BIOENERGY AND FOOD SECURITY RAPID APPRAISAL (BEFS RA)

User Manual

COMBUSTION

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BEFS Rapid Appraisal

Energy End Use Options Module

Rural Electrification Sub-Module

Section 3: Combustion

User Manual

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[1] Unless otherwise specified, all authors were affiliated to FAO at the time of their contribution.

[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.

[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.

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    - Section 2: Crop Budget Tool
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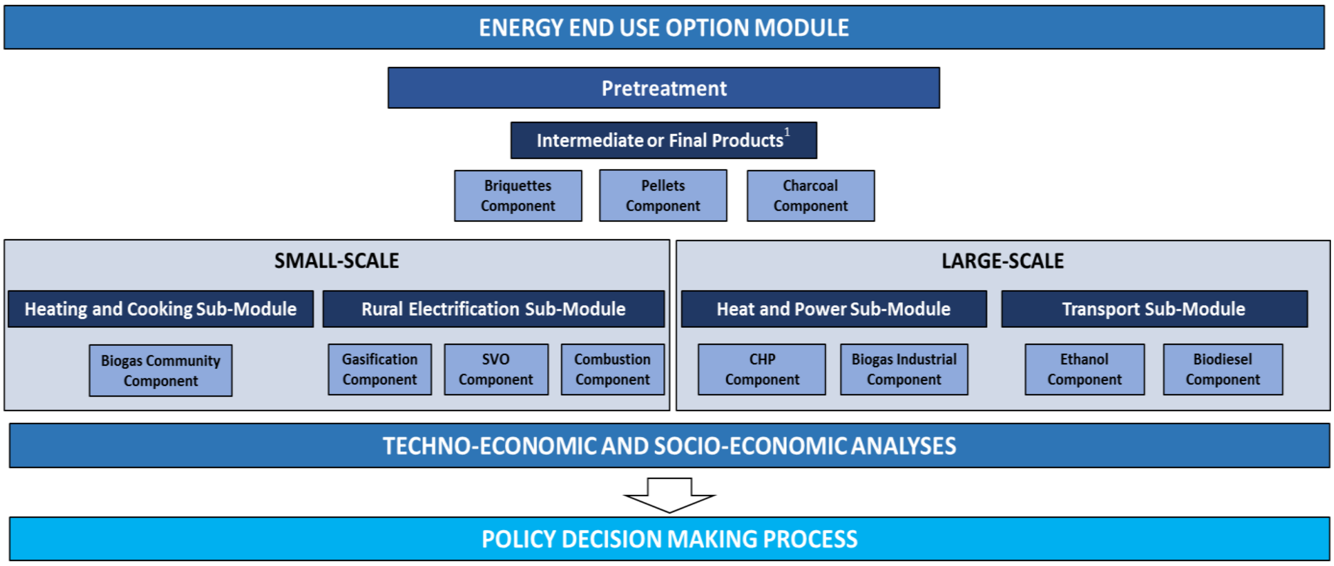
1 Overview of the Energy End Use Option (End Use) Module

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

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[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 *Combustion Component*

The *Combustion Component* is designed to assist the user in evaluating the potential to develop biomass combustion to supply electricity in rural areas without current access to electricity and where extension of the national grid is not feasible. The boundary of the combustion analysis is shown in Figure 2. The tool is based on extensive literature reviews. The detailed assumptions and calculations used to develop the tool are provided in the Annex.

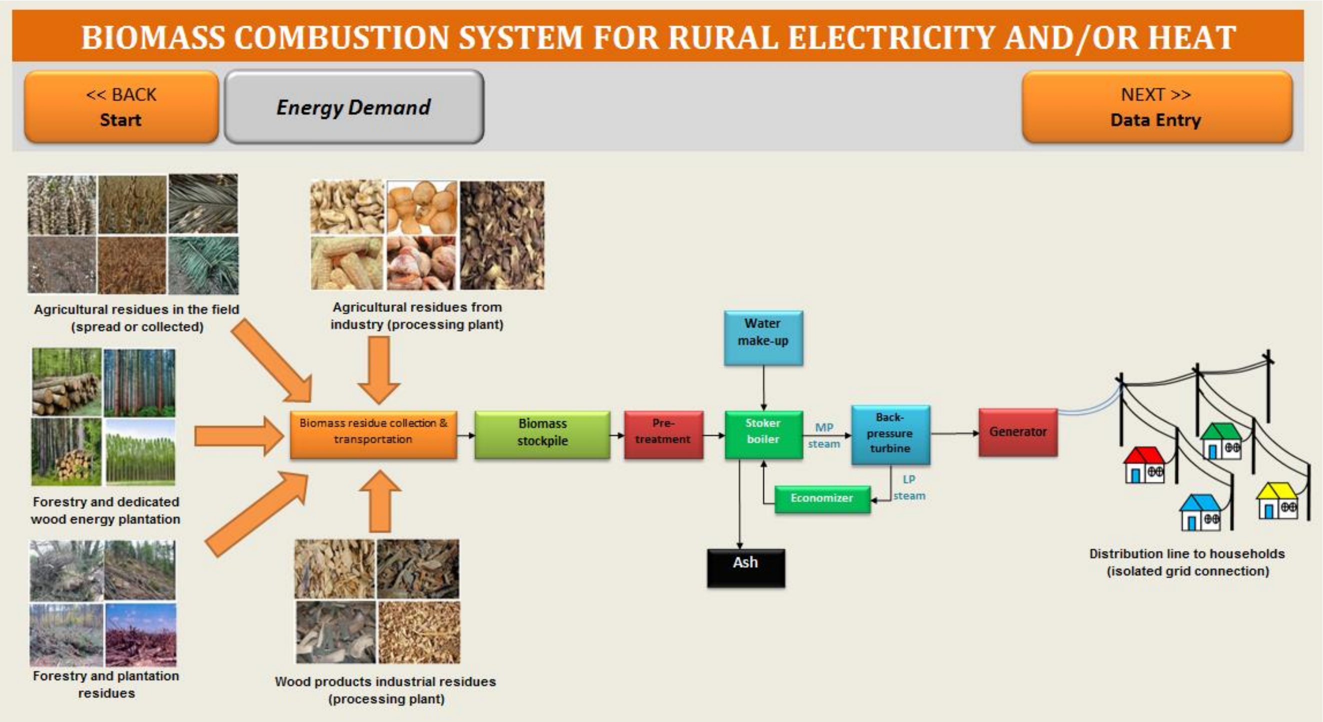

Figure 2: Biomass Combustion System for Rural Power Generation

After completing the analysis, the user will have an indication on: 1) the biomass consumption and area required to set up the various scales of biomass combustion plants; 2) the potential number of biomass sustainable combustion plants that can be developed in the country; 3) the investment cost and production cost per kWh for each scale; 4) the number of households that could be electrified; 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 biomass types (feedstock) and plant capacities to identify the most appropriate biomass sources based on a number of factors including physical availability, economic and social results.

