Food and Agriculture Organization
of the United Nations

BIOGAS INDUSTRIAL

User manual

Bioenergy and food security
Rapid appraisal (BEFS RA)

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[2] The BEFS working group in Malawi comprises the following members: Ministry of Energy, Ministry of Lands, Housing, and Urban Development, Ministry of Finance, Ministry of Agriculture and Food Security, Ministry of Environment and Climate Change and Department of Forestry, Ministry of Industry and Trade, Ministry of Economic Planning and Development, Ministry of Labour and Vocational Training, Ministry of Transport and Public Infrastructure, Ministry of Information and Civic Education, Ministry of Local Government and Rural Development.

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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.

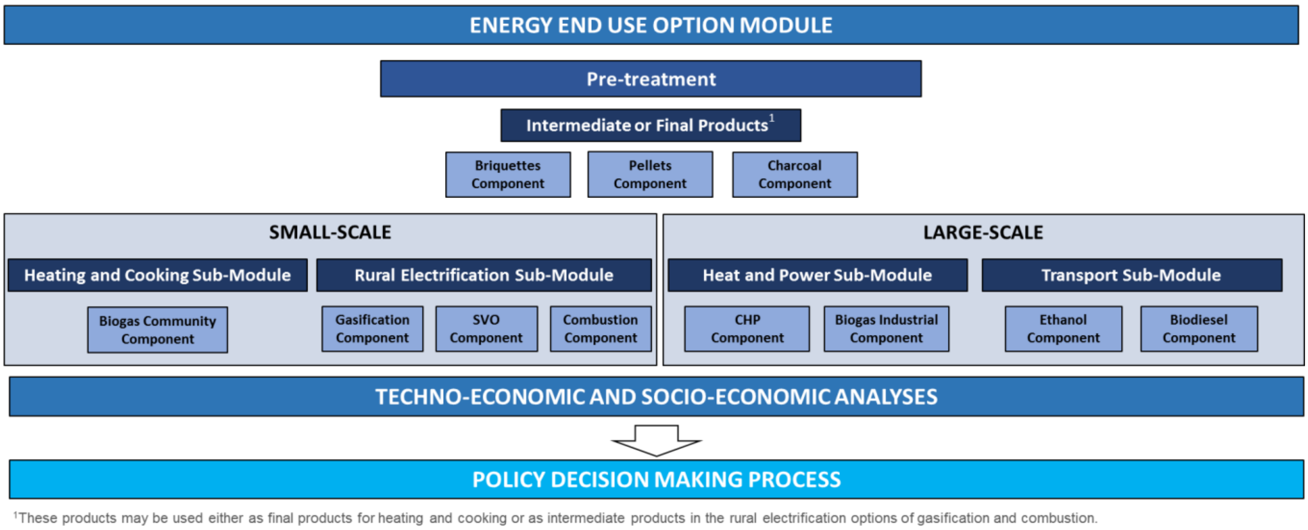


Figure 1: The Structure of the energy end use option module

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

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

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 industrial component

The Biogas industrial component is designed to assist the user in evaluating the potential to develop industrial-scale biogas production from different organic materials with one of the following objectives: electricity production, heat and electricity production, heating and/or cooking, and selling the biogas to the natural gas line. The boundary of the biogas industrial analysis is shown in Figure 2. The tool is based on extensive literature review. The detailed assumptions and calculations used to develop the tool are provided in the Annex.

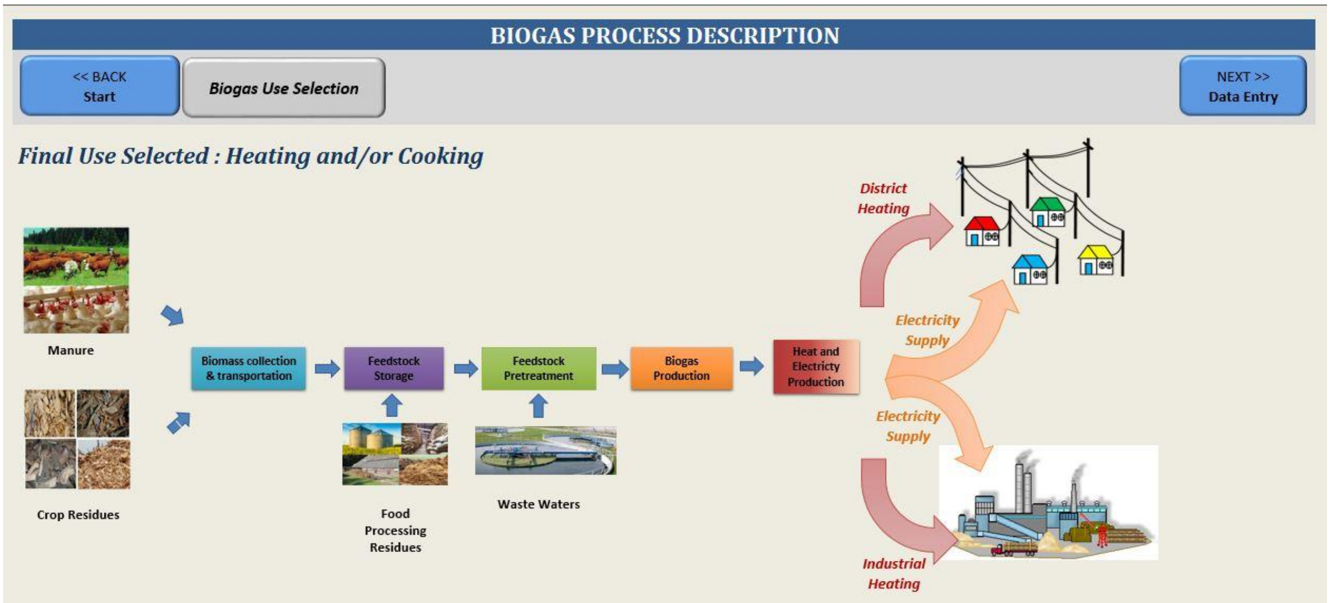


Figure 2: Biogas production system at the industrial level

After completing the analysis, the user will have an indication on: 1) the production cost of the main product for various scales of biogas production as well as the share of production cost and the total investment cost; 2) the feedstock consumption and demand for each production scale; 3) the annual feedstock distribution; 4) the number of plants and consumers potentially supplied; and 5) the employment generation potential and financial viability associated to each level of production as shown in Figure 3. The user will also be able to compare across different process and plant capacities to identify the most appropriate biomass sources based on a number of factors including physical availability, economic and social results.

[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.

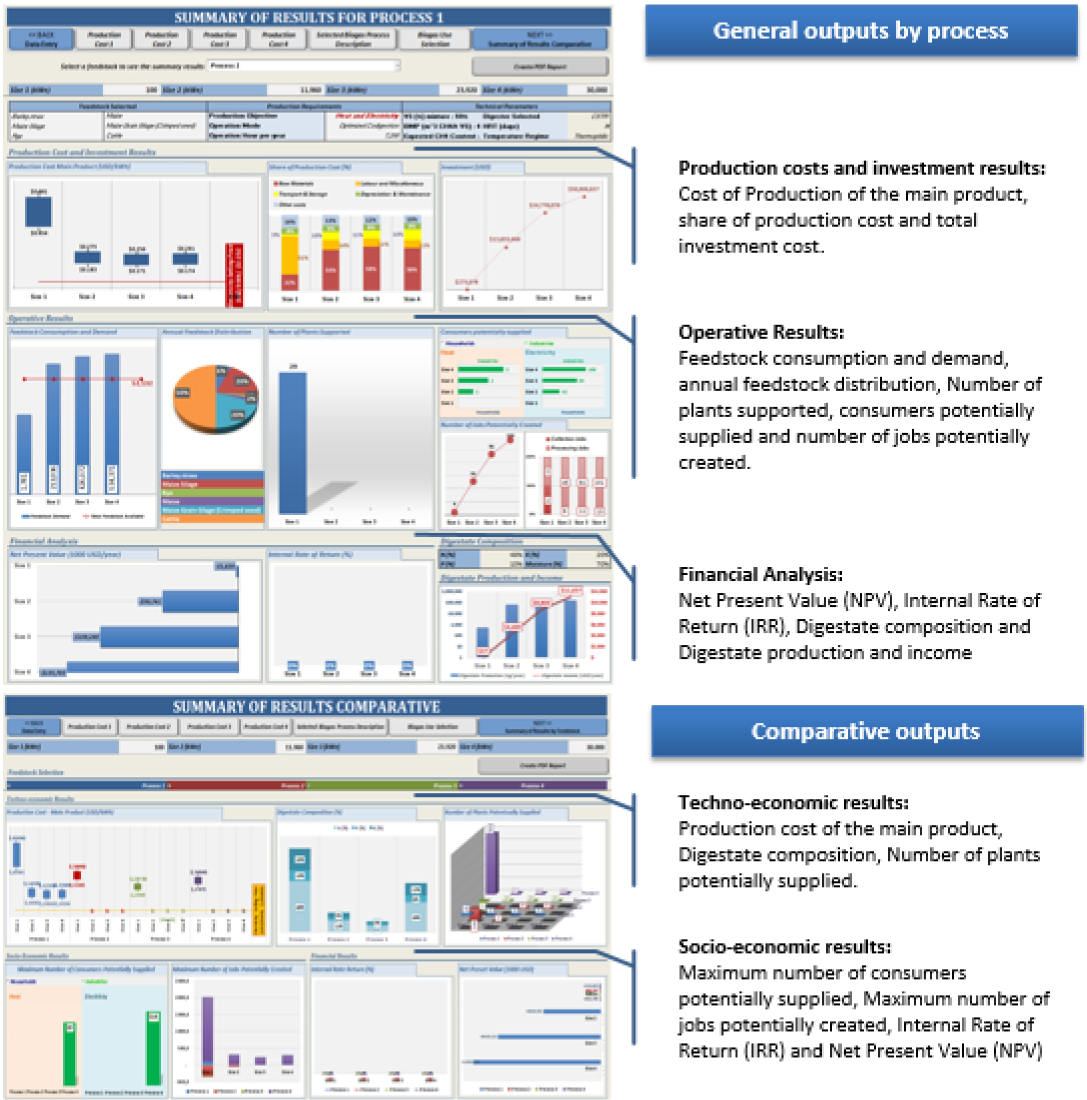


Figure 3: Layout of the biogas – Industrial results sheets

3 Terms and definitions used in the biogas industrial component

This section includes the definitions of specific terms used in the biogas industrial 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 during anaerobic digestion (AD) of wastewater, organic wastes and biomass. During the biological conversion of the organic material in an oxygen-free environment, biogas and bio-fertilizers are obtained as useful end products. 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. Besides, it is a renewable energy source and CO_2 neutral, mainly composed of methane and carbon dioxide. The biogas can be used to generate heat and/or electricity by burning it, as feedstock to produce methanol and chemical feedstock to replace carbon and coal, among others applications.
- The **Upflow Anaerobic Sludge Blanket (UASB)** is the most used technology for wastewater treatment worldwide (Strezov and Evans, 2015, Chan *et al*., 2009, Abbasi *et al*., 2012). In an UASB, a gas collection device replaces the packing material. These biodigesters operate in upflow mode, feeding the influent by the bottom, going through dense sludge bed with high microbial activity and a gas-liquid-solid separation device (Strezov and Evans, 2015, Chan *et al*., 2009). This separator device allows separating the liquid effluent, that flows out from the reactor from the solid sludge, that remains in the digester, while biogas is collected (Strezov and Evans, 2015). The process is based on the natural immobilization of anaerobic bacteria, forming 1-4 nm of diameter dense granules (Chan *et al*., 2009, Wang *et al*., 2005).
- The **Continuously Stirred Tank Reactor (CSTR)** is the most common and easy to operate biodigester for treating wastewater with high solid concentration and chemical oxygen demand (COD) values higher than 30.000 mg/L (Chan *et al*., 2009, Wang *et al*., 2005). Usually the CSTR volumes ranges between 500 to 700 m^3 with an organic loading rate (OLR) ranging from 1-4 kg organic dry matter per m^3 per day (Wang *et al*., 2005). The CSTR digester is mostly used to stabilize the sludge by converting the biodegradable fractions into biogas (Massoud *et al*., 2007). It is usually operated at high temperatures, to increase the process rates. CSTR digestion units are designed in big volumes that make perfect mixing difficult. Mixing is done mechanically or by recycling either flow or the produced biogas. Therefore, the mixing efficiency is an important factor in modelling the solids transport in the reactor and evaluation of the Solids Retention Time (SRT). Materials with very high COD loading rates (30 kg per m^3 per day) can be digested using this technology, reaching an adequate treatment at lower Hydraulic Retention Times (HRT) (even 4 hours) (Wang *et al*., 2005). Generally, a removal efficiency of 85-95% of the COD of the inlet material and a methane content in the produced biogas of 80-95% have been reported for this type of digestion (Chan *et al*., 2009, Wang *et al*., 2005).
- The **Plug Flow Reactors (PFR)** have a constant volume, but produce biogas at a variable pressure. The size of such digesters varies from 2.4 to 7.5 m^3. PFR digesters consist of a narrow and long tank with an average length to width ratio of 5:1. The inlet and outlet of the digester are located at opposite ends, kept above ground, while the remaining parts of the digester is buried in the ground in an inclined position. As the fresh substrate is added from the inlet, the digestate flows towards the outlet at the other end of the tank. The inclined position makes it possible to separate acidogenesis and methanogenesis longitudinally, thus producing a two-phase system (Rajendran *et al*., 2012). Although the optimal digestion in PFRs is reached at thermophilic conditions, they can be also operated at mesophilic temperatures (Strezov and Evans, 2015). Under thermophilic conditions the HRT is usually of 15 to 20 days. In order to avoid temperature fluctuations during the night and to maintain the process

temperature, a gable or shed roof is placed on top of the digester to cover it, which acts as an insulation both during day and night (Rajendran *et al*., 2012). The optimal solids concentration of the feed is in the range of 11% to 14% (Abbasi *et al*., 2012).

- In a **batch** reactor the biomass is loaded once and discharged until the end of the process. Because of its simplicity and portability, batch reactors are a good option for treating biowaste in countries where landfilling is the most common waste management method utilized (Abu-Reesh, 2014). Batch reactors function similar to a landfill, but at higher temperatures and with continuous leachate recirculation the biogas yield is between 50 and 100 percent higher than in landfills (Mogal, 2013). Another advantage of batch fermentation is the possibility to recover recyclables and other materials after the anaerobic fermentation is completed (Mogal, 2013). As the batch digestion is simple and requires less equipment and lower levels of design work, it is typically a cheaper form of digestion (Baskar *et al*., 2012).
- In **batch** biodigestion, the reactor is loaded once and discharged until the end of the anaerobic process takes place. Because of its simplicity and portability, batch reactors are a good option for treating biowaste in countries where landfilling is the most common waste management method utilised. Batch reactors function similar to a landfill, but at higher temperatures and with continuous leachate recirculation. The biogas yield is between 50 and 100 percent higher than in landfills (Vandevivere *et al*., 1999). Another advantage of batch fermentation is the possibility to recover recyclables and other materials after the anaerobic fermentation is completed. On the other hand, extra safety must be taken to avoid explosions when unloading the reactor after the digestion is complete.
- The **Hydraulic Retention Time (HRT)** is defined as the time that the influent remains into the digester (Kangle *et al*., 2012). The HRT depends on the technology, temperature and feedstock composition. For instance, for mesophilic digestion the HRT ranges between 10 to 40 days, while for thermophilic operation, lower HRT are required (approximately 14 days for high solids reactors). The HRT influences the economics of the digestion. For shorter retention times, smaller biodigesters are required, and therefore, have more favourable economics (Parawira, 2004). The numeric definition of this parameter is given by the following equation.

  $$\theta = \frac{V}{Q}$$

  Where θ is the HRT (d), V is the volume of the reactor (m^3) and Q is the influent flow rate (m^3/d).
- The operational temperature for biogas production determines the species of methanogens in the digesters. For instance, **mesophilic digestion** is performed at 30 to 40°C, where mesophiles are the primary microorganism present. For temperatures between 50 to 60°C, **thermophilic degradation** occurs, where thermophiles are the primary microorganisms present (Wang *et al*., 2014). The reaction rate of biological processes strongly depends on the growth rates of the involved microorganisms that are temperature-dependent. Usually high temperatures lead to faster chemical and biological reaction rates. Besides, temperature should be kept constant as much as possible during all the process, since fluctuations of even ±2% can reduce the biogas production in 30% for thermophilic operation (Zupančič and Grilc, 2012).
- The **Total Solids (TS)** content in anaerobic digestion can be divided into two different ranges: low solid content (LS) also called liquid anaerobic digestion, containing between 15 to 20% of TS and high solid (HS) or solid state anaerobic digestion, with a range between 22 to 40% of TS (Kangle *et al*., 2012, Monnet, 2003, Arsova, 2010). Municipal solid wastes and sludge from aerobic wastewater treatment are digested under low-solids conditions. Since these systems contain a large volume of water, liquid AD requires higher retention time and size for too low nutrient levels (Massoud *et al*., 2007).

