle	Swine
CH_4	0.591	0.577	0.588
CO_2	0.343	0.375	0.387
H_2	4.766E-2	3.250E-3	4.900E-3
N_2	1.573E-2	0.025	0.015
CO	9.532E-4	3.250E-3	0
O_2	9.532E-4	0.010	0
H_2S	4.766E-4	0.006	5.100E-3
NH_3	9.533E-5	5.000E-4	0
Reference	(Flores 2009)		

8.1.5 Bioslurry properties

Table 6: Bioslurry N-P-K Values

Manure	Nutrients concentration dry basis			Reference
	N (kg N/kg bioslurry)	P (Kg P2O5/kg bioslurry)	K (Kg K2O/kg bioslurry)	
Buffalo	0.0105	0.0082	0.0055	(Islam 2006)
Dairy Cattle	0.0170	0.0140	0.0060	

Swine	0.0220	0.0180	0.0080	

8.1.6 Calculations

Item	Equation and Assumption	Remark
Energy Demand		
Annual Fuel $_i$ consumption household (biogas equivalent/year)	$$AF_i = \frac{Fuel_i}{Be_i}$$ Where: AFi = Annual fuel i consumption; Fuel $_i$ = fuel i consumption (kg/day); i = Briquette, Fuel wood, Charcoal, kerosene and LPG	Fuel $_i$ (kg/day) is input by User
Annual biogas consumption equivalent (tonnes/year)	$$ABe = \sum \frac{AF_i}{CF_i}$$ Where: ABe = Annual biogas equivalent; AFi = Annual fuel i consumption; CFi = Conversion factor of fuel i; i = briquette, fuelwood, charcoal, kerosene and LPG	Table 10 CF of briquette = 1 kg/ $kg_{briquette}$ CF of fuel wood =6.11 kg/$kg_{briquette}$ CF of charcoal = 1.14 kg/$kg_{briquette}$ CF of kerosene = 0.32kg/$kg_{briquette}$ CF of LPG = 0.26 kg/$kg_{briquette}$ (Young & Khennas, 2003)
Energy expenditure of fuel i (USD/year)	$$EE_i = \text{Unit price fuel i x } AF_i$$ Where: EEi = Energy expenditure of fuel i; Unit price fuel i (USD/kg); AFi = Annual fuel i consumption; i = briquette, fuelwood, charcoal, kerosene and LPG	Unit price fuel i (USD/kg) is input by user
Potential revenue (USD /year)	Biogas m3 per year x Market Price of substitution fuels	Input data by user
Other Calculations		
Time savings	Time savings = Time required to collect and use the wood – Time required to produce biogas	Input data by user
Bioslurry fertilizer equivalent	Bioslurry fertilizer equivalent=Bioslurry produced x Nitrogen fertilizer content x 0.5 It is assumed that just 50% of the bioslurry is used	Input data by user
Employment generation		

8.2 Data requirements for running the tool

Table 7 includes data requirements for running the *Biogas Community Component*. A suggested data source is provided.

Table 7: Data Requirements for Running the Tool

Data	Definition and Sources
Livestock manure	The user selects the type of livestock manure for the analysis and provides information on the number animal heads per household in order to estimate the volatile solids (VS) content needed in the technical model. The model is set to carry out the analysis for 4 biodigester reactor sizes based on this information.
Country selection	The user identifies the country it wishes to analyse.
The environment temperature	The user provides the environmental temperature (°C); this can be an average temperature in the country.
Feedstock price (USD/ton)	The user inputs the cost of manure.
Water price (USD/m^3)	The user inputs the price of water.
Price of construction material	The user enters the price of construction material required for constructing the biodigester reactor.
Price of fuels used for heating and cooking	The user enters information on the price of fuelwood, charcoal, kerosene, LPG and the level of consumption of each of these in rural households.
Percentage of collected fuel wood	The user provides an estimated percentage of rural households that collect fuel wood. This value will be used to calculate the estimated percentage of households in rural areas that purchase fuelwood.
Labour cost	The user inputs data on estimated hourly wages (USD/hour) for semi-skilled and unskilled workers.

Manure and fertilizer consumption	The user identifies the consumption (kg/year) of manure and fertilizers (Nitrogen, Phosphorous, Potassium) per household and its respective prices.
Time use of fuel collection	The user can utilise the default values provided by the tool or input its own information on the time rural households employ in collecting fuelwood, dung and water, and preparing manure for digester (mixing) and cooking.
Financial parameters	The user provides information on the following financial parameters: ○ Discount rate (%) ○ Loan interest rates (%) ○ Loan term (years) ○ Loan ratio (%) ○ Plant cost index http://base.intratec.us/home/ic-index This information can come from current loans given by agricultural banks to smallholder farmers.
Types and quantities of typical fuels used for heating and cooking	Fuels are charcoal, fuelwood, kerosene, briquette, electricity and LPG that used for heating and cooking in urban and rural households (original unit of fuel per day per household).
Price of fuels used for heating and cooking	The current price of fuels such as charcoal, fuelwood, kerosene, briquette, electricity and LPG in unit of USD per original unit of fuel.

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