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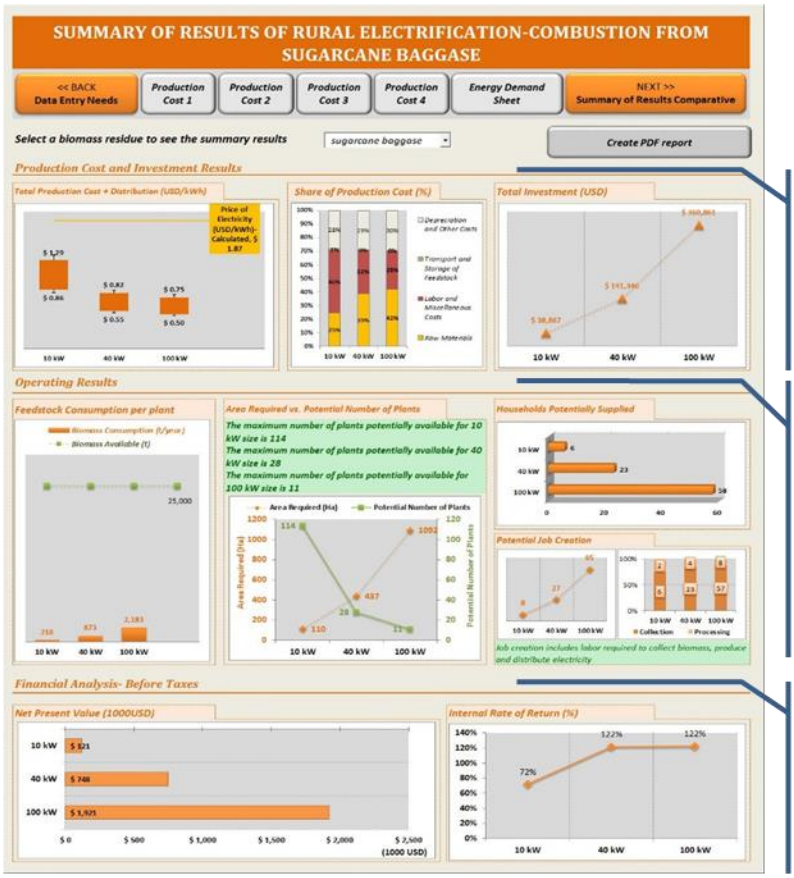
[5] The Pretreatment Calculator can be used prior to utilising the Energy End Use Tools. The exceptions are the *Biogas Community and Transport Tools*, as these tools already include pretreatment.

General Outputs by Feedstock

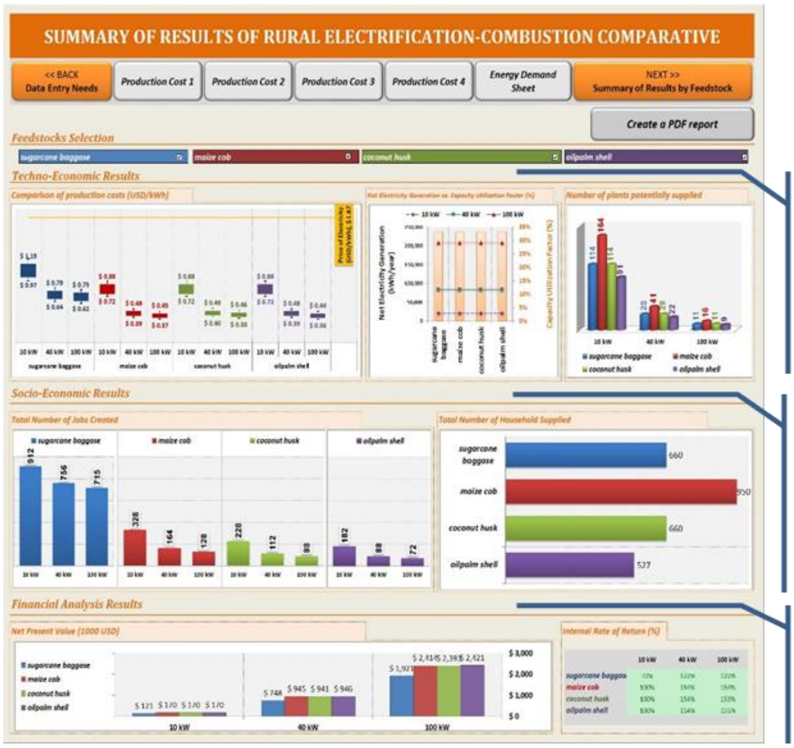


Production Costs and Investment Results: Cost of production of electricity, Share of total production costs and Total investment cost

Operating Results: Biomass consumption, Biomass area required, Potential number of combustion plants, Number of households supplied and Potential job creation

Financial Analysis-Before Taxes: Net Present Value (NPV) and Internal Rate of Return (IRR)

Comparative Outputs by Capacity



Techno-Economic Results: Production cost of electricity, Net electricity generation, Capacity utilization factor and Number of combustion plants

Socio-Economic Results: Total number of jobs created, Total number of households supplied

Financial Analysis-Before Taxes: Net Present Value (NPV) and Internal Rate of Return (IRR)