For substrates having higher solids content, solid state anaerobic digestion (SS-AD) technology should be applied (Abbasi *et al*., 2012). SS-AD can be used to degrade food industry wastes, the biodegradable organic fraction of municipal solid waste, agricultural and forestry residues, and other high-solids wastes (Rajendran *et al*., 2012, Li *et al*., 2015, Brown *et al*., 2012). Typically, high-solids wastes must be mixed with water or a low-solids waste, e.g. wastewater treatment sludge, to dilute the solids content to the operating range (Yang *et al*., 2015). TS contents up to 30% have minimal effects on conversion rates and efficiency. However, TS contents range between 30 to 50% causes inhibition of AD because of the building-up of volatile fatty acids (Liew, 2011). The most used TS content for SS-AD ranges between 20% and 40% (Liew, 2011) (Table 1).

Table 1: Type of reactor depending on the TS content

Substrate	Reactor options
Low total solids content (<15%) *Examples: soluble industrial wastewater, municipal sewage, sewage sludge, aquatic/marine plants, particulate industrial wastes, animal manures*	▪ Anaerobic filter ▪ Upflow Anaerobic Sludge Blanket Reactor (UASB) ▪ Fluidized Bed Reactor ▪ Continuous stirred tank reactor (CSTR) ▪ Solids concentrating reactor (SOL-CON)
High total solids content (>15%) *Examples: municipal solid waste, agricultural residues, energy crops*	▪ Continuous stirred tank reactor (CSTR) ▪ Leach bed reactor (e.g. SEBAC-sequential batch anaerobic composting)

Source: Adapted from (Lai *et al*., 2009)

4 Scope and objective of the biogas industrial component

The aim of the biogas industrial component is to assess the potential of developing biogas production at the industrial level from different types of organic raw materials, such as crop residues, manure, wastewater, etc., to be used for different purposes, i.e. heat and electricity, heating and/or cooking, only electricity and biogas for the natural gas line. It provides the user with a technical foundation to identify the viability of producing biogas. The results present the financial analysis for the selected biodigester and raw materials and the socio-economic benefits that biogas production involves.

The following section describes the flow of analysis and options within this component. The background methodology for the biogas industrial financial analysis, feedstock collection and feedstock storage is described in detail in the Annex.

Figure 4: Rapid appraisal tool for heat and power

5 Running the biogas industrial component

The flow of analysis within the biogas industrial 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 industrial 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, particularly aspects related to food security, agricultural trade and the sustainable use of natural resources.

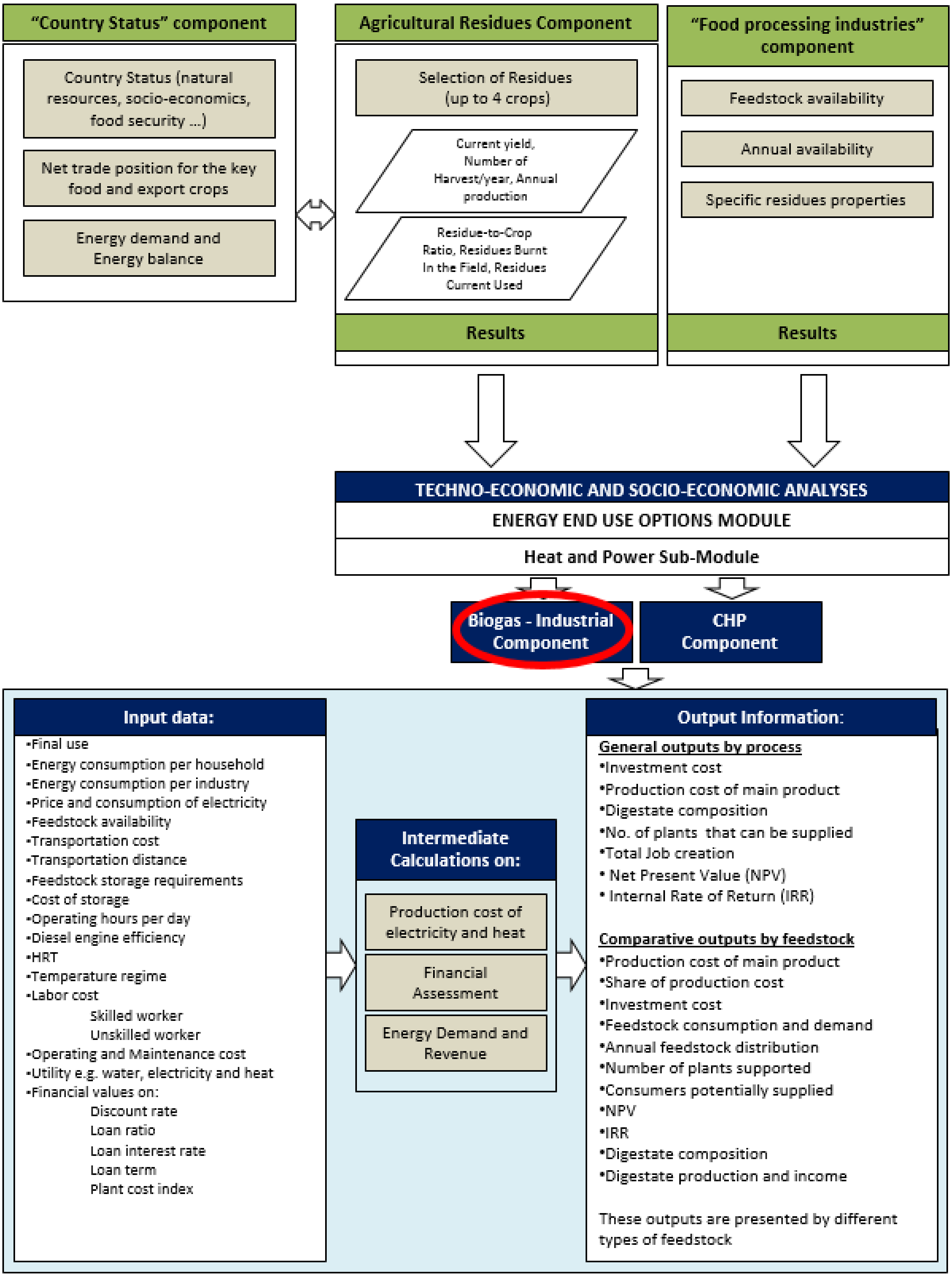


Figure 5: The Biogas industrial component: flow of analysis and inter-linkages with BEFS RA modules and components

The user navigates step by step through the options and is asked to input necessary data to obtain final results. When the required data are limited or unavailable, then the default values provided by the tool can be utilised.

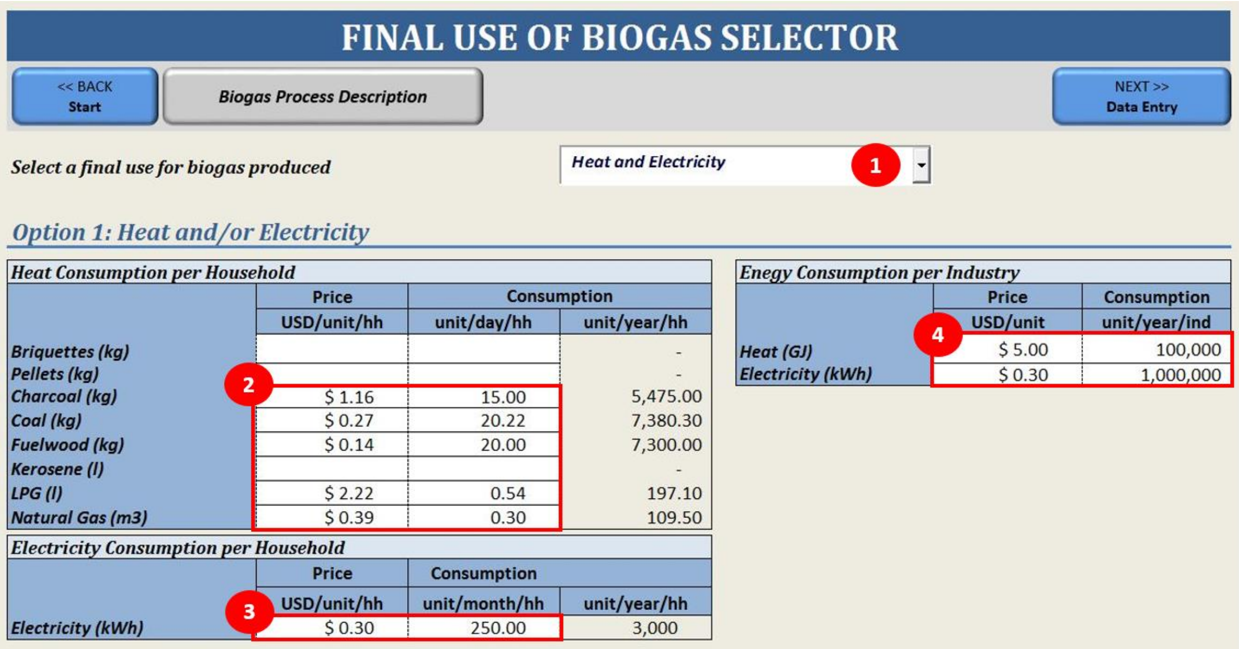
The navigation buttons are placed on the top and bottom of each sheet, indicating the next step with the button "NEXT>>" and allowing the user to return to a previous section with the "<<BACK" button.

The following sub-chapters describe each step of the analysis required to operate the biogas industrial tool. All input parameters are based on a generic situation.

5.1 Step 1: Biogas use selection

The user will:

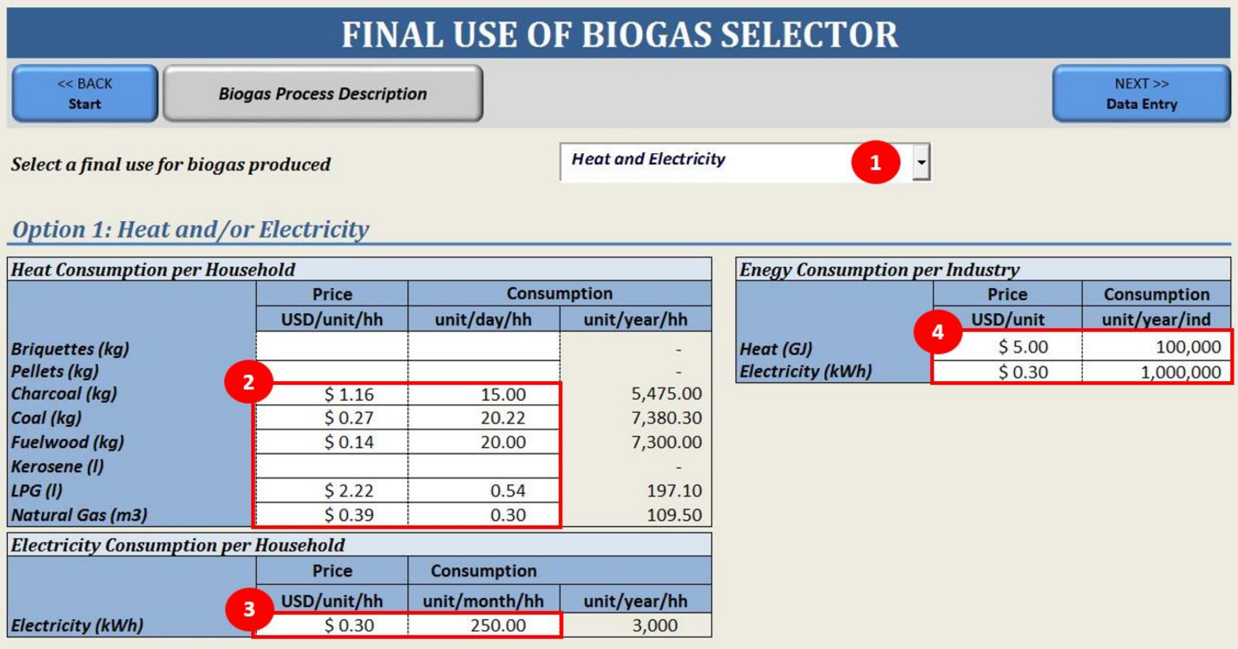
1. Select the final use for the obtained biogas (



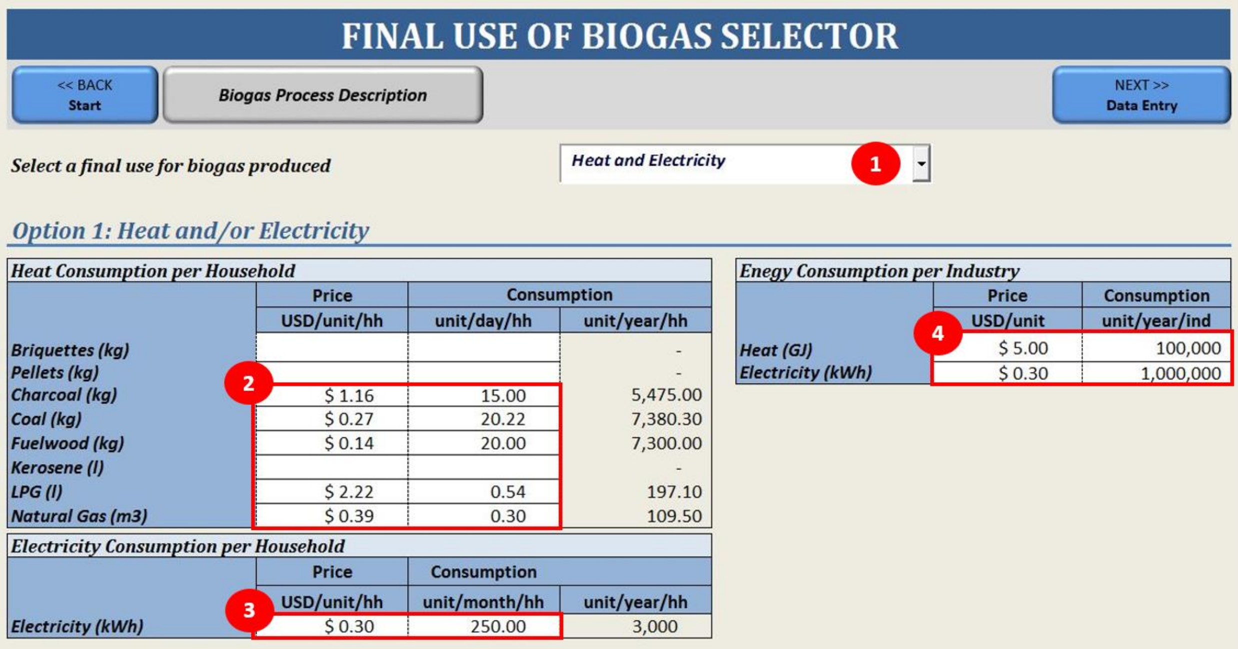
2. Figure 6, label 1). In this tool four possible final uses are considered:
   a. Option 1: Heat and electricity,
   b. Option 2: Heating and/or cooking,
   c. Option 3: Electricity only; and
   d. Option 4: Connection to natural gas line.

For this example, heat and electricity production was selected as the final use for the obtained biogas.

3. Define market prices and consumption of each energy type at the household level (

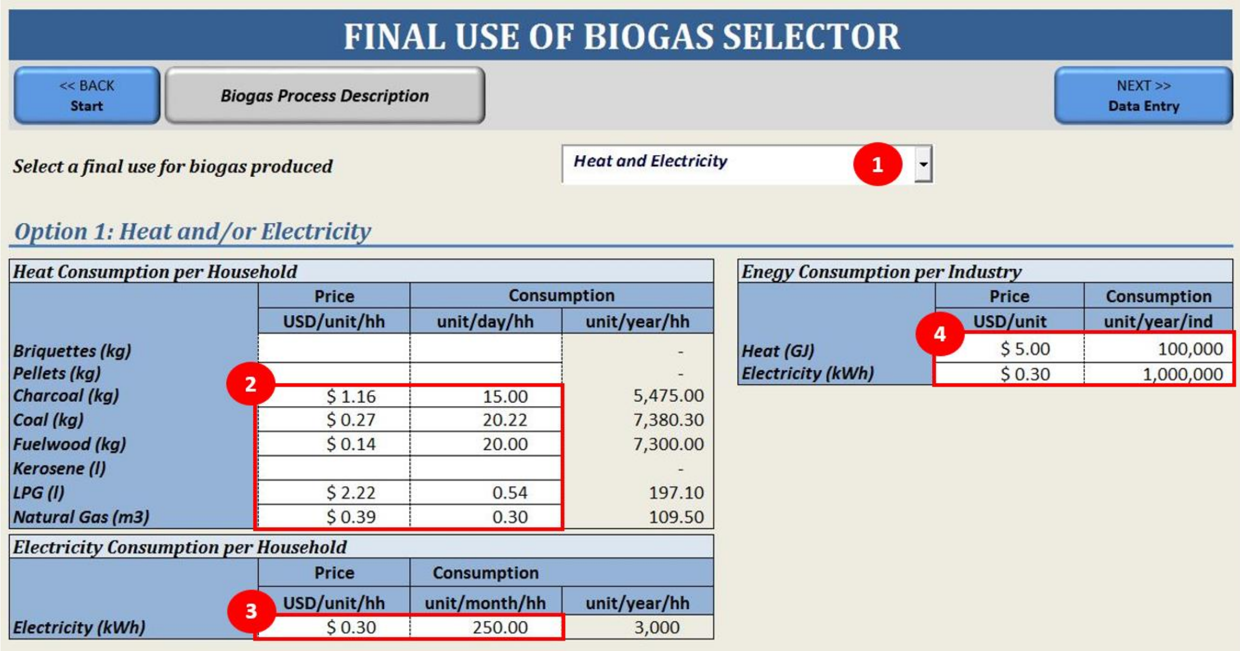


4. Figure 6, label 2).
5. Define the electricity market price and consumption at the household level (



6. Figure 6, label 3).

7. Define the electricity and heat market price and consumption at the industrial level (



8. Figure 6, label 4).

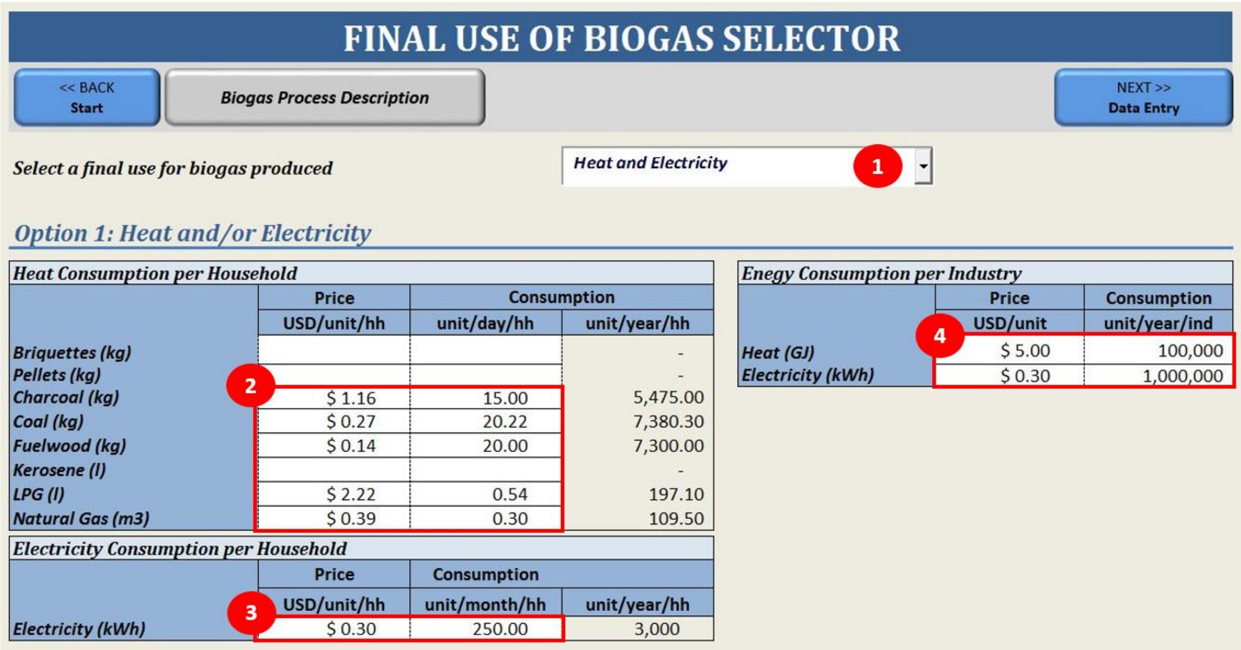


Figure 6: Final use of biogas – option 1

Depending on which of the options for the final use is selected, the data required varies. The market prices and consumption for different energy types are needed at both the household and industrial level. Additionally, for option 2 and 4, the user must also decide whether or not to include biogas transport and distribution to final consumers. Lastly, for option 4, the user must input the distance between the plant and the connection point.

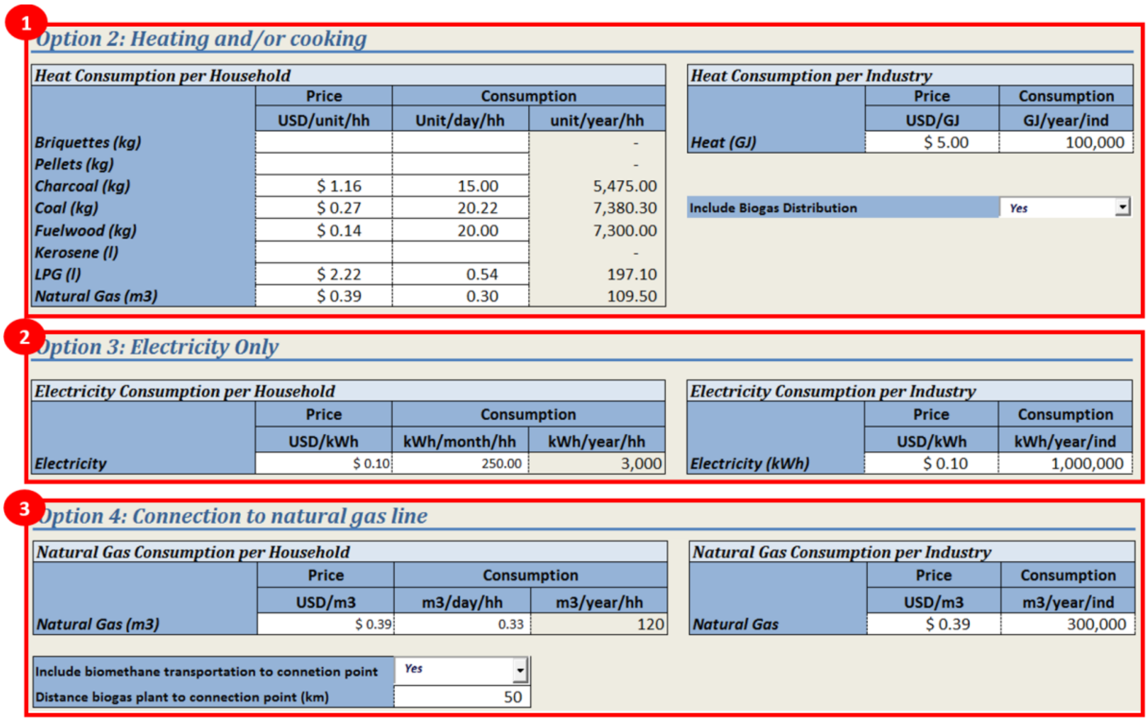


Figure 7: Final use of biogas – options 2 through 4

5.2 Step 2: Number of processes and operation mode selection

Before proceeding with the analysis, the user can choose to load the default values for running this component by clicking on the "Load Default Values" button as shown in Figure 8, label A.

Biogas industrial tool allows user to compare up to 4 processes, under 3 operation modes. In order to start the analysis the user will:

1. Define the number of processes to analyse in order to perform comparisons (Figure 8, label 1).
2. Select the operation mode among the following options:
   a. Single feedstock: When only one single feedstock is used throughout the year (Figure 8, label 2).
   b. Multi-feedstock: Up to 5 feedstock options can be used throughout the year. But only one option can be allocated to each month (Figure 8, label 3).
   c. Optimized co-digestion: Up to 5 feedstock options can be used throughout the year, plus 1 main co-digestion feedstock. All combinations are accepted. Use of manure or wastewater as co-digestion[6] feedstock is required (Figure 8, label 4).

For this example, 4 processes were compared under optimized co-digestion with manure as the co-digestion feedstock.

[6] *"Co-digestion is the simultaneous anaerobic digestion of multiple organic wastes in one digester. Co-digestion is used to increase methane production from low-yielding or difficult to digest materials. For the co-digestion process, care must be taken to select compatible feedstock's that enhance methane production (and to avoid materials that may inhibit methane generation)."* Extracted from: Prabhu, A., Raja, S. & Lee, C. 2014. Biogas production from biomass waste: a review. *IJIRT,* 1**,** 73-83.

Based on literature review, optimal co-digestion should involve manure or wastewater as a co-digestion feedstock in at least 50% contain (see Annex 8.6).

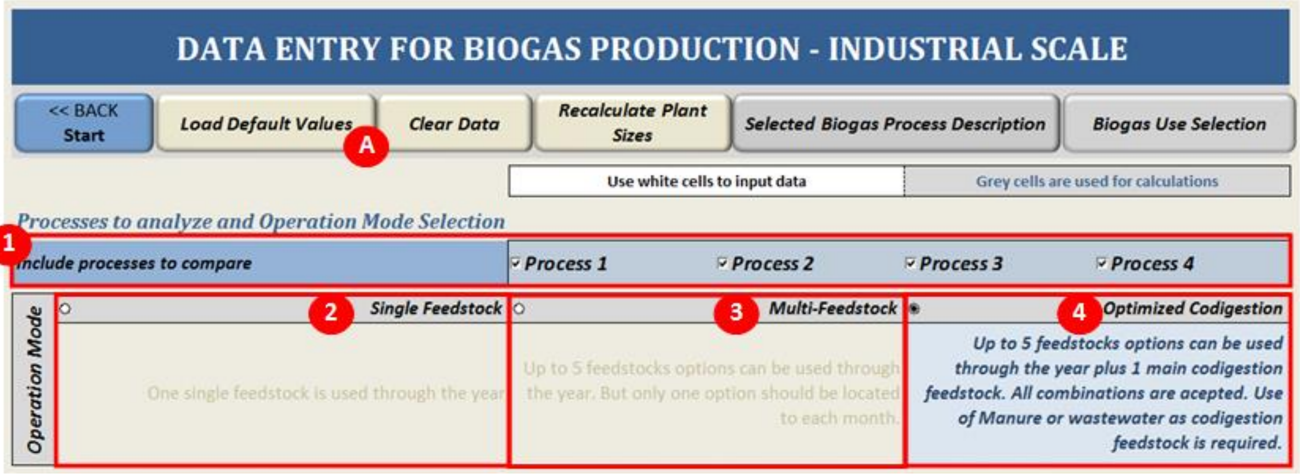


Figure 8: Number of processes and operation mode selection

5.3 Step 3: Defining the feedstock

Step 3. A Selection of the feedstock

The user will:

1. Select the main feedstock category from the dropdown menu (Figure 9, label 1). This list includes 12 options: biodiesel/oilseed industry, crop residues, crops, dairy-milk industry, energy crops, ethanol-sugar-starch industry, food processing residues, grass, other options, slaughterhouse wastes, yeast-alcoholic beverages and manure. Once, the main feedstock category is selected, the user can select the specific feedstock associated to this category (Figure 9, label 2). A list of all categories and feedstock included can be found in Annex 8.5.

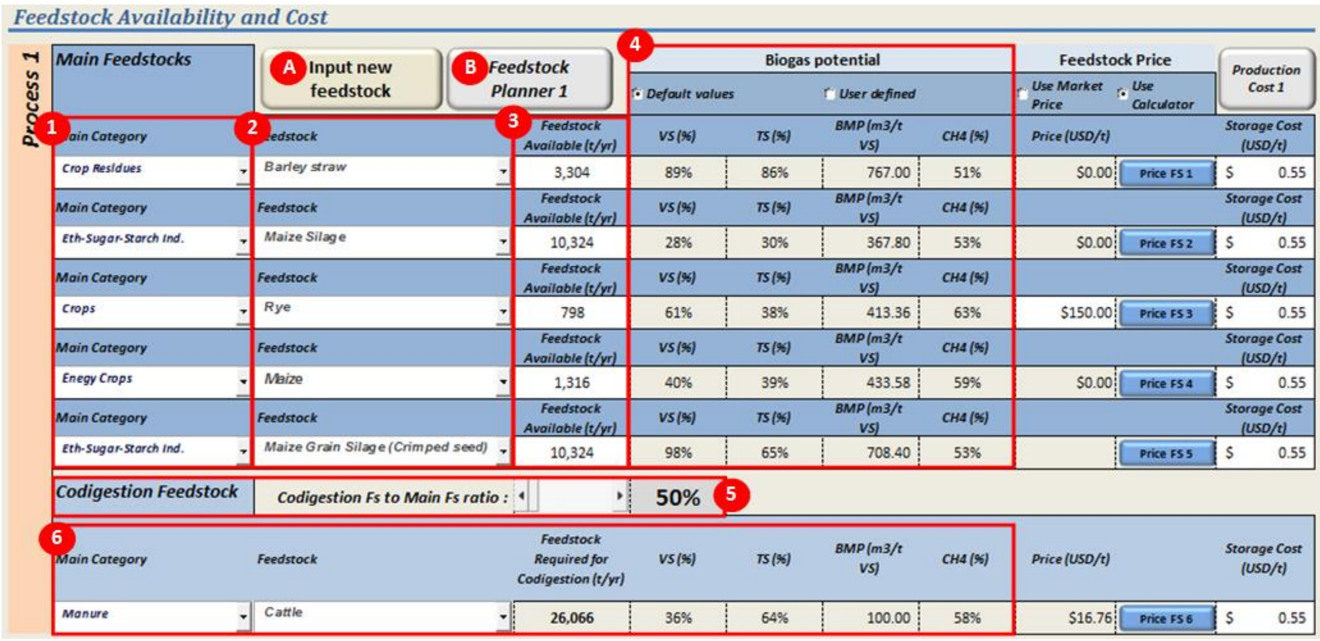


Figure 9: Feedstock selection

2. Enter data on the feedstock available (t/year) of the selected raw material (Figure 9, label 3). *Most of this information is generated in the Natural Resources module. Specific information for food processing and biofuel industries must be collected directly by the user.*
3. The volatile solids (VS) and total solids (TS) contents as well as the biogas potential (BMP) and its methane composition (%) of the feedstock can be automatically generated from the technical database in the tool if default values are selected (Figure 9, label 4). Although these values can be also defined by the user when *user defined* is selected.

For this example, the following feedstock for Process 1 were selected: Feedstock 1 "Barley straw", Feedstock 2 "Maize Silage", Feedstock 3 "Rye", Feedstock 4 "Maize" and Feedstock 5 "Maize Grain Silage" (Figure 9). Meanwhile, for Processes 2, 3 and 4 "Cheese waste", "Mango wastes" and "Grass silage" were selected as feedstocks, respectively.

4. For optimized co-digestion, it is required to define the co-digestion feedstock to the main feedstock ratio (Figure 9, label 5). For optimal co-digestion processes, the co-digestion feedstock (manure or waste water) to main feedstock ratio should be higher than 50%. Besides, both feedstocks should be compatible in order to preserve the microorganisms.
5. Define the co-digestion feedstock among two possibilities: manure or waste water (Figure 9, label 6). The required co-digestion feedstock is automatically calculated by the tool based on the co-digestion feedstock to main feedstock ratio. VS, TS, BMP and methane content can again be either defined by the tool or by the user.

Step 3.B Feedstock available per month

The *Feedstock planner* is a new feature presented in this tool. It allows the user to define the distribution of the feedstock throughout the year (Figure 9, label B). The user will:

1. Define the monthly average environmental temperature in °C (Figure 10, label 1).
2. Distribute the feedstock available during the year, according to monthly availability. The user may also use the spread button to automatically distribute the feedstock (Figure 10, label 2).

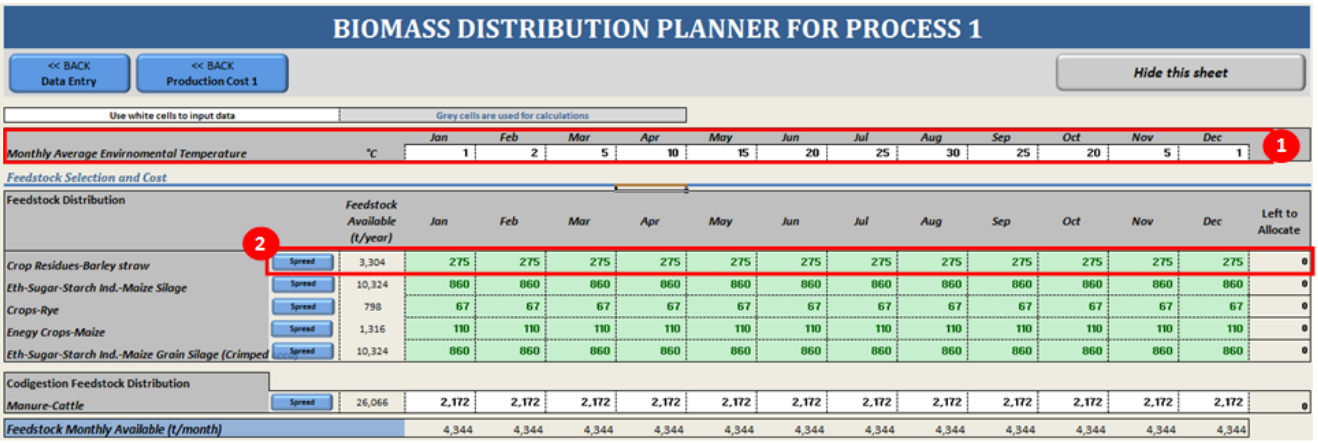


Figure 10: Biomass distribution throughout the year

Step 3.C Feedstock price (USD/t)

The user has two options for determining the feedstock price:

A. If there is a current price in the country for this feedstock, the user clicks on the "Market Price" (Figure 11, label 1) and directly inputs the price of the selected feedstock (USD/t) in the corresponding cell.
B. If there is *no* current price for this feedstock, the user can estimate the feedstock price by clicking on the "Use Calculator" (Figure 11, label 2) and selecting the "Price Calculator" (Figure 11, label 3).