Figure 3: Layout of the Combustion Results Sheets

3 Terms and Definitions in the *Combustion Component*

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

- **Combustion** refers to a thermochemistry process where a fuel and an oxidant agent (air or oxygen) react exothermally, generating heat and series of converted products named combustion gases. Different types of substance or materials can be employed as combustion fuels, including fossil fuels, residues or biomass. Essentially, a good fuel needs to be easily available, cheap, environmentally friendly and with a good calorific value. The combination of calorific value of a fuel and the operation conditions (pressure, excess oxidant, etc.) determines the quality of combustion and consequently the heat output obtained.
- **The biomass combustion analysis** involves the following steps: collection of the biomass residues, transport and storage at the combustion plant. Before feeding the biomass residues to the boiler for combustion, these undergo pretreatment processes. For example, drying to remove excess moisture or billet size reduction for big sizes of agriculture/wood residues (U.S. Department of Energy, 2012a). After the pretreatment processes, the biomass residue is ready to be feed to a boiler for direct combustion, where the heat obtained is used to produce steam. This steam is used to drive a steam turbine and generator to produce electricity. The output of the combustion process is electricity, which is distributed to households in a particular area (Pinheiro, G., et al., 2011).
- **Steam** is technical name for vaporized water. Steam has different applications as a mean for energy transportation. These include low toxicity, ease of transportability, high efficiency, high heat capacity, and relative low cost. Steam holds a significant amount of energy on a unit mass basis that can be extracted as mechanical work through a turbine or as heat for process use. Since most of the heat content of steam is stored as latent heat, large quantities of heat can be transferred efficiently at a constant temperature, which is a useful attribute in many process heating applications (U.S. Department of Energy, 2004).
- **Feedstock** is biomass raw material that is used in the combustion process to produce heat.
- **Boilers** are used for steam generation by adding energy to a feedwater supply. This energy is obtained from the combustion of fossil fuels or from process waste heat. The boiler provides a heat transfer surface (generally a set of tubes) between the combustion products and water. In order to operate a boiler, other elements are required: the fuel supply system, combustion air system, feedwater system, and exhaust gases venting system. There are two basic types of boilers: firetube and watertube. The fundamental difference between these boiler types is which side of the boiler tubes contain the combustion gases or the boiler water/steam (U.S. Department of Energy, 2004; Quaak, P., H. Knoef, and H.E. Stassen, 1999; IRENA, 2012).
- **Steam turbine** converts heat energy contained in steam into useful mechanical or electrical energy by means of rotational motion. The quantum of power generation is a function of two main variables: Steam Flow and Pressure Drop through the turbine. These two parameters determine how much power can be obtained from this device. Steam turbines are used to drive electric generators or other rotating machinery such as compressors, pumps, and fans. Steam turbines are used in many different system designs, depending on the relative requirements for steam, electricity, or other mechanical loads. Steam turbines provide an effective means of stepping down steam pressure while extracting mechanical work (U.S. Department of Energy, 2012b).

- **Pretreatment of biomass:** Biomass residues have a great potential in most developing countries, since they are able to replace energy sources such as firewood. However, only a small proportion of biomass residues are being used as fuel because of their high moisture content, high polymorphism and low energy density. These troublesome characteristics increase costs for transport, handling, and storage, making the use of biomass as a fuel impractical (Patel, Gami, & Bhimani, 2011). There are many varieties of biomass (agri-residues) that have different heating values, sizes, moisture content, and chemical composition. Pretreatment processes include: drying to remove excess moisture, size reduction for big sizes of agri-residues, densification process (e.g. pellets and briquettes) to increase the size and energy density of fine grain feedstock, and the torrefaction process to improve characteristics and storage efficiency of biomass.

4 Scope and Objective of the *Combustion Component*

The aim of the *Combustion Component* is to assess the feasibility to develop a biomass combustion system to supply electricity in rural areas where the extension of the national electric grid is not economically or physically viable. It provides the user with a technical foundation to perform an analysis of biomass combustion systems for the production of electricity at 10kW, 40kW and 100kW from an assortment of biomass sources. The results of the analysis can be used to identify the viability of electricity production from combustion in terms of feedstock availability, the financial viability of the different electricity production scales, the optimum electrical production capacity and the feedstock combination, and the socio and economic benefits that can be attained for each production scheme. The information generated by the analysis can also be used as an initial basis to discuss potential strategies to promote the development of electrification through biomass combustion systems in rural areas without current electricity access.

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

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Figure 4: Rapid Appraisal Tool for Rural Electrification

5 Running the *Combustion Component*

The flow of analysis within the *Combustion 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 *Combustion 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.