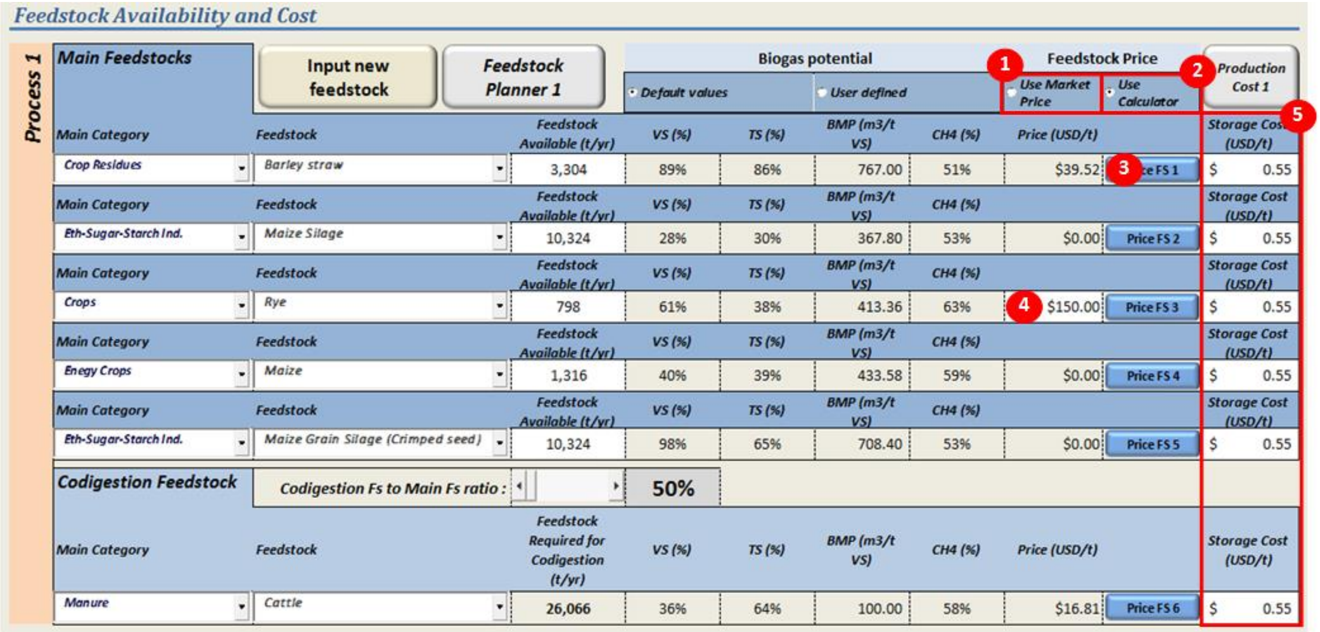
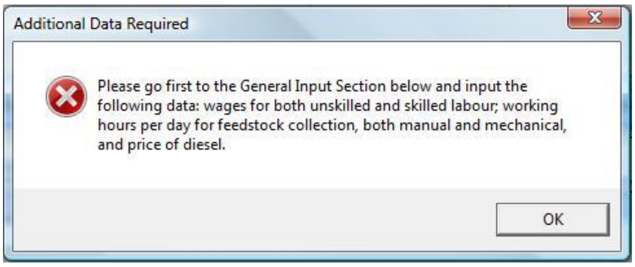


Figure 11: Feedstock price and feedstock storage cost

The user will get a "warning" before continuing with the use of the calculator, and the user will need to enter:



1. The wage for both unskilled and skilled labour in the "labour" section in unit of USD per person-hour.

2. The working hours and price of diesel in the corresponding lines under "Feedstock collection".

The "Price Calculator" assists the user in estimating the potential feedstock price, according to the following options:

1. Raw materials such as food, market and industrial wastes: No collection method is required, since the raw material is already collected. In this case, the tool assumes that the feedstock does not have a price, so the user should define the feedstock price based on the transportation and/or market price (Figure 12).

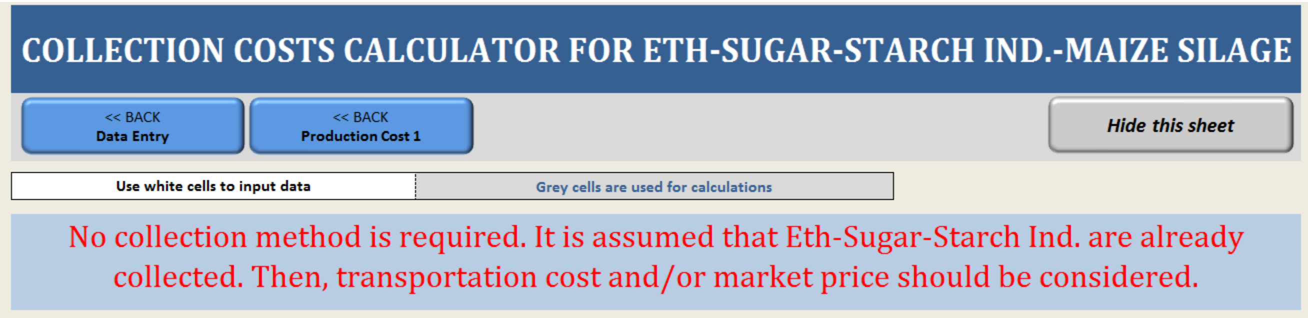


Figure 12: Collection cost when no collection method is required

For this example, is considered that no collection method is required for Feedstock 2 "Maize Silage", Feedstock 4 "Maize" and Feedstock 5 "Maize Grain Silage" (Figure 11).

2. Raw materials such as crop residues and grass lands: The *Traditional calculator* is used and the user will need to:

   Select the *biomass collection method* from the following options (Figure 13, label 1):
   - manual
   - semi-mechanized
   - mechanized

   Guidance: The collection method can be identified based on similar practices currently applied in the country.

   Define the biomass yield in t/ha (Figure 13, label 2):

   Enter the labour requirements (person-hour per hectare) and the fuel needs (litres per hour) associated with the selected biomass collection method (Figure 13, label 3). To return to the previous section, the user must click on the "<<BACK Data Entry" button.

   Note: The type of labour and diesel required will depend on the collection method: manual, semi-mechanized and mechanized.

The calculator will automatically generate a feedstock price (Figure 11), and this value is transferred to the "Data Entry Needs" worksheet for further calculation, when the user clicks on "<< BACK Data Entry" button (Figure 13, label A).

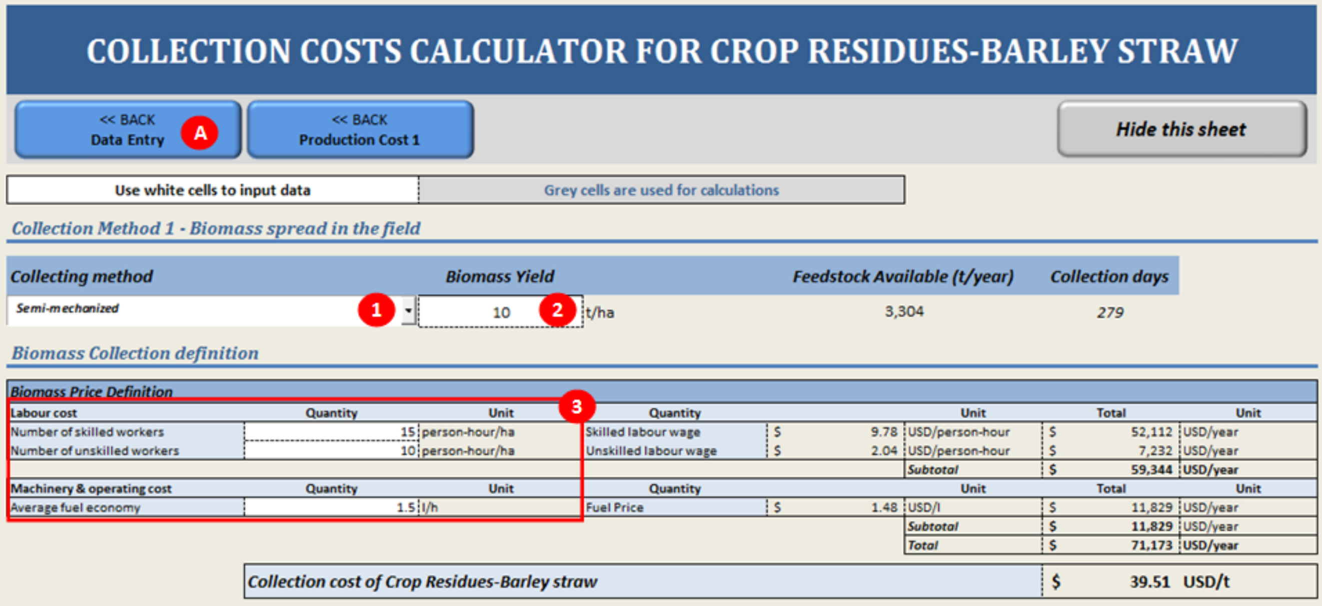


Figure 13: Feedstock price calculation using the traditional calculator (method 1)

For this example, the selected Feedstock 1 "Barley straw" is assumed to be collected with "semi-mechanized" method. The number of person-hours for skilled workers (machine operators) is 15 per hectare and for unskilled workers is 10 per hectare, and the diesel consumption of the machine is 1.5 litres per hour. Using the information that manual labour works 8 hours per day and machinery works 18 hours and diesel price of 1.48 USD per litre, a proxy price of the feedstock is calculated at 39.51 USD/t (Figure 13).

3. For raw materials such as manure and wastewater: An special *Price calculator* is used and the user will need to:
   Select the collection method for the feedstock (Figure 14, label 1) among the following options:

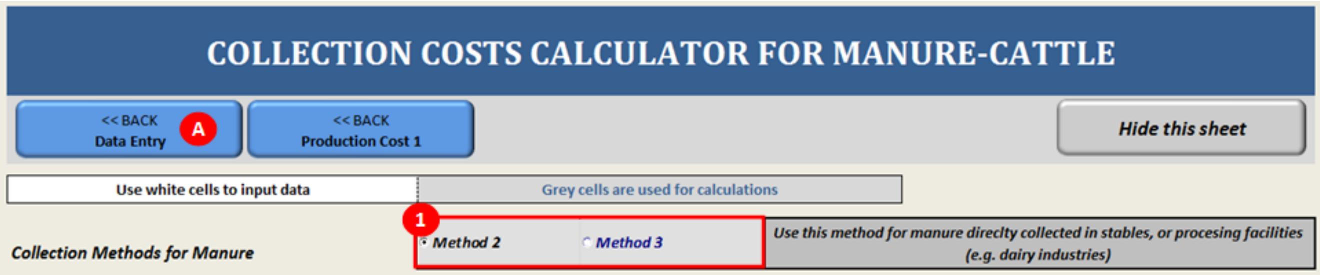


Figure 14: Selection of collection method for manure

A. Method 2: For collecting manure directly from stables or processing facilities. The user needs to:
   - Define the collection method (Figure 15, label 1).
   - Select the data source either to use the default values or to define them manually (Figure 15, label 2).
   - Define the operation cost of electricity, diesel, water make-up and unskilled workers (Figure 15, label 3), if the option of "user defined values" is selected.
   - Define the capital investment cost (Figure 15, label 4), if the option of "user defined values" is selected.

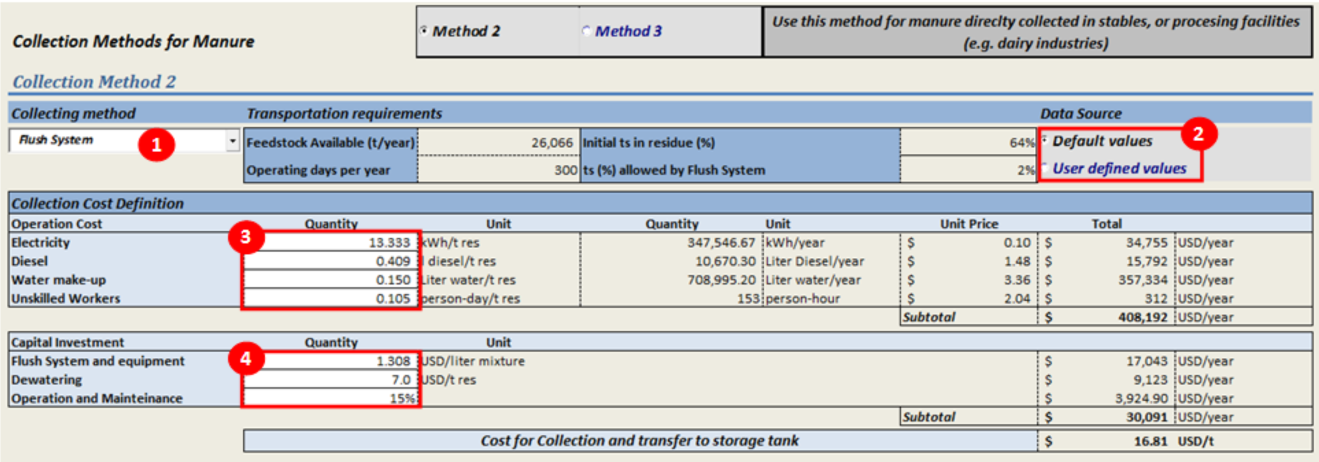


Figure 15: Cost of collection method of manure for method 2

B. Method 3: For collecting and transporting manure from different farms to a central collection point. The user needs to:

- Define the collection method (Figure 16, label 1).
- Define the transportation method (Figure 16, label 2).
- Select the data source to use the default values or to define them manually (Figure 16, label 3).
- Define the transport method requirements (Figure 16, label 4), if the option of "user defined values" is selected.
- Define the number of farms supplying manure and the average distance from the farms to the collection point (Figure 16, label 5).
- Define the labour cost (Figure 16, label 6), if the option of "user defined values" is selected.
- Define the collection machinery requirements (Figure 16, label 7), if the option of "user defined values" is selected.
- Define the equipment requirements and its corresponding cost (Figure 16, label 8), if the option of "user defined values" is selected.

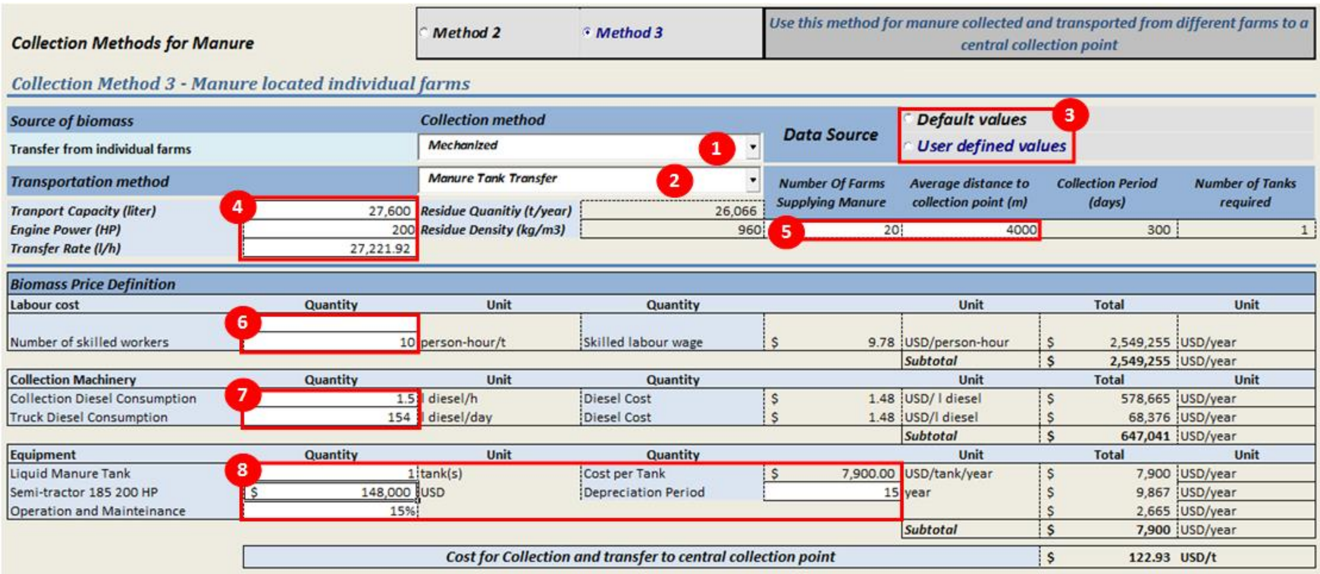


Figure 16: Cost of collection method of manure for method 3

This special calculator will automatically generate a feedstock price (Figure 11), and this value is transferred to the "Data Entry Needs" worksheet for further calculation only when the user clicks on << BACK Data Entry button (Figure 14, label A). Otherwise the result will not be transferred.

For this example, it is considered that manure is collected using Method 2 with a flush system, obtaining a proxy price of the feedstock of 16.81 USD/t (Figure 16).

4. For raw materials such as crops: Since these raw materials already have a market price, the user needs to specify the feedstock price (Figure 11, label 4), and the cell is white even when "Use Calculator" is selected.

For this example, Feedstock 3 "Rye" has a market price of 150 USD/t (Figure 11).

5. The user will need to carry out similar steps for each feedstock chosen.

Step 3.D: Feedstock storage cost (USD/t)

Step 2.C.1 The user can enter *the existing prices* of storage of agricultural products in the country as a proxy. The price should be entered in the respective cell for each feedstock (USD/tonne). If this information is not available, then the user should go to the next step.

Step 2.C.2 The user can determine *a proxy* for this value. The user will need to do the following:

1. Identify a type of feedstock storage likely associated with conditions of his/her country from the options presented in Table 2.
2. For the selected storage option, look up the global building cost provided in Table 2.
3. Enter the proxy value (USD/tonne) in the respective cell for each feedstock (Figure 11, label 4).

Table 2: Estimated cost of storage

Estimated Cost of Storage	Unit	Min	Average	Max
Enclosed structure with crushed rock floor	USD/tonne	10	12.5	15
Open structure with crushed rock floor	USD/tonne	6	7	8
Reusable tarp on crushed rock	USD/tonne	n/a	3	n/a
Outside unprotected on crushed rock	USD/tonne	n/a	1	n/a
Outside unprotected on ground	USD/tonne	n/a	0	n/a

Source: (EPA, 2007)

For this example, all feedstock are stored on crushed rock and covered by a reusable tarp. Therefore, the cost of storage is 0.55 USD/tonne. (User inputs the cost in the corresponding cells as shown in Figure 11, label 5).

5.4 Step 4: Production cost and financial parameters

General inputs required to run the operations are shown in Figure 17. The user will need to provide data on:

1. **Utilities cost:** the cost of water (USD/m^3), caustic soda (USD/t), electricity (USD/kWh) and heat (USD/GI).
2. **Labour cost (USD/person-hour)**: the labour rate for unskilled and skilled workers (USD per person per hour). These parameters are required to calculate the feedstock price (as explained in Step 3.B) and the labour cost of the combustion process.

3. **Feedstock collection:** these parameters are required to calculate the feedstock price as explained in Step 3.B. The user enters the hours of labour required for manual labour, hours of labour required for running the machinery and the price of diesel.
4. **Market prices:** the market prices of electricity (USD/kWh), heat (USD/GI), biogas (USD/m^3), natural gas (USD/m^3) and digestate (USD/t).
5. **Operating parameters:** The user enters:
   - Operating days per year
   - Digestate recovery system (Sedimentator, floater, centrifuge, belt press, screen sieves or screw press)
   - Heat loss in production (%),
   - Electricity loss in production (%),
   - Storage safety rate of biogas (%),
   - Solids recovery (%),
   - Heat loss in distribution (%) and
   - Electricity loss in distribution (%)
6. **Other costs (%):** The user enters the percentage of:
   - Plant overhead,
   - Maintenance,
   - Miscellaneous and
   - General and administrative cost,

These parameters are used to estimate the production cost of electricity.

7. **Financial parameters**: The user identifies the values for the following financial parameters:
   - Loan ratio (For the 4 sizes) (%),
   - Discount rate (%),
   - Loan interest rate (%),
   - Loan term (years) and
   - Plant cost index.

The plant cost index data for equipment cost is obtained from technical literature and based on past technical and economic conditions. Therefore, the Intratec chemical plant construction index (IC), a dimensionless index used as a proxy to update the capital cost of a chemical plant, which accounts for price changes due to inflation/deflation and economic conditions, is applied to the BEFS RA tool. This index is freely updated and available on (http://base.intratec.us/home/ic-index).

For this example, the values shown in Figure 17 were used to carry out the analysis.

Production Cost and Financial Parameters

Utilities and other Raw Material		**Unit**			
Water	$ 3.36	USD/m³	*Electricity*	$ 0.10	USD/kWh
Caustic Soda (NaOH)	$ 490.00	USD/t	*Heat*	$ 5.00	USD/GJ
http://www.icis.com/chemicals/channel-info-chemicals-a-z/					
Labour		**Unit**			
Skilled worker	$ 9.78	USD/person-hour	*Unskilled worker*	$ 18.00	USD/person-hour
Feedstock collection		**Unit**			**Unit**
Working hours per day (manual)	8	h/day	*Working hours per day (mechanized)*	18	h/day
Diesel price	$ 1.48	USD/l	*Operating days per year*	300	days/year
Market Prices		**Unit**			
Electricity Selling Price	$ 0.30	USD/kWh	*Natural Gas Selling Price*	$ 0.39	USD/m³
Heat Selling Price	$ 6.00	USD/GJ	*Digestate Market Price*	$ 70.00	USD/t
Biogas Selling Prince	$ 0.20	USD/m³			
Operating parameters		**Unit**			
			Storage safety rate of Biogas	10%	
Digestate Recovery System	Centrifuge		*Solids Recovery (%)*	68%	
Heat Loss In Production	20%		*Heat loss in Distribution*	10%	
Electricity Loss In Production	10%		*Electricity loss in Distribution*	5%	
Other costs		**Unit**			
Plant overhead (%)	5%		*Miscellaneous (%)*	20%	
Maintenance (%)	20%		*General and administrative (%)*	10%	
Financial parameters		**Unit**	**Investment cost update**		
Loan ratio Size 1	50%		*Discount rate*	9%	
Loan ratio Size 2	40%		*Loan interest rate*	7%	
Loan ratio Size 3	30%		*Loan term*	20	year
Loan ratio Size 4	20%		*Plant Cost Index during 3/2017*	160	
			http://base.intratec.us/home/ic-index		

Figure 17: General inputs

5.5 Step 5: Calculation of the production cost

After entering the data in Steps 1 to 5, the user can click on the "Production Cost" button (Figure 18- label A).

Note: This section also shows the budgets for calculating the processing cost. These calculations are done automatically using the information entered by the user in the previous steps and can be reviewed if needed (see section 7.1 for more details).

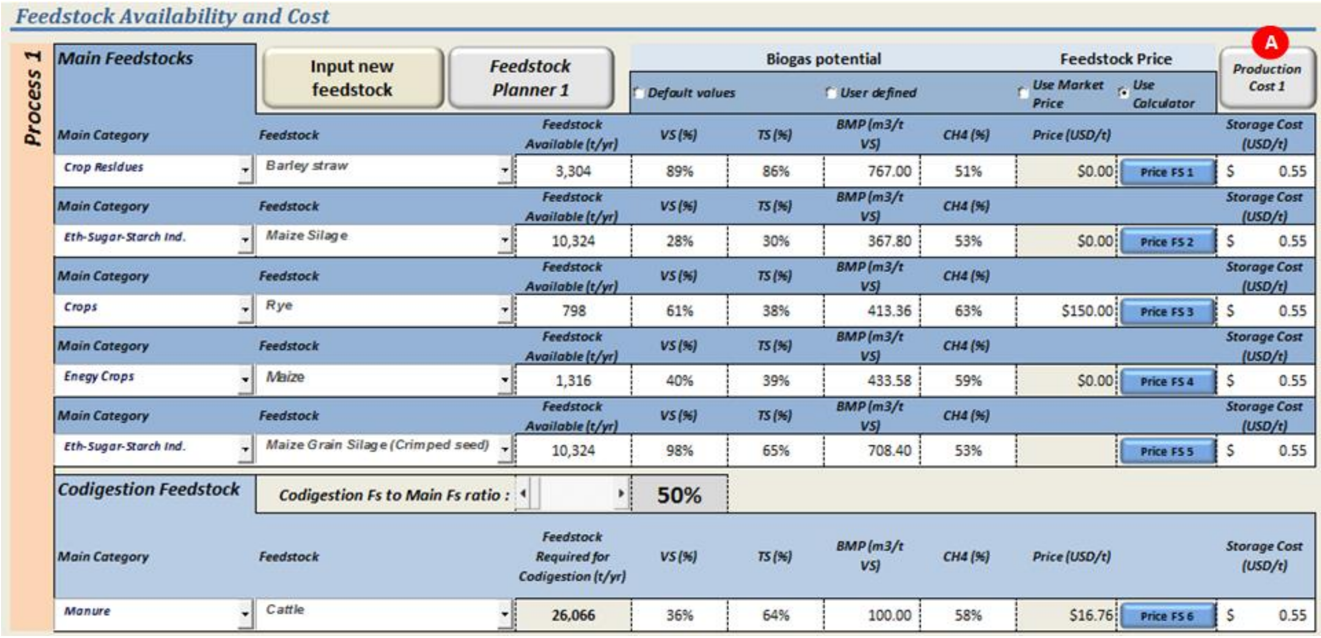


Figure 18: Production cost calculation

This will take the user to the budget processing section for the selected feedstock (Figure 19).

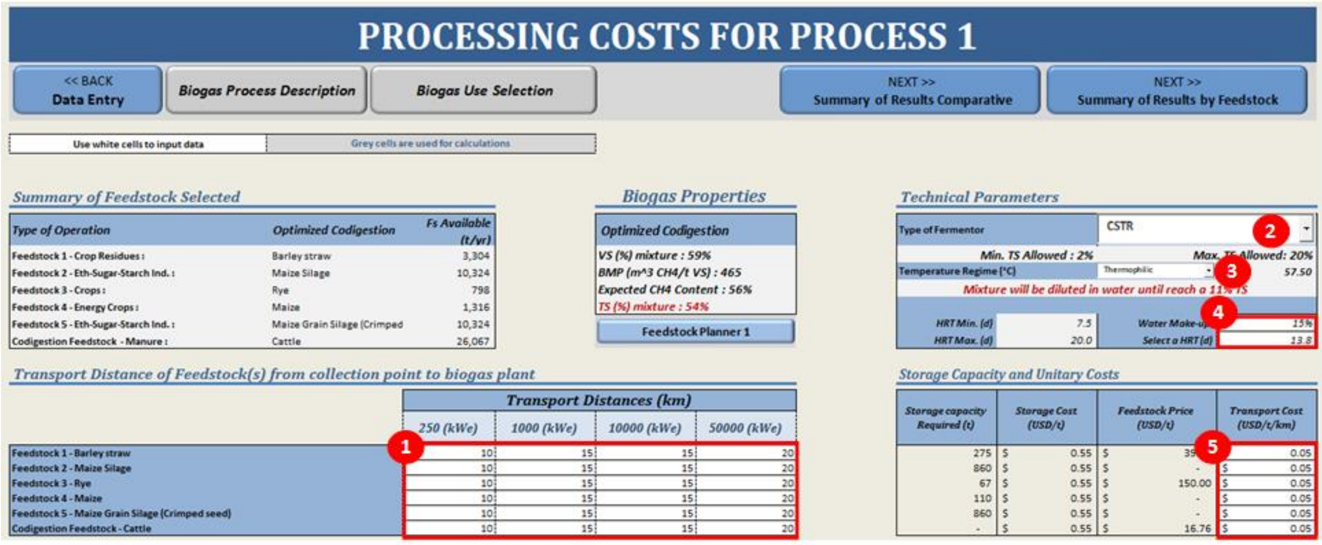


Figure 19: Processing costs for power generation

In this worksheet, the user will need to enter additional data in the white cells, specifically on:

1. **The transportation distance of feedstock to the biogas plant:** The user identifies an estimated distance, in kilometres, that will be required to transport the feedstock. The transportation distance depends on the availability of biomass in a particular area and the amount of biomass required for each production capacity (Figure 19-Label 1).

Guidance: The small-scale plants use less biomass compared to the medium and large-scale ones. Therefore, the distance of transportation could be shorter. If the availability of biomass in that area is high and sufficient enough to supply for all production scales of the plants, then the users can input the same transportation distance of feedstock for all production scales.

2. **Technical parameters:** The user will define:
   - The type of digester choosing one of the following options (Figure 19-Label 2): CSTR, plug flow, UASB or batch[7].
   - Depending on the operation temperature the user can define mesophillic or thermophillic regime (Figure 19-Label 3).
   - Specify the water make-up and the HRT (days) (Figure 19-Label 4).

3. **Transport cost from the collection point to the biogas plant**

Once all data is entered, the user must click on "<<BACK Data Entry" to return to the Data Entry Needs sheet. The user can repeat the same steps for all the processes.

For this example the values that were used to carry out the analysis are:

Type of fermentor:	**CSTR**
Temperature regime (°C):	**Thermophilic**
Water make-up:	**15%**
HRT (days):	**13.8**
The transportation distance of feedstock to biogas plant:	
Distance for 250 kWe:	**10 km**
Distance for 1000 kWe:	**15 km**
Distance for 10000 kWe:	**15 km**
Distance for 50000 kWe:	**20 km**

The transport cost is 0.05 USD/t/km for all the feedstocks

These parameters are used for further analysis.

6 Assumptions and limitations of the biogas industrial 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 industrial component are:

1. Up to four processes can be assessed to carry out comparisons
2. For each process, a maximum of 5 main feedstocks. 1 additional feedstock can be analysed if co-digestion feedstock is selected.
3. The business lifetime is considered to be 20 years for the financial analysis.

The details of key assumptions and calculation equations are presented in the Annex.

[7] This option won't be available fro co-digestion option

7 The results of the biogas industrial component

7.1 Overview of the production cost calculation (optional)

After user inputs all required data (Steps 1 to 5), then the user has the option to review the detailed production cost as shown in Figure 20. There are five main sections in this worksheet as explained below.

- **PART 1** (Figure 20-label 1) shows the distribution of production cost along the following categories: inputs, labour and miscellaneous, transportation of feedstock, storage, investment, maintenance, plant overhead, general and administrative cost and loan interest. The total production costs (USD/year) of the three four capacities (250kWe, 1000kWe, 10000kWe and 50000kWe) are presented for comparative analysis.
- **PART 2** (Figure 20-label 2) shows the energy balance, in terms of electricity production and consumption in unit of kWh per year and heat production and consumption in unit of GI per year. Finally the electricity and heat for selling are also summarized. The results are presented for all the capacities.
- **PART 3** (Figure 20-label 3) shows the unit cost of biogas (USD per unit product) for all the capacities.
- **PART 4** (Figure 20, label 4) summarizes the loan details, e.g. loan amount, loan interest, annual loan payment, etc., for financial analysis.
- **PART 5** (Figure 20-label 5) the “Financial Analysis” buttons will open the worksheet with the details on the financial analysis for each biogas production system.
- **PART 6** (Figure 20-label 6) the “Detailed investment cost 1” button will open the worksheet with the details on the investment cost for each biogas production system.

Note: Depending on the final use selected by the user, the plant will produce heat and electricity, heat and or electricity, only electricity or biogas to connect to the natural gas grid.
The tool automatically takes

Production Cost Details

Financial Analysis Size 1	Financial Analysis Size 2	Financial Analysis Size 3	Financial Analysis Size 4

	Capacities (kWe)							
	250		1,000		10,000		50,000	
	Operating hours per year	7,200	Operating hours per year	7,200	Operating hours per year	7,200	Operating hours per year	7,200

uts	Unit	Unit Price (USD/Unit)	Quantity (Unit/year)	Total (USD/year)	Quantity (Unit/year)	Total (USD/year)	Quantity (Unit/year)	Total (USD/year)	Quantity (Unit/year)	Total (USD/year)
Optimized Codigestion	t	$ 13.21	4,455	$ 58,827	17,819	$ 235,309	178,186	$ 2,353,090	890,932	$ 11,765,448
Water Make-Up	m³	$ 3.36	2,612	$ 8,776.49	10,448	$ 35,106	104,482	$ 351,060	522,410	$ 1,755,298
Electricity -Consumption Self-Supplied	KWh	$ 0.00	51,317	$ -	205,269	$ -	2,052,694	$ -	10,263,468	$ -
Heat - Consumption Self-Supplied	USD/GJ	$ 0.00	4,018	$ -	16,070	$ -	160,700	$ -	803,501	$ -
NaOH	t	$ 490.00	89.09	$ 43,656	356.37	$ 174,623	3,563.73	$ 1,746,227	17,818.64	$ 8,731,133
Subtotal			$	111,259	$	445,038	$	4,450,376	$	22,251,879

Labour and miscellaneous costs	Unit	Unit Price (USD/person-	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)
Unskilled worker	# employee	$ 2.04	1	$ 14,688	4	$ 58,752	31	$ 455,328	152	$ 2,232,576
Skilled worker	# employee	$ 9.78	1	$ 70,416	1	$ 70,416	4	$ 281,664	16	$ 1,126,656
Miscellaneous costs			20%	$ 17,021	20%	$ 25,834	20%	$ 147,398	20%	$ 671,846
Subtotal			$	102,125	$	155,002	$	884,390	$	4,031,078

Transportation	Unit	Unit Price (USD/t/km)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)
Feedstock 1 - Barley straw	km	$ 0.00	-	$ -	-	$ -	-	$ -	-	$ -
Feedstock 2 - Maize Silage	km	$ 0.05	10	$ 2,227	15	$ 13,364	15	$ 133,640	20	$ 890,932
Feedstock 3 - Rye	km	$ 0.05	10	$ 2,227	15	$ 13,364	15	$ 133,640	20	$ 890,932
Feedstock 4 - Maize	km	$ 0.05	10	$ 2,227	15	$ 13,364	15	$ 133,640	20	$ 890,932
Feedstock 5 - Maize Grain Silage (Crimped se	km	$ 0.05	10	$ 2,227	15	$ 13,364	15	$ 133,640	20	$ 890,932
Codigestion Feedstock - Cattle	km	$ 0.05	10	$ 2,227	15	$ 13,364	15	$ 133,640	20	$ 890,932
Subtotal			$	11,137	$	66,820	$	668,199	$	4,454,660

Storage	Unit	Unit Price	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)
Feedstock 1 - Barley straw	USD/t		28	$ -	113	$ -	1,129	$ -	5,647	$ -
Feedstock 2 - Maize Silage	USD/t	$ 0.55	88	$ 49	353	$ 194	3,529	$ 1,941	17,644	$ 9,704
Feedstock 3 - Rye	USD/t	$ 0.55	7	$ 4	27	$ 15	273	$ 150	1,364	$ 750
Feedstock 4 - Maize	USD/t	$ 0.55	11	$ 6	45	$ 25	450	$ 247	2,249	$ 1,237
Feedstock 5 - Maize Grain Silage (Crimped se	USD/t	$ 0.55	88	$ 49	353	$ 194	3,529	$ 1,941	17,644	$ 9,704
Feedstock 5 - Cattle	USD/t	$ 0.55	223	$ 123	891	$ 490	8,909	$ 4,900	44,547	$ 24,501
Biogas Low-pressure system	USD/m³	$ 0.01	107,143	$ 1,060	428,571	$ 4,240	4,285,714	$ 42,403	21,428,571	$ 212,014
				$ -		$ -		$ -		$ -
Subtotal			$	1,290	$	918	$	9,179	$	45,896