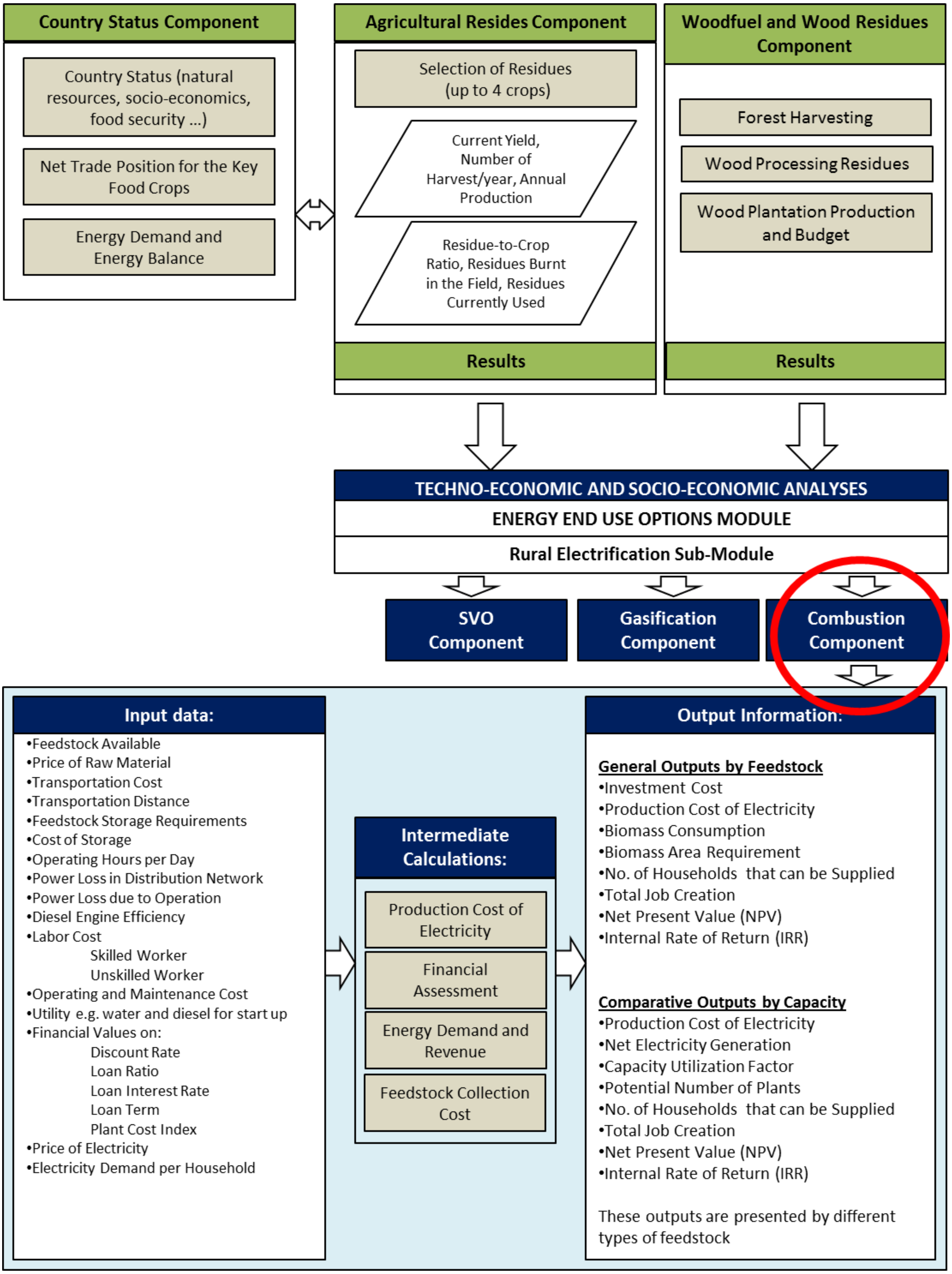


Figure 5: Combustion Component: Flow of Analysis and Inter-linkages with BEFS RA Modules and Components

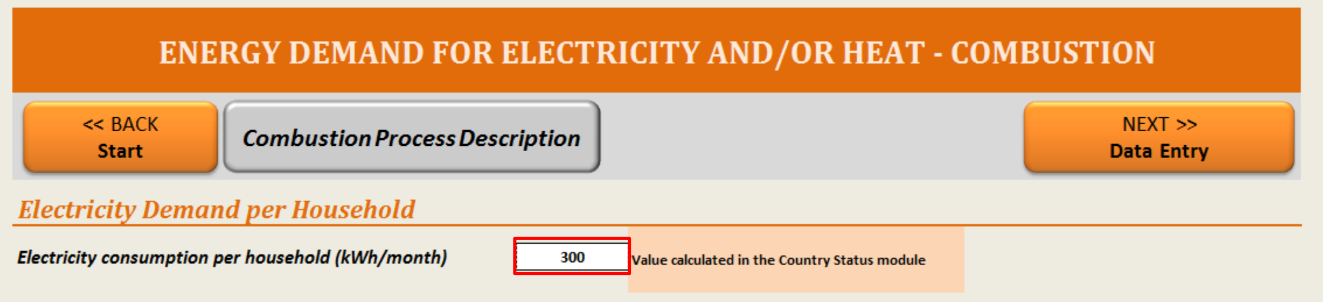
The user navigates step by step through the options and is asked to input necessary data to obtain final results. When the required data are limited or unavailable, then the default values provided by the tool can be utilised. The navigation buttons are placed on the top and bottom of each sheet, indicating 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, using an example from the ***Agriculture Residues Component*** to feed the combustion system to generate power in a rural remote area without current electricity access. All input parameters are based on a generic situation.

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: “Combustion Process Description”, “Data Entry Sheet” and “Energy Demand” as shown in Figure 4.

5.1 Step 1: Energy demand

The user needs to enter the electricity consumption per household (kWh/month) as it was defined in the *Country Status* module (Figure 6).