Investment	Unit	Years	Total (USD)	Depreciation (USD/year)	Total (USD)	Depreciation (USD/year)	Total (USD)	Depreciation (USD/year)	Total (USD)	Depreciation (USD/year)
Equipments	USD	20	$ 394,587	$ 19,729	$ 1,168,787	$ 58,439	$ 7,123,233	$ 356,162	$ 25,298,523	$ 1,264,926
Building	USD	20	$ 121,033	$ 6,052	$ 356,871	$ 17,844	$ 2,150,359	$ 107,518	$ 7,545,840	$ 377,292
Installation Distribution and/or Upgrade	USD	20	$ 171,893	$ 8,595	$ 580,858	$ 29,043	$ 4,619,249	$ 230,962	$ 20,407,942	$ 1,020,397
Total investments			$ 687,513		$ 2,106,516		$ 13,892,841		$ 53,252,304	
			Total Depreciation	$ 34,376	Total Depreciation	$ 105,326	Total Depreciation	$ 694,642	Total Depreciation	2,662,615
Maintenance cost		20%		$ 6,875		$ 21,065		$ 138,928		$ 532,523
Subtotal			$	41,251	$	126,391	$	833,570	$	3,195,138

Other costs	Unit	Rate (%)		Total (USD/year)		Total (USD/year)		Total (USD/year)		Total (USD/year)
Plant overhead	USD	5%		$ 4,599		$ 7,512		$ 43,796		$ 194,588
General and administrative cost	USD	10%		$ 22,486		$ 62,862		$ 551,749		$ 2,701,007
Loan interest	USD	7%		$ 31,982		$ 78,393		$ 387,760		$ 990,875
Subtotal			$	59,066	$	148,766	$	983,305	$	3,886,470

Total costs	Total (USD/year)	Share (%)	Total (USD/year)	Share (%)	Total (USD/year)	Share (%)	Total (USD/year)	Share (%)
Total operating costs	$ 224,521	69%	$ 666,859	71%	$ 6,002,965	77%	$ 30,737,618	81%
Total fixed costs	$ 41,251	13%	$ 126,391	13%	$ 833,570	11%	$ 3,195,138	8%
Total other costs	$ 59,066	18%	$ 148,766	16%	$ 983,305	13%	$ 3,886,470	10%
Total production costs	$ 324,838		$ 942,016		$ 7,819,841		$ 37,819,225	

rgy Balance	Unit	Capacities (kWe) 250	1,000	10,000	50,000
Electricity Production	kWh/year	936,735	3,746,939	37,469,388	187,346,939
Heat Production	GJ/year	6,943	27,771	277,714	1,388,571
Electricity Consumption	kWh/year	-51,317	-205,269	-2,052,694	-10,263,468
Heat Consumption	GJ/year	-4,018	-16,070	-160,700	-803,501
Electricity Available for Selling	kWh/year	885,417	3,541,669	35,416,694	177,083,471
Heat Available for Selling	GJ/year	2,925	11,701	117,014	585,070

Detailed Investemt Cost 1	Capacities (kWe) 250	1,000	10,000	50,000
t cost of biogas (USD/kWh)	$ 0.367	$ 0.266	$ 0.221	$ 0.214

Average loan interest	Unit	Total investment (USD)	Loan amount (USD)	Total investment (USD)	Loan amount (USD)	Total investment (USD)	Loan amount (USD)	Total investment (USD)	Loan amount (USD)
Loan amount	USD	$687,513	$ 343,757	$ 2,106,516	$ 842,606	$ 13,892,841	$ 4,167,852	$ 53,252,304	$ 10,650,461
Loan interest rate	%		7%		7%		7%		7%
Loan payment	USD/month		-$ 2,665		-$ 6,533		-$ 32,313		-$ 82,573
Annual loan payment	USD/year		-$ 31,982		-$ 78,393		-$ 387,760		-$ 990,875
Loan terms	year		20		20		20		20
Total loan payment	USD		-$ 639,634		-$ 1,567,852		-$ 7,755,196		-$ 19,817,498
Loan interest	USD		-$ 295,877		-$ 725,246		-$ 3,587,343		-$ 9,167,037
Average loan interest	USD/year		-$ 14,794		-$ 36,262		-$ 179,367		-$ 458,352

Figure 20: Detail of production costs of biogas production by capacity

7.2 The summary results comparative

The information presented in this section aims at helping the user in the decision making process to support the development of industrial-biogas production for power and heat generation in his/her country. The results aim to answer the following questions:

- What are the investment and production costs per unit of product for the various production capacities and feedstock selections?

- How much biomass and area are required to secure the supply of biomass for the development of biogas systems?
- How many potential biogas plants can be developed based on the availability of biomass?
- How many households or industries can gain access to electricity through biogas productions?
- How many jobs can be created through biogas production?
- Which type of feedstock(s) might be more suitable and could be promoted for the biogas production?
- What is the financial viability of the biogas system?

Results for the biogas industrial component are divided along three main categories: Techno-economic results, socio economic results and financial results.

1. The techno-economic results are presented as follows:
   - Cost of production of electricity (USD per unit of product, in this case kWh) (Figure 21-label 1). The user can compare the production cost to the price of electricity (according to the method selected in Step 3).
   - Digestate composition (%) in terms of N, P and K (Figure 21-label 2).
   - Number of plants potentially supplied according to process and size (Figure 21-label 3).

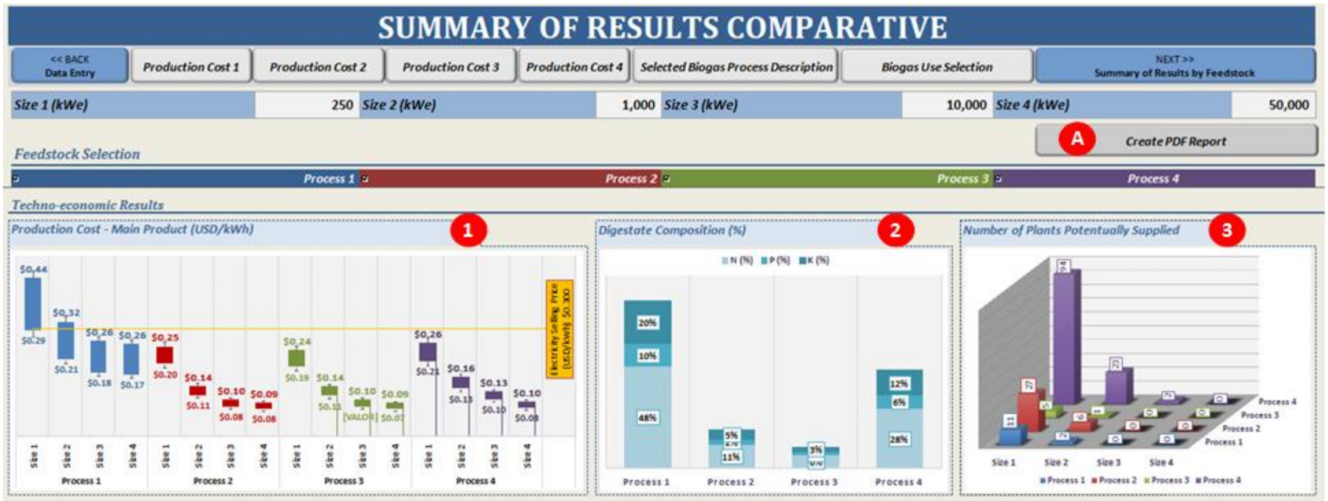


Figure 21: Techno-economic results

2. The socio economic results are presented as follows:
   - Maximum number of consumers potentially supplied for all the processes for households (Figure 22-Label 1) and industries (Figure 23, label 1).
   - Maximum number of jobs potentially created for all the processes and sizes (Figure 22, label 2).

3. The financial results are presented as follows:
   - Internal rate of return (IRR) (Figure 23-label 1)
   - Net present value (NPV) (Figure 23-label 2)

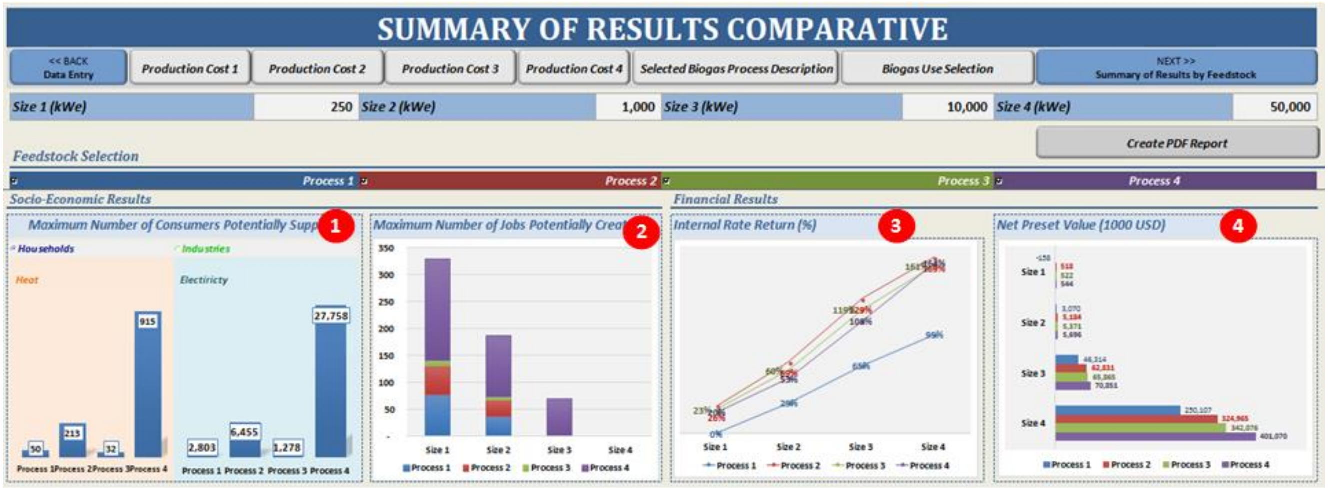


Figure 22: Socio-economic and financial results for households

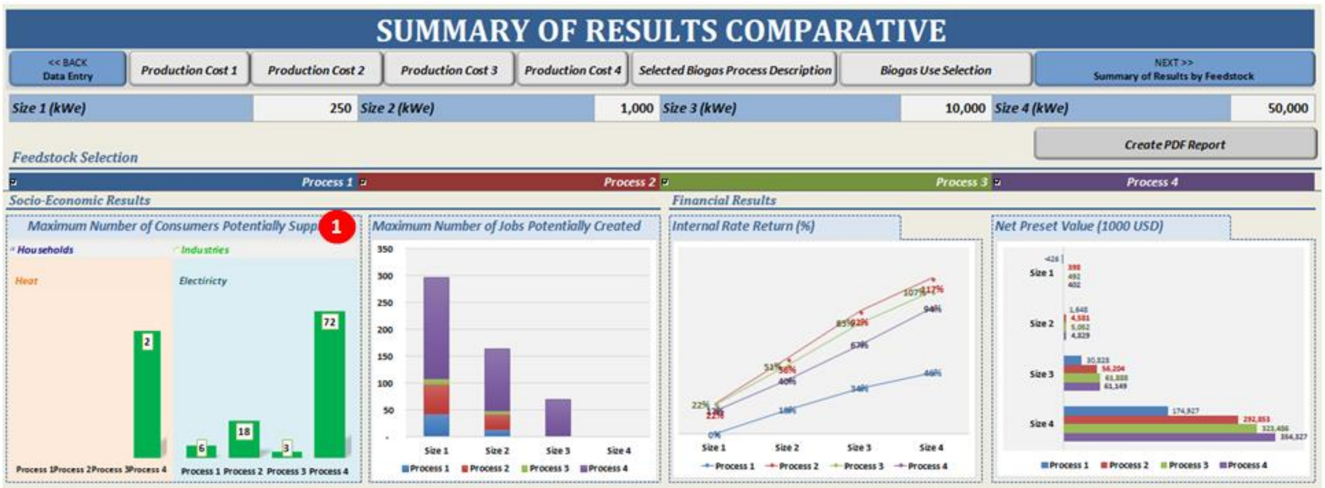


Figure 23: Socio-economic and financial results for industries

The user can save and print the results in PDF format by using “Create a PDF report” and following the instructions (Figure 21, label A).

7.3 The summary of results by process

The information presented in this section helps the user in the decision making process to develop biomass combustion for power generation in rural areas. The user can compare the results across the different feedstock selected in the analysis.

1. The user first selects the process to see the summary results from the dropdown menu (Figure 24-Label 1). The results for that specific process will be generated.

2. Comparison results are presented on:
   - Production costs of the main product for all the considered sizes (USD/kWh) (Figure 24-label 2)
   - Share of production cost (%)(Figure 24-label 3)
   - Investment cost (USD) (Figure 24-label 4)
   - Feedstock consumption and demand (Figure 24-label 5)
   - Annual feedstock distribution (Figure 24-label 6)
   - Number of plants supported (Figure 24-label 7)
   - Consumers potentially supplied (Figure 24-label 8)
   - Number of jobs potentially created (Figure 24-label 9)
   - NPV (1000 USD/year) (Figure 24-label 10)
   - IRR (%)(Figure 24-label 11)
   - Digestate composition in N, P, K values (Figure 24-label 12)
   - Digestate production and income (Figure 24-label 13)

Guidance: These results can help identify the type of feedstock and electricity production scale that is most viable and should be promoted for combustion

The user can save and print the results in PDF format by using "Create a PDF report" and following the instructions (Figure 24, label A).

For sake of simplicity this section is presented for results obtained in single mode option

Figure 24: Layout of comparative results

8 Annex

8.1 Methodology and outputs

This section describes the methodologies integrated in the biogas industrial 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 Cost calculation of required inputs

The required inputs consist of the cost of feedstock (biomass), cost of water, and cost of diesel consumption. The equations used to calculate the cost of these items are presented in Table 3.

Table 3: Inputs cost equations

Item	Equation and Assumption	Remark
Biogas Production	$\gamma' = B_0 \times S_0 \times [1-K / (HRT \times \mu_M - 1 + K)]$ Where: γ' is Volumetric methane production rate (m^3/h) B_0 is Biomethane potential S_0 is influent VS concentration μ_M is Maximum specific growth rate (1/day) HRT is Hydraulic retention time (day) K is kinetic parameter	Modified Hashimotos's kinetic model (Hashimoto *et al.*, 1981, Hashimoto, 1983, Hashimoto, 1984, Hashimoto, 1986) 20°C < T < 60°C
Quantity of feedstock	QF = BR (m^3/year) / (γ' x DE) Where: QF is Quantity of feedstock (tonne per year) BR is biogas rate (m^3/year) DE is Digestor efficiency (%)	Default value of DE is assumed as 63%.
Water Make-up	WM = QF x TS / (100 – TS) Where: WM is Water Make-Up (m^3 per year) QF is Quantity of feedstock (tonne per year) TS is Total solids content (%)	Default value of MR is assumed as 35%.
Energy potential (EP) (MJ per year)	EP = BR (m^3/year) x Cp (kWh/m^3) x Operating hours per year x 3.6 Where, EP is Energy potential (MJ/year) BR is biogas rate (m^3/year) Cp is the calorific capacity of biogas (kWh/m^3) Operating hours per year= Operating hours per day x 365 days per year	Cp is assumed to be 6 kWh/m^3 Operating hours per year entered by the user.
Power Generation (PG) (kWh per year)	PG = EP (MJ/year) x TE – (HG x 1000) / 3.6 Where, PG is Power generation (kWh/year) EP is Energy potential (MJ/year) TE is thermal efficiency (%) HG is Heat generation (MJ/year)	Thermal efficiency is assumed to be 60%
Heat Generation (HG) (kWh per year)	HG = EP (MJ/year) x TE – (EE x 1000) / (1 – EE / α) Where, HG is Heat generation (kWh/year)	Thermal efficiency is assumed to be 60%

	EP is Energy potential (MJ/year) TE is thermal efficiency (%) EE is Electricity efficiency (%) α is Energy use factor	Electricity efficnecy is assumed to be 40% α is assumed to be 75%

8.1.2 Cost calculation of required labour

This step presents the equations and assumptions for calculating the labour and miscellaneous cost based on the power generation capacity as shown in Table 4.

Table 4: Labour and miscellaneous cost equations

Item	Equation and Assumption	Remark
Number of unskilled labour	Unskilled labour = 0.42 x kWe x OP	
Number of skilled labour	skilled labour = (0.42 x kWe x OP) / 5	
Total unskilled labour cost (USD per year)	Unit cost of unskilled labour x number of unskilled labour x operating hours per year	Unit cost of unskilled labour (USD/person/hour) Input entered by user in "Data Entry Needs" Operating hours per year same as Table 2.
Total skilled labour cost (USD per year)	Unit cost of skilled labour x number of skilled labour x operating hours per year	Unit cost of skilled labour (USD/person/hour) Input entered by user in "Data Entry Needs" Operating hours per year same as Table 2.
Miscellaneous cost (USD per year)	Percentage of miscellaneous cost (%) x (Total unskilled labour cost + Total skilled labour cost)	Percentage of miscellaneous cost input by user. Default value is 10%
Total labour cost (USD per year)	Total Unskilled labour cost + Total skilled labour cost + Miscellaneous cost	

Note that miscellaneous costs consist of labour benefits, health & life insurance, operating supplies and/or laboratory charges (if any).

8.1.3 Cost calculation of required transportation

This step presents the calculation equations of transportation cost as shown in Table 5.

Table 5: Transportation of feedstock cost equations

Item	Equation and Assumption	Remark
Transportation of feedstock (field to plant) (USD per year)	Unit transportation cost x Transportation distance x QF Where: QF is Quantity of feedstock (tonne per year)	Unit transportation cost (USD/tonne/km) and Transportation distance (km) entered by the user QF is calculated in Table 2.

8.1.4 Cost calculation of storage

Table 6 presents the calculating equations for estimating the storage cost.

Table 6: Storage cost equations

Item	Equation and Assumption	Remark
Storage capacity (tonne/year)	The estimate storage capacity in “Feedstock Planner” worksheet by pressing on the “Feedstock planner”	According to the feedstock distribution designed by the user
Storage cost (USD per year)	Unit storage cost x Storage Capacity	Unit storage cost (USD/tonne) entered by user based on guidance provided in the manual.

8.1.5 Fixed cost calculation

Fixed cost consists of the cost associated with equipment, building, installation and distribution network. **Table 7** presents the equations and assumptions applied to calculate the fixed cost and the depreciation cost.

Table 7: Equipment costs proxies

Item	Unit	Cost
Pretreatment		
Other (Hygenization, crushing, homogenization)	**USD/m3 BIOGAS**	$ 10.80
Pre-processing equipment	**USD/t feedstock**	$ 4.50
Equipments		
Digester CSTR	**USD/m3 BIOGAS**	$ 174.6
Digester UASB	**USD/m3 BIOGAS**	$ 608.4
Digester plug flow	**USD/m3 BIOGAS**	$ 485.4
Digester batch	**USD/m3 BIOGAS**	$ 58.2
Effluence storage pool	**USD/m3 BIOGAS**	$ 87.1
Buffer tank	**USD/m3 BIOGAS**	$ 15.9
Odor control system	**USD/t feedstock**	$ 4.3
Metering pumps	**USD/t feedstock**	$ 2.0
Pumps	**USD/t feedstock**	$ 4.5
Trommel screen	**USD/t feedstock**	$ 5.5
Mixers	**USD/t feedstock**	$ 2.0
Post digestion tank (for gravity separation)	**USD/m3 BIOGAS**	$ 15.9
Gas collection equipment	**USD/t feedstock**	$ 7.5
Desulfurizing tower	**USD/m3 BIOGAS**	$ 0.9
Microturbines (30-500 kW)	**USD/kW**	$ 650.0
Combustion turbine (500 kW - 50 MW)	**USD/kW**	$ 650.0
Reciprocating engine (5 kW - 7 MW)	**USD/kW**	$ 600.0
Building		
Building w/slab	**USD/t feedstock**	$ 6.4
50' Truck weighing scales	**USD/t feedstock**	$ 3.3

Foundation for scales inclu. const.	**USD/t feedstock**	$ 2.0
Front-End loader	**USD/t feedstock**	$ 5.9
Solids drying area concrete slab	**USD/t feedstock**	$ 9.6
Installation		
Connection and earthing	**USD/kW**	$ 27.1
Land Preparation	**USD/t feedstock**	$ 8.7
Installation CSTR	**USD/m3 ch4/year**	$ 0.007
Installation UASB	**USD/m3 ch4/year**	$ 0.006
Installation plug flow	**USD/m3 ch4/year**	$ 0.003
Installation batch	**USD/m3 ch4/year**	$ 0.004
Infrastructure (fencing)	**USD/t feedstock**	$ 4.6
Infrastructure (roads) ($/ft2)	**USD/t feedstock**	$ 6.0
Electricity distribution network		
Primary electricity cable	**USD/m**	$ 7.5
Secondary cable, installation and meter	**USD/household**	$ 164.0
Heat distribution System		
Dwelling system	**USD/MJ**	$ 0.0014222
Biogas distribution System		
Pipe system (Biogas distribution)	**USD/household**	$ 52.6
Pipe system (BIOMETHANE distribution)	**USD/m**	$ 108.7
Upgrade and connection to natural gas		
Biogas upgrading, testing, and injection systems	**USD/m3/year**	$ 1.2
Connection to utility natural gas pipeline	**USD/m3/year**	$ 0.3

Item	Equation and assumption	Remark
Equipment cost (EC) (USD)	The database of cost details is provided and adjusted by considering the replacement equipment that has the lifetime less than the project lifetime. EC at current period = EC (base year) x [Plant Cost Index (current period) / Plant Cost Index (base year)]	Plant cost index (current period) input by the user
Building cost (BC) (USD)	The database of cost is provided including: building of combustion system, gas engine, water pool, and civil work. BC at current period = BC (base year) x [Plant Cost Index (current period) / Plant Cost Index (base year)]	Plant cost index (current period) input by the user
Item	**Equation and assumption**	**Remark**
Installation cost (IC) (USD)	The database of cost is provided including: feasibility study, development and engineering, installation,	Plant cost index (current period) input by the user

	Erection, commissioning, training, shipping, duty, insurance, clearance, etc. IC at current period = IC (base year) x [Plant Cost Index (current period) / Plant Cost Index (base year)]	
Distribution network cost (USD)	(27.1 x Power capacity (kW)) + (7.5 x10 x Number of households access electricity) Where: Connection and earthing: 27.1 USD/kW. Primary electricity cable: 7.5 USD/m Average electricity cable length : 10 m/household	
Total investment (USD)	Equipment cost + Building cost + Installation cost + Distribution network cost	
Equipment depreciation (USD per year)	Equipment cost divided by project life time	Straight line method of depreciation calculation
Building depreciation (USD per year)	Building cost divided by project life time	Straight line method of depreciation calculation
Installation depreciation (USD per year)	Installation cost divided by project life time	Straight line method of depreciation calculation
Distribution network depreciation (USD per year)	Distribution network cost divided by project life time	Straight line method of depreciation calculation
Total depreciation (USD per year)	Equipment Depreciation + Building Depreciation + Installation Depreciation + Distribution network Depreciation	Straight line method of depreciation calculation
Maintenance cost (USD per year)	Percentage of maintenance cost (%) x Total depreciation	Percentage of maintenance cost input by the user. Default value is 10%.
Total of fixed cost (USD per year)	Total depreciation + Maintenance cost	

Note: The plant cost index is used to update equipment, building and installation cost to the current period.
Please visit this website for further information: http://en.wikipedia.org/wiki/Chemical_plant_cost_indexes.
The assumption in this tool is that plant cost index can be applied to any type and size of plant. It provides an acceptable proxy to update the investment costs.

8.1.6 Calculation of other costs

The plant overhead is defined as a charge to the production for services, facilities and payroll overhead. The general and administrative cost comprises rents, insurances, managerial, administrative and executive salaries. Table 8 shows the equations for calculating the cost associated with plant overhead, general and administrative cost, average loan interest payment and corporate tax.

Table 8: Other costs equations

Item	Equation and assumption	Remark
Plant overhead (USD per year)	Percentage of plant overhead (%) x (total labour cost + maintenance cost)	Percentage of plant overhead input by the user. Default value is 30%.
General and administrative cost (USD per year)	Percentage of general & administrative cost (%) x (total inputs cost + total labour cost + maintenance cost + plant overhead)	Percentage of general & administrative cost input by the user. Default value is 5%.
Average loan interest payment (USD per year)	Loan amount = loan ratio (%) x total investment cost Loan payment (USD/month) = PMT([loan interest rate/12],[12x loan term], loan amount) Annual loan payment = loan payment (USD/month) x 12 months Total loan payment =Annual loan payment x loan terms Loan interest payment = total loan payment - loan amount Average loan interest payment = loan interest payment divided by project lifetime	PMT is a financial function in Microsoft Excel for calculating the payment for a loan based on constant payments and a constant interest rate.

8.1.7 Total production cost and unit cost of electricity calculation

Table 9 presents the calculation equations of the total operating costs, total fixed costs, and total other costs. The final results of these costs are used to compute the total production cost of electricity and unit production cost per kWh.

Table 9: Total production cost equations

Item	Equation and assumption	Remark
Total operating costs (USD per year)	annual inputs cost + annual labour cost + annual transportation cost + annual storage cost	
Total fixed costs (USD per year)	depreciation fixed cost +annual maintenance cost	
Total other costs (USD per year)	annual plant overhead + annual general &administration cost + annual loan payment + annual income tax	
Total production cost (USD per year)	total operating costs + total fixed costs + total other costs	
Production cost per kWh	total production cost divided by Power generation	The equation of power generation (kWh per year) is presented in Table 3.

8.2 Data requirements for running the tool

Table 10 includes data requirements for running the *Combustion component*.

Table 10: Data requirements for running the tool

Data	Definition and sources
Biomass and its residue	The user selects the biomass/crops and its residue for detailed analysis.
Price of feedstock	If the price of feedstock is not available, the user will need information on hourly wages for skilled and unskilled workers (USD per employee per hour) and fuel consumption of machinery typically used in agricultural or forestry operations to calculate a proxy for this value.
Price of water	The user enters the current price of water (USD/m^3).
Price of caustic soda	The user enters the current price of caustic soda (USD/kg).
Price of electricity	The user enters the current price of electricity (USD/kWh).
Price of heat	The user enters the current price of heat (USD/GJ).
Feedstock storage cost (USD per tonne)	The user identifies the cost for storing the feedstock. The user can enter the current prices on storage for agricultural products in the country. If this information is not available in the country, the user can estimate this based on the selection on the type of storage available in the country and use the estimated global cost for building this type of storage that is provided in the tool. Moreover, the size of the storage site or container is estimated using the biomass storage calculator.

Data	Definition and sources
Labour cost	Unskilled and skilled workers in the unit of USD per employee per hour.
Working hours of feedstock collection	Working hours of feedstock collection for manual and mechanized method.
The cost of transportation of feedstock (field/collecting point to plant) in unit of USD per tonne per km	Cost of transportation of feedstock from the collection point (or field) to the biogas plant, the user enters the cost of transportation in unit of USD per tonne per km. If transportation is done on foot or by bike, the user can include this cost in the collection cost of feedstock. Alternatively, the user estimate the cost by using the cost of labour per hour, working time, the amount of material that can be transported and the approximate kilometres that can be travelled under the selected method.
Operating hours per day for combustion system	The user will provide an estimated number of hours per day that the system is expected to operate. Most literature indicates that combustion systems are operated only for a few hours during the day. For example, in cases where the combustion system supplies only household electricity, these operate 4 hours, usually during the night time. The user may want to determine this value based on potential energy demands.

Data	Definition and sources
Costing parameters	Percentage of plant overhead cost, general and administrative cost, maintenance cost and miscellaneous cost.
Financial parameters	Inflation rate (%) Discount rate (%) Loan ratio (%) Loan interest rate (%) Loan term (years), Plant cost index http://base.intratec.us/home/ic-index
Electricity demand per household	The user inputs data from the *Country Status* module. The electricity consumption will be estimated based on the type of appliances typically used in a rural household, the quantity of these appliances per rural household and the average hours of operation of the appliances. Note that this value will be used as a proxy to identify the number of potential households that can be supplied with electricity. A more detailed and localized analysis according to energy demand profiles and time framework will need to be carried out for adequate planning and implementation of a combustion system.

8.3 New feedstock creator wizard

The user may also define a new feedstock by using the new feature "Input new feedstock button" (Figure 25-label A).

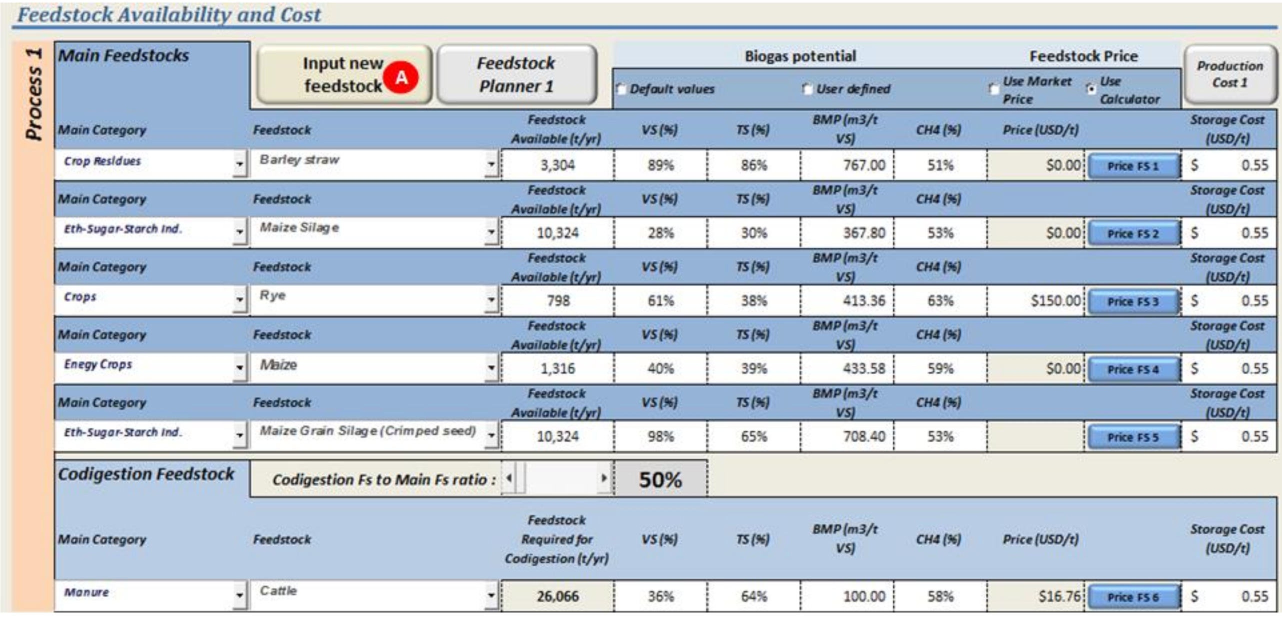


Figure 25: Input new feedstock

The user will:

1. Define the type of feedstook among the following options:
   - Wastewater (Figure 26-Label A)
   - Other type of feedstock (Figure 26-Label B)

Figure 26: New feedstock creator

2. When wastewater is selected:
   - Define the residue ID (Figure 27-Level 1)
   - Define the following properties (Figure 27-Level 2): COD (g/l), COD degradability (%), methane content (%) and biogas potential (m^3/t COD removed)

Figure 27: Wastewater definition

3. When other type of residues is selected:
   - Define the residue ID (Figure 28-Level 1)
   - Define TS (%) and VS (%) (Figure 28-Level 2)
   - Select the method to assign the biogas potential (Figure 28-Level 3)
   - If user defined is selected, define the biogas potential (m^3/t VS) and the methane content (%)
   - If calculator is selected, click on “Use biogas potential calculator” (Figure 29-Label A)
   - Select the method to calculate the biogas potential (Figure 29-Label 1)
   - If method 1 is selected, define the properties to run the ultimate analysis (Figure 29-Label 2) and click on “Calculate using method 1” (Figure 29-Label 3)
   - If method 2 is selected, define the properties to run the proximate analysis (Figure 29-Label 4) and click on “Calculate using method 1” (Figure 29-Label 5)

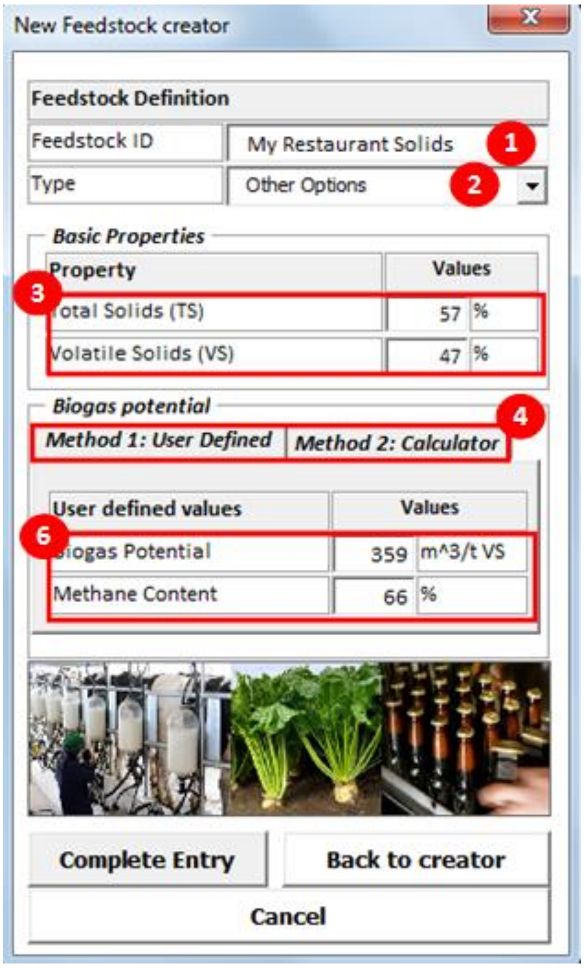


Figure 28: Other type of feedstock definition. Biogas potential defined by the user