Electricity consumption per household (kWh/month): 300

Value calculated in the Country Status module

Figure 6: Energy Demand

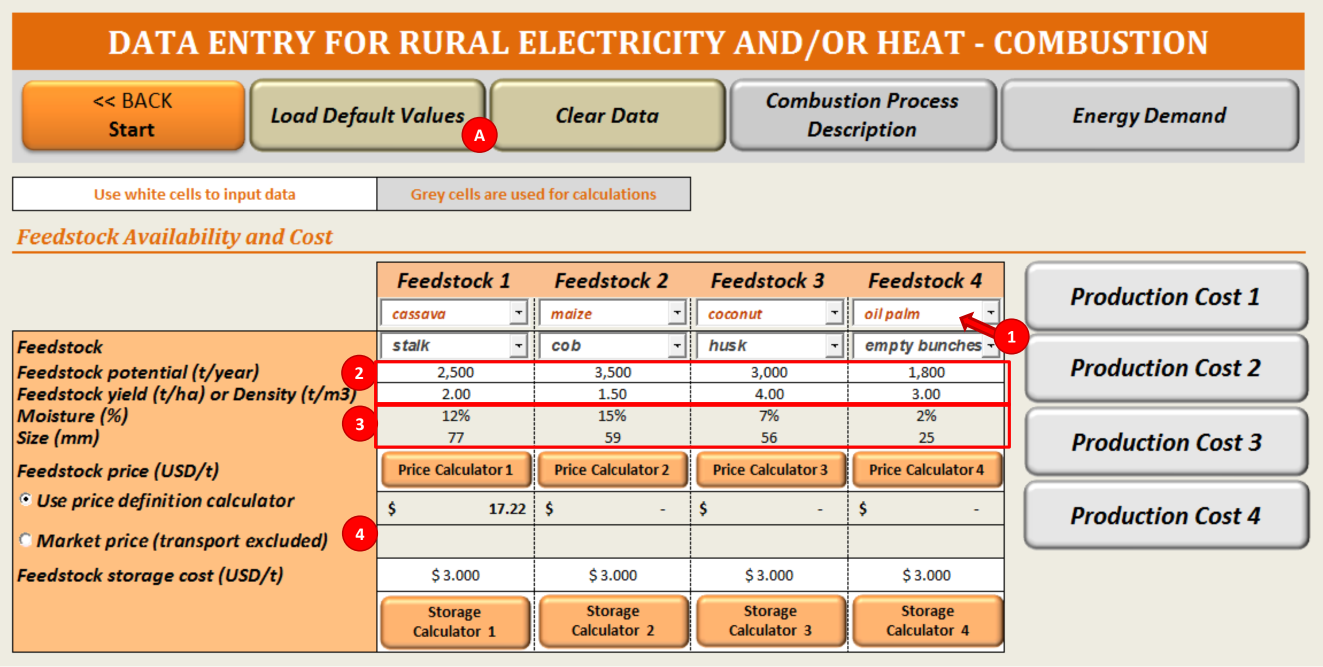
5.2 Step 2: Defining the feedstock

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 7, label A.

Step 2.A Selection of the feedstock

The user will:

1. Select the crop(s) from the dropdown menu and the residue associated with the crop. The list includes 15 key food/cash crops, two types of wood processing residues and briquettes (Figure 7, label 1). Up to four crop residues can be analysed at the same time.



	Feedstock 1	Feedstock 2	Feedstock 3	Feedstock 4
	cassava	maize	coconut	oil palm
Feedstock	stalk	cob	husk	empty bunches
Feedstock potential (t/year)	2,500	3,500	3,000	1,800
Feedstock yield (t/ha) or Density (t/m3)	2.00	1.50	4.00	3.00
Moisture (%)	12%	15%	7%	2%
Size (mm)	77	59	56	25
Feedstock price (USD/t)	Price Calculator 1	Price Calculator 2	Price Calculator 3	Price Calculator 4
● Use price definition calculator	$ 17.22	$ -	$ -	$ -
○ Market price (transport excluded)				
Feedstock storage cost (USD/t)	$ 3.000	$ 3.000	$ 3.000	$ 3.000
	Storage Calculator 1	Storage Calculator 2	Storage Calculator 3	Storage Calculator 4

Figure 7: Feedstock Selection

2. Enter data on feedstock available (t/year) and yield (t/ha) of the selected crop residues (Figure 7, label 2). *This information is generated in the Natural Resources module*.
3. The moisture content (%) or average percentage of moisture content of the selected crop residues and the size (mm) or average size of feedstock in millimetre are automatically generated from the technical database in the tool (Figure 7, label 3).

For this example, the following were selected: Feedstock 1 "Cassava stalk", Feedstock 2 "Maize cob", Feedstock 3 "Coconut husk" and Feedstock 4 "Oil palm empty bunches" (Figure 7).

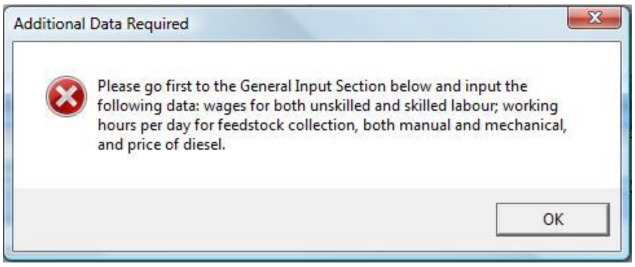
Step 2.B Feedstock price (USD/t)

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 (transport excluded)" (Figure 7, label 4) 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 Price Definition Calculator" and selecting the "Price Calculator" (Figure 7, label 4).