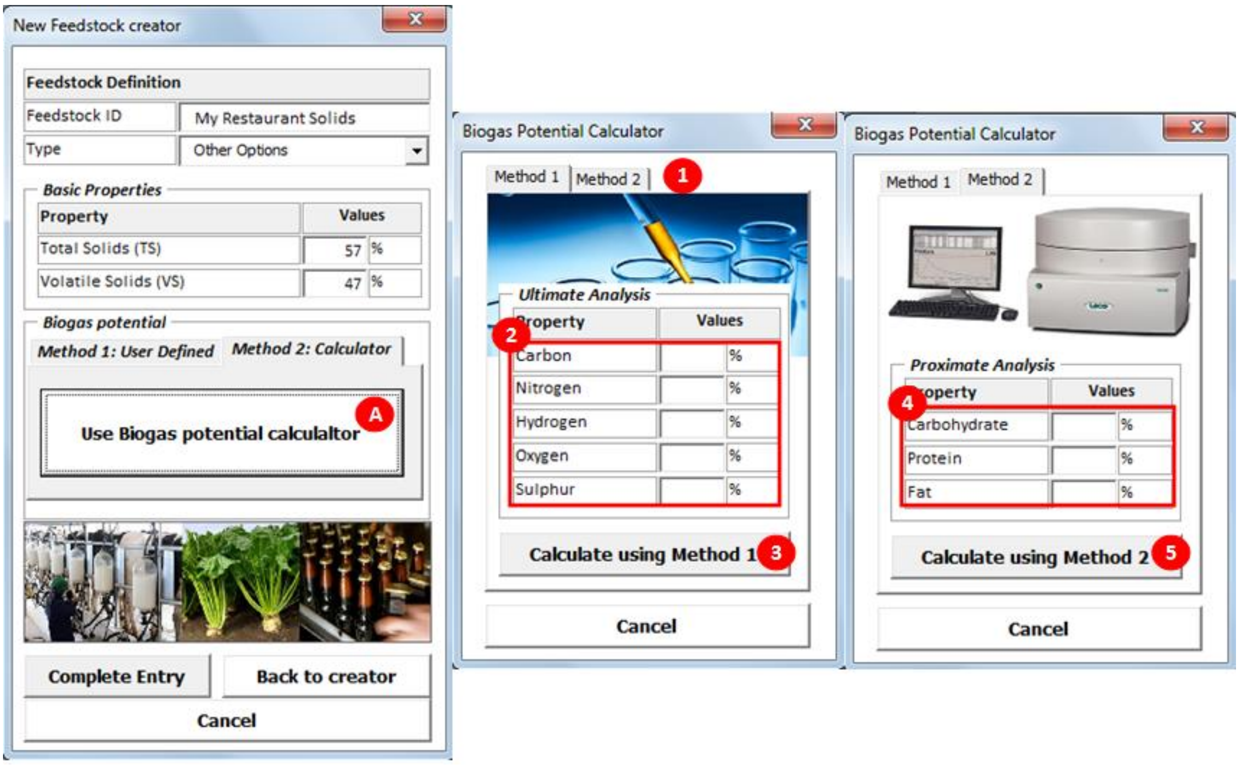
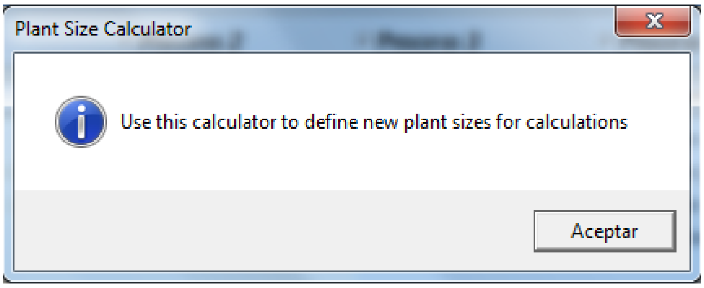


Figure 29: Other feedstock definition. Biogas potential calculated by the tool

8.4 Recalculate plant size

Recalculate Plant Size is a new feature included in this tool (Figure 30-Label A) that allows defining the plant sizes according to the biogas final use and the minimum and maximum sizes required.



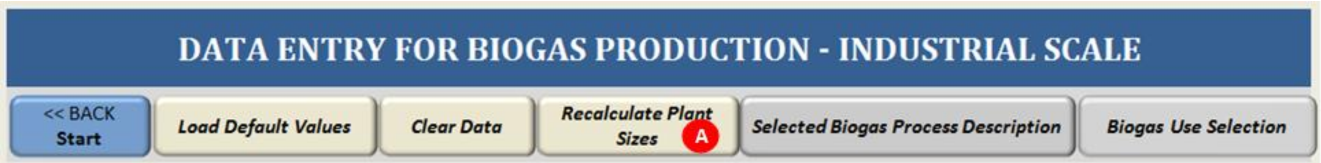


Figure 30: Recalculate plant sizes

The user will:

1. Define a base unit from the dropdown menu (Figure 31-Label 1)
2. Define the minimum and maximum plant sizes required (Figure 31-Label 2)
3. Click on the Calculate button (Figure 31-Label 3)
4. Recalculate the plant sizes, if necessary (Figure 31-Label 4)
5. Apply the calculated plant sizes to continue with the process (Figure 31-Label 5)

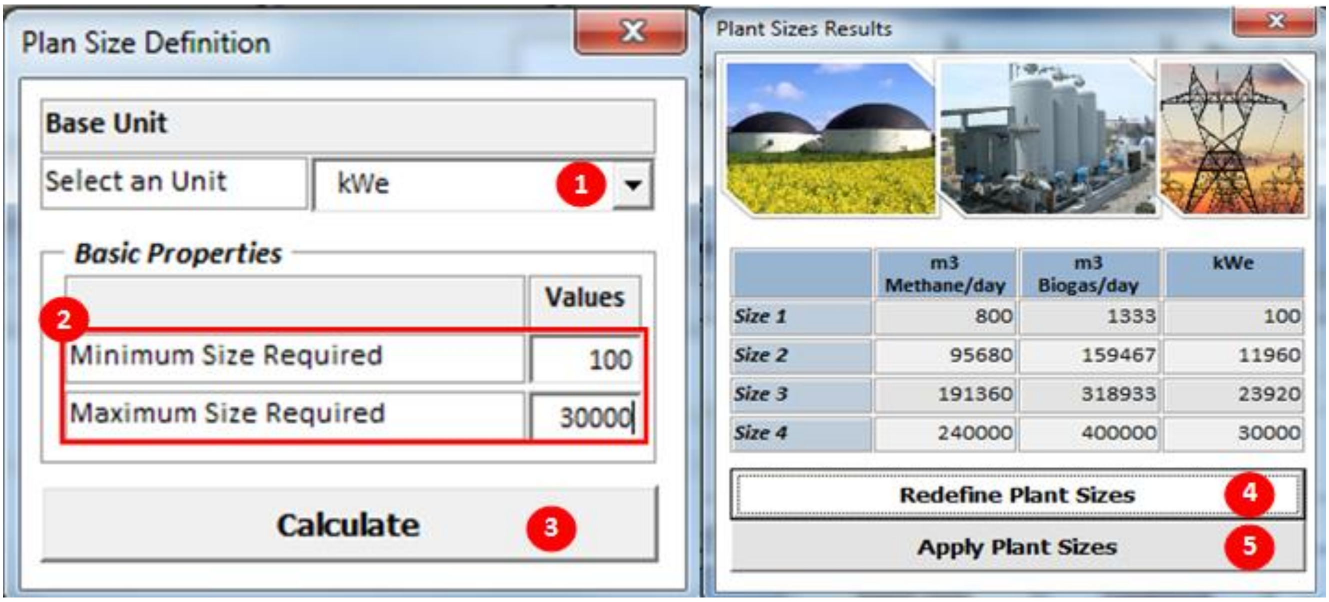


Figure 31: Plant size definition

8.5 List of feedstock included in biogas industrial tool

Food Process. Res.	Crops	Crop Residues	Biodiesel/Oilseed Ind.	Enegy Crops	Eth-Sugar-Starch Ind.
Apple pulp	Alfalfa	Apple cake	Coconut cake/expeller	Barley	Maize Grain Silage (Crimped seed)
Apple slurry	Apple	Apple waste	Coconut extraction meal	Barley grain	Maize Silage
Asparagus peels	Banana	Apricot fibre	Cotton seed extraction meal	Forage sorghum	Miscanthus silage
Baking wastes	Beans	Asparagus waste	Fish Oil	Grain sorghum	Miscanthus sillage
Banana peels	Buckwheat	Banana Residues	Flax cake/expeller	Grass Clipings	Sugar beet leaves, silage
Barley fresh mass	Cabbage	Barley straw	Flax extraction meal	Grass fresh	Sugar beet silage
Barley silage	Carrot	Cauliflower Residues	Glycerin	Green maize	Wheat strip waste
Field fodder silage	Cauliflower	Cut flower wastes	Hemp press cake, fresh	Maize	Apple Marc
Hemp press cake	Clover	Eggplant Residues	Linseed oil	Maize grain dry	Maize gluten
Hemp silage	Comfrey	Feeding beet leaves, fresh	Maize germ cake/expeller	Oat grain	Maize gluten feed
Loose skinned mandarin	Coriander plant	Feeding beet leaves, silage	Maize germ extraction meal	Rapeseed	Mash from distillations
Maize strip waste	Eggplant	Field fodder hay	Oilseed Residuals (pressed)	Reed, cattail, fresh	Molasses
Mango Peels	Field beans	Grape Residues	Olive pulp	Rice	Potate chips
Rapeseed strip waste	Field fodder fresh	Lemmon Residues	Palm Kernell	Seaweed, fresh	Potate flakes
Reed, cattail, silage	Fodder beet	Maize cobs	Palm-kernel cake/expeller	Sorghum	Potato press water
Bakery residues	Garden beet	Maize stover	Palm-kernel extraction meal	Sorghum grains	Potato pulp, dried
Barley bran	Garden beet tops	Maize Straw	Peanut cake/expeller	Sugar beet	Potato starch
Barley feeding meal	Garden pea	Mango Resdiues	Peanut extraction meal	Sunflower	Residue from production of sweets
Bran and cereal strip waste (70:30), fresh	Giant knotweed	Oat straw	Rape cake (pressed cold)	Sunflowers green start of flowering	Sugar beet chips
Cereal Mash	Grape vine	Orange Residues	Rapeseed cake/expeller	Sweet Sorghum	Sugar beet dried & shredded
Cereal strip waste, fresh	Ipomoea fistulosa	Pea straw	Rapeseed extraction meal	Triticale	Sugar beet fresh
Chip fat	Jerusalem Artichoke	Pineapple Residues	Rapeseed oil	Triticale grains	Sugar beet melasse
Coffee pulp	Lady´s finger (Okra)	Pineapple waste	Raw Glycerol	Wheat	Sugar beet pulp, dired
Dairy industry wastes	Lupine	Potatoe Residues	Safflower extraction meal	Wheat grain	Sugar beet tops clean
Discarded wheat flour	Mirabilis	Rapeseed straw	Sesame extraction meal	White fir	Sugar filter cake
Field bean grain	Mustard	Rice Straw	Soy beans seeds steam-heated	Willow	Sugar for feeding
Grain Peas	Nettle	Rye straw	Soya Oil	Winter Barley	
Maize , broken	Orange	Ryegrass straw	Soybean extraction meal		
Maize grain powder	Parsnips	Spinach waste	Sunflower cake cold pressed		
Malt coffee marc	Pea	Other Straw	Sunflower extraction meal		

Food Process. Res.	**Crops**	**Crop Residues**	**Biodiesel/Oilseed Ind.**
Medical tea (Production waste)	Pineapple	Sugar Beet leaf	Sunflower Oil
Mixed grain	Pomegranate	Sugar beet tops	Sunflower peelings
Oat bran	Potatoes	Sugar beet waste	
Oats fodder flour	Quinoa	Sugar beet, leaves and tops, silage	
Old bread	Red clover	Sugas beet leaf (fresh)	
Old chip fat	Rhubarb	Tangarine Residues	
Onion Residues	Rosebay willow-herb	Tea Waste	
Other cereals straw	Rye	Tomatoe Residues	
Potato flakes	Sweet clover	Turnip Residues	
Potato peeling wastes roughly	Tomato	Turnips tops, fresh	
Potato Pulp/Peelings	Turnip	Wheat straw	
Potatoes amniotic fluid (Stach production)	Vetch	Cocoa Shell	
Potatoes mash	White cabbage		
Potatoes pulp			
Potatoes shredder			
Potatoes waste water			
Processing waste (filtration cake, pulp)			
Pulp			
Rice Bran			
Rice feeding meal			
Rolled oats			
Rye bran			
Rye feeding meal			
Silage seep water			
Succory chaff			
Succory mush			
Vegetable wastes			
Wheat bran			
Wheat chaff			
Wheat flakes			
Wheat germs			
Wheat semolina bran			
Fruit slurry			
Lemon pulp			
Mango pulp			
Orange peel and seeds			

Grass	Yeast-Alcoholic Bev.	Slaughterhouses wastes	Other Options	Wastewater	Dairy-milk ind.	Manure
Alemangrass	Apple pomace	Fat seperator residues	Algae	Coffee Industry wastewater	Butter milk fresh	Buffalo
Bermuda grass	Beer Barm	Floating Sludge	bio-waste container	Dairy Industry wastewaters	Cheese waste	Cattle
Glover grass hay	Brewer`s grains	Flotate sludge, fresh	Clover 1st cut in flower	Slaugtherhouse wastewater	Dairy cow slurry	Dairy Cattle
Glover grass silage	Brewer`s grains and yeast	Animal fats	Fodder carrot	Distillery wastewater	Dairy slurry inc. fodder remains	Poultry
Grass	Brewers yeast, fresh	Fish liver meal	Food leftovers Opt 1.	Oilseed proceesing wastewater	Milk Whey	Swine
Grass cut (golf course)	Distiller`s dried grain, solubles only	Fish meal	Food Leftovers Opt 2.	Fruit industry wastewater	Skimmed milk dry	
Grass cut (loppings)	Distiller`s dried grains	Flotate fat	Green Mustard before flower	Pulp and paper industry wastewater	Skimmed milk fresh	
Grass cuttings from lawns	Draff	Hydrolyzed Meat and Bones	Green oats in flower	Textile industry wastewater	Sour whey fresh	
Grass hay	Grain mash	Leftovers Average fat	Makrophyt	Brewery industry wastewaters	Whole cows milk fresh	
Grass silage	Grain strip waste	Leftovers fat-rich	Market waste Opt. 1	Vinasses		
Lawn	Grape marc	Leftovers low fat & wet	Market Wastes Opt. 2			
Meadow grass green	Grape marc, fresh	Meat waste	Meadow Hay			
Miscanthus fresh	Malt coffe draff, fresh	Pig muck	Microalgae			
Napier grass	Pomace	Poultry meat offals	News paper			
Ray Grass	Potato pulp, fresh	Purines	Salad			
Ray Grass Silage	Fermentation Residues	Rumen content	Sisal Pulp			
Reed canary grass	Yeast	Slaughterhouse wastes mixtures	Waste Sludge			
Rye grass			Waste Sludge (concentrated)			
Spartina-Cordgrass						
Sudan grass fresh						
Sudan grass silage						
Tall fescue						
Timothy grass						
Turf grass						
Wood grass						

8.6 Codigestion rates

Feedstock 1	Feedstock 2	Optimal Codigestion Rate
Manure	Oilseeds	2:1
Manure	Fruit Residues	85:15
Manure	Sugar Beet	62:38
Manure	Energy Crops	1:4
Manure	Maize	44:56
Manure	Glycerol	25.8:71.5
Manure	Straw	50:50
Manure	Silage	83:17
Manure	Vegetable Wastes	60:40
Manure	Potatoe Residues	80:20
Pig Manure	Corn stover	75:25
Pig Manure	Potato waste	85:15
Pig Manure	Wheat Straw	75:25
Cow Manure	Wheat Straw	50:50
Cow Manure	Beet silage	83:17
Cow Manure	Fruit and vegetabe waste	80:20
Cow Manure	Barley straw	80:20
Cow Manure	Sugar beet tops	70:30
Cow Manure	grass silage	70:30
Cow Manure	Straw	70:30
Cow Manure	Whey	75:25
Buffalo manure	Maize silage	75:25
Dairy Manure	whey	75:25
Dairy Manure	Potatoes	75:25
Dairy Manure	Plain pasta	75:25
Dairy Manure	Switchgrass	75:25
Dairy Manure	Waste Oil	75:25

(DUONG, 2014, ESPOSITO *ET AL*., 2012, WU, 2007, PRABHU *ET AL*., 2014)

Table 11 Optimal codigestion rates from selected literature sources

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This user manual assists in the utilization of BEFSRA biogas industrial tool. Moreover, this manual provides useful definitions related to biogas digestor options, its operation and key parameters affecting production performance. After completing this manual and operate the tool, users will be able to perform the techno-economic analysis of biogas production and different potential uses for electricity generation, cogeneration of heat and power (CHP), direct use for heating and cooking or upgrade to natural gas. In this manual, users will be guided through a practical example on how to use the more than 450 feedstock options included in the database and that range from agriculture residues to common agro-industrial residues, for codigestion or seasonal operations. A correct use of manual and tool will provide an indication of production costs and investment; financial viability feedstock demand, and potential socio-economic benefits of biogas industrial plants. Biogas industrial manual is part of the Heat and Power submodule of Energy End Use Option in BEFS RA tools. 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.

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