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

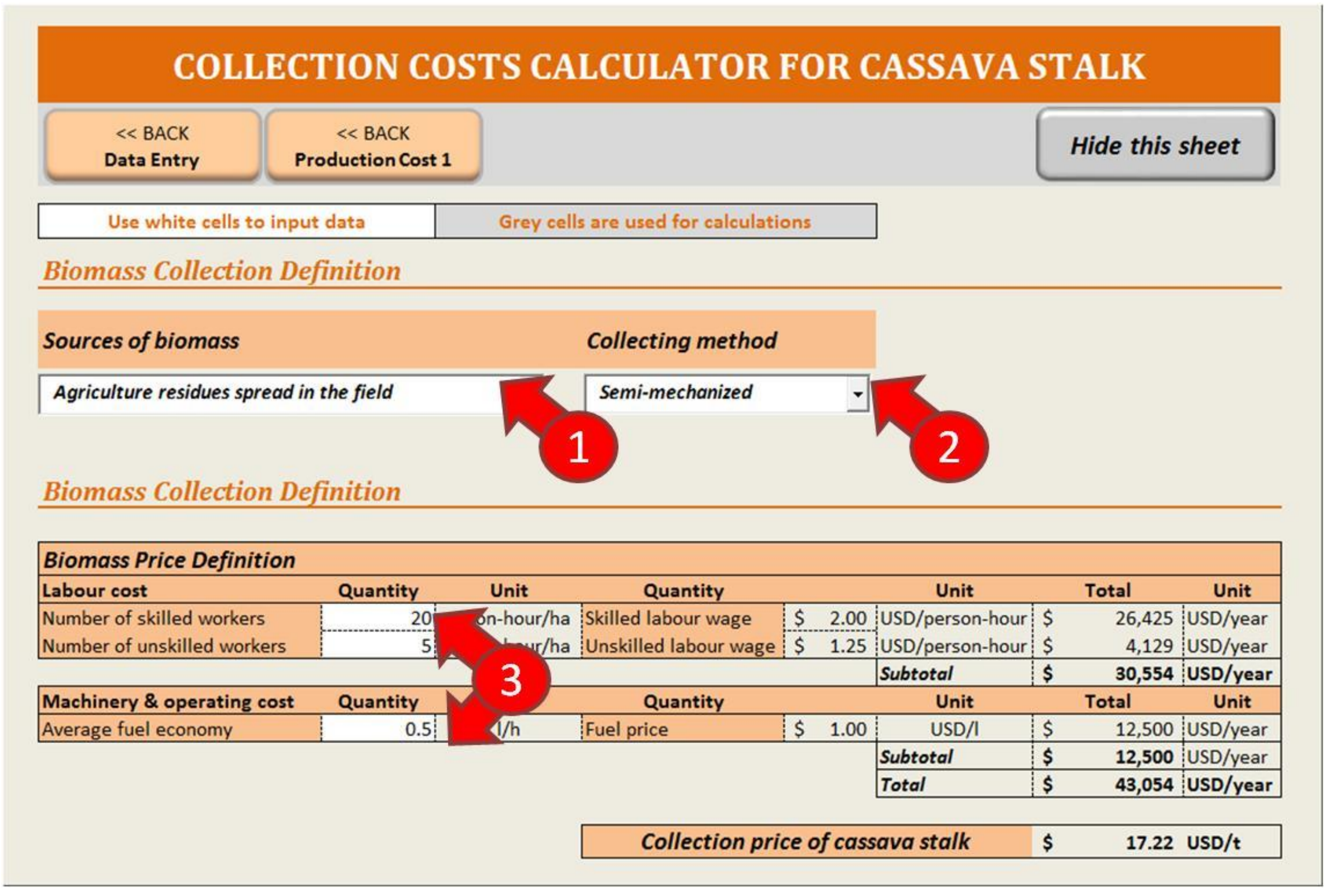


Please go first to the General Input Section below and input the following data: wages for both unskilled and skilled labour; working hours per day for feedstock collection, both manual and mechanical, and price of diesel.

1. The wage for both unskilled and skilled labour in "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” (Figure 8) assists the user in estimating the potential feedstock price based on the source and collection method of the feedstock.



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

Biomass Collection Definition

Sources of biomass: Agriculture residues spread in the field

Collecting method: Semi-mechanized

Biomass Collection Definition

Biomass Price Definition

Labour cost	Quantity	Unit	Quantity		Unit	Total	Unit
Number of skilled workers	20	on-hour/ha	Skilled labour wage	$ 2.00	USD/person-hour	$ 26,425	USD/year
Number of unskilled workers	5	ur/ha	Unskilled labour wage	$ 1.25	USD/person-hour	$ 4,129	USD/year
					Subtotal	**$ 30,554**	**USD/year**
Machinery & operating cost	**Quantity**		**Quantity**		**Unit**	**Total**	**Unit**
Average fuel economy	0.5	l/h	Fuel price	$ 1.00	USD/l	$ 12,500	USD/year
					Subtotal	**$ 12,500**	USD/year
					Total	**$ 43,054**	**USD/year**

Collection price of cassava stalk $ 17.22 USD/t

Figure 8: Feedstock Price Calculation based on the Collection Method and Source

To run the price calculator, the user will need to:

1. Identify the *biomass source* from one of the following options (Figure 8, label 1):
    - Agriculture residues spread in the field
    - Agriculture residues collected from the field
    - Agriculture residues from food processing plant
    - Forestry
    - Forestry and plantation residues
    - Residues from wood industry
    - Dedicated wood energy plantation

2. Select the *biomass collection method* from the following options (Figure 8, label 2):
    - manual
    - semi-mechanized
    - mechanized

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

3. Enter the labour requirements (person-hour per hectare) and the fuel needs (litres per hour) associated with the selected biomass collection method (Figure 8, 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 8), and this value is transferred to the "Data Entry Needs" worksheet for further calculation.

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

For this example, the selected Feedstock 1 "Cassava stalk" is assumed to be sourced from "agricultural residues spread in the field" and the collection method is "semi-mechanized". The number of person-hours for skilled workers (machine operators) is 20 and for unskilled workers is 5, and the diesel consumption of the machine is 0.5 litres per hour. Using the information that manual labour works 8 hours per day and machinery works 16 hours and diesel price of 1 USD per litre, a proxy price of the feedstock is calculated at 17.22 USD/t (Figure 8).

Step 2.C: 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:

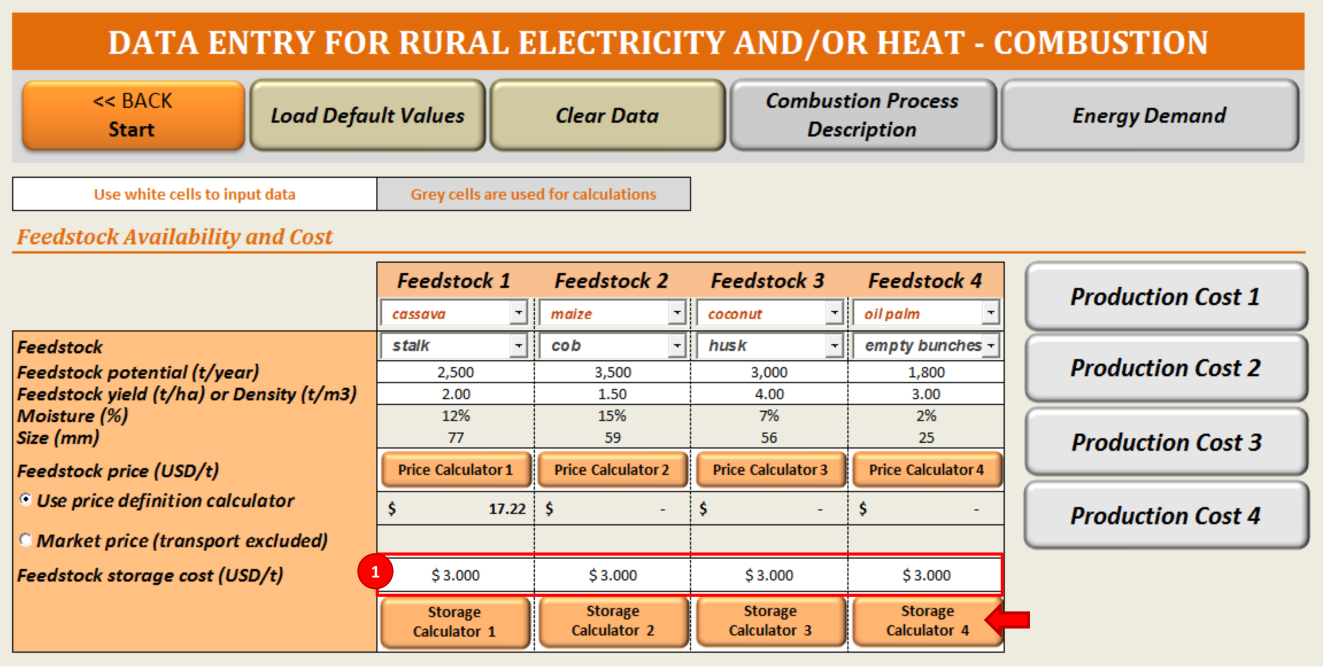
1. Identify a type of feedstock storage likely associated with conditions of his/her country from the options presented in Table 1.
2. For the selected storage option, look up the global building cost provided in Table 1.
3. Enter the proxy value (USD/tonne) in the respective cell for each feedstock.

Table 1: 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 3 USD/tonne. (User inputs the cost in the corresponding cells as shown in Figure 9, label 1).



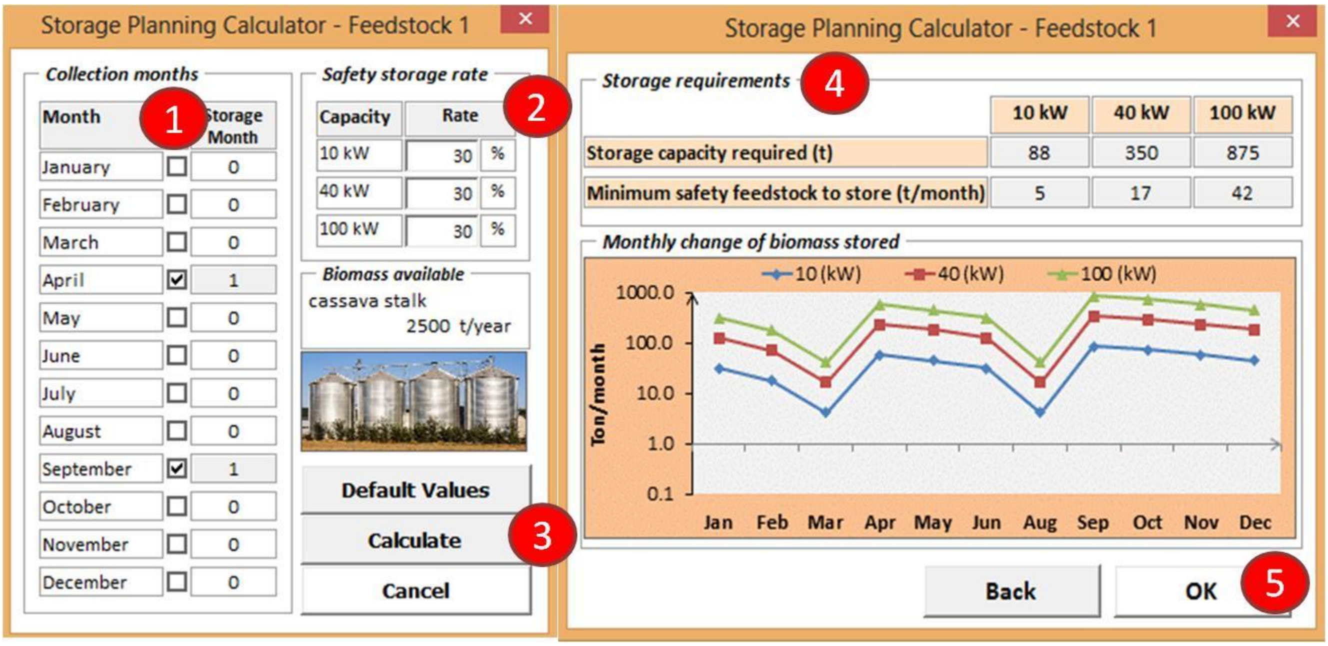
Feedstock Availability and Cost

	Feedstock 1	Feedstock 2	Feedstock 3	Feedstock 4
	cassava	maize	coconut	oil palm
Feedstock	stalk	cob	husk	empty bunches
Feedstock potential (t/year)	2,500	3,500	3,000	1,800
Feedstock yield (t/ha) or Density (t/m3)	2.00	1.50	4.00	3.00
Moisture (%)	12%	15%	7%	2%
Size (mm)	77	59	56	25
Feedstock price (USD/t)				
● Use price definition calculator	$ 17.22	$ -	$ -	$ -
○ Market price (transport excluded)				
Feedstock storage cost (USD/t)	$ 3.000	$ 3.000	$ 3.000	$ 3.000

Figure 9: Feedstock Storage Cost

Step 2.C.3 In order to calculate the storage capacity needs, the user needs to click on the "Storage Calculator" (Figure 9, red arrow). This will take the user to the Biomass Storage Calculator (Figure 10). In this worksheet, the user will need to:

1. Selects the harvesting month(s) of the crop (Figure 10, label 1).
2. Enter the biomass safety stock rate (%). This is the percentage of biomass needed to secure continuous supply of feedstock to deal with uncertainty in production due to seasonal availability, flood, drought, and other factors. This stock rate % is used to estimate the storage capacity (Figure 10, label 2).
3. Click on "Calculate" (Figure 10, label 3) to automatically compute the amount of maximum storage capacity required (tonnes) and the minimum safety storage (tonnes per month) for each of the pre-defined capacities (Figure 10, label 4).
4. Clicks "OK" to return to the Data Entry Needs sheet (Figure 10, label 5).
5. Repeat the same steps for all feedstock.



Collection months

Month		Storage Month
January	☐	0
February	☐	0
March	☐	0
April	☑	1
May	☐	0
June	☐	0
July	☐	0
August	☐	0
September	☑	1
October	☐	0
November	☐	0
December	☐	0

Safety storage rate

Capacity	Rate	
10 kW	30	%
40 kW	30	%
100 kW	30	%

Biomass available

cassava stalk

2500 t/year

Storage requirements

	10 kW	40 kW	100 kW
Storage capacity required (t)	88	350	875
Minimum safety feedstock to store (t/month)	5	17	42

Monthly change of biomass stored

Figure 10: Storage Calculator of Feedstock

For this example, Feedstock 1 is harvested in 2 months: April and September. As a result, the storage capacity required is 88 tonnes for a 10kW production capacity. The minimum safety feedstock to store is 5 tonnes per month. For other pre-defined capacities please see Figure 10.

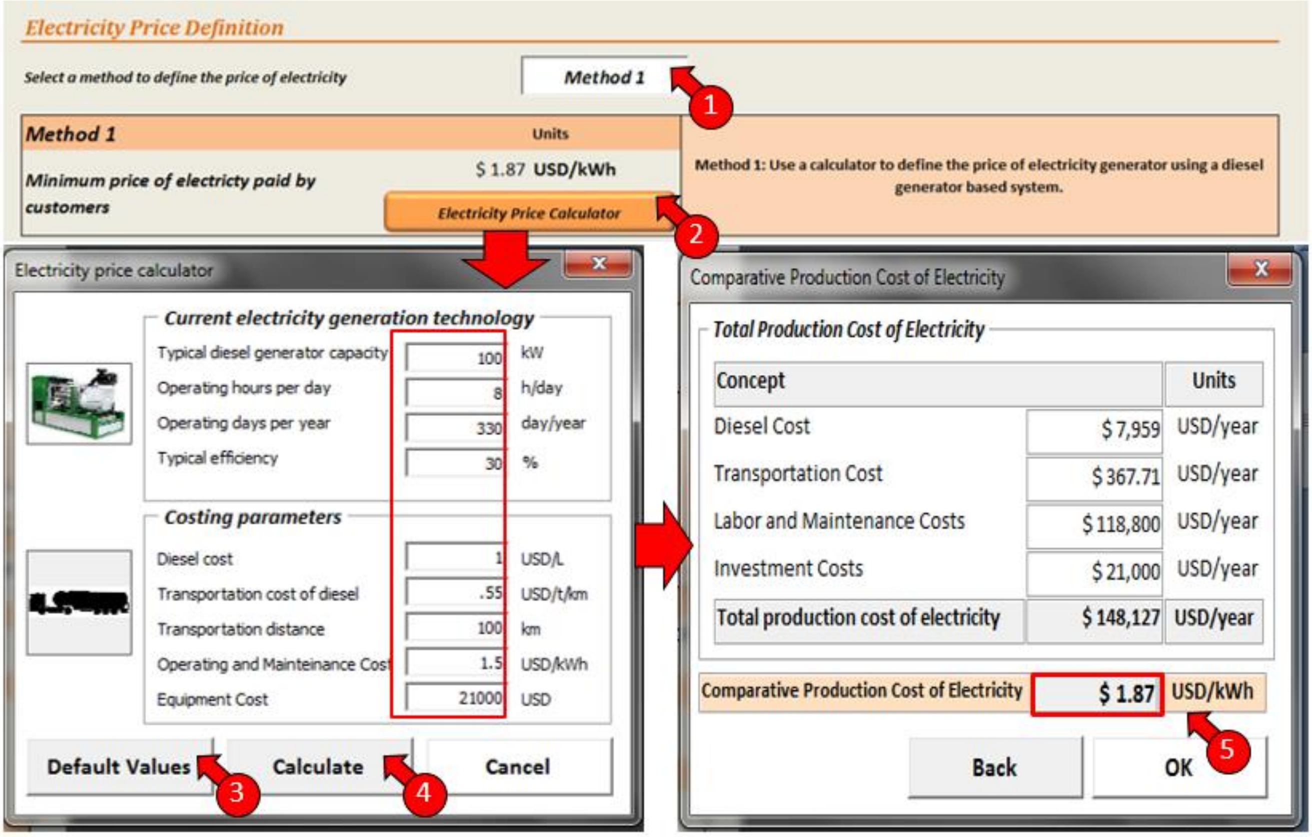
5.3 Step 3: Defining the electricity price

The electricity price is used to analyse the total revenue of power generation by the combustion plant. The user selects a method to define the price of electricity from the following options:

A. **Method 1:** Use a calculator to define the price of electricity based on a diesel generator system. To run this option the user must:

1. Select "Method 1" to define the price of electricity (
2. Figure 11, label 1).
3. Click on "Electricity Price Calculator" (
4. Figure 11, label 2).
5. Enter the following data in the "Electricity Price Calculator" (
6. Figure 11, red box). However, if specific data are unavailable, then default values are provided in the tool (
7. Figure 11, label 3).
   - Current electricity generation technology:
     - Diesel generator capacity (kW)
     - Operating hours per day
     - Operating day per year
     - Typical efficiency (%)
   - Cost parameters:
     - Diesel cost (USD/litre),
     - Transportation cost of diesel (USD/t/km)
     - Transportation distance (km),

   - Operating and maintenance cost (USD/kWh)
   - Equipment cost (USD)
8. Once all data is entered, click on “Calculate” (
9. Figure 11, label 4).
10. The comparative production cost of electricity will be generated (
11. Figure 11, label 5). This is linked to the “Data Entry Needs” worksheet and will be used for further calculation.



Electricity Price Definition

Select a method to define the price of electricity: Method 1

Method 1		Units
Minimum price of electricty paid by customers	$ 1.87	USD/kWh

Method 1: Use a calculator to define the price of electricity generator using a diesel generator based system.

Current electricity generation technology

Typical diesel generator capacity	100	kW
Operating hours per day	8	h/day
Operating days per year	330	day/year
Typical efficiency	30	%

Costing parameters

Diesel cost	1	USD/L
Transportation cost of diesel	.55	USD/t/km
Transportation distance	100	km
Operating and Mainteinance Cost	1.5	USD/kWh
Equipment Cost	21000	USD

Total Production Cost of Electricity

Concept		Units
Diesel Cost	$ 7,959	USD/year
Transportation Cost	$ 367.71	USD/year
Labor and Maintenance Costs	$ 118,800	USD/year
Investment Costs	$ 21,000	USD/year
Total production cost of electricity	$ 148,127	USD/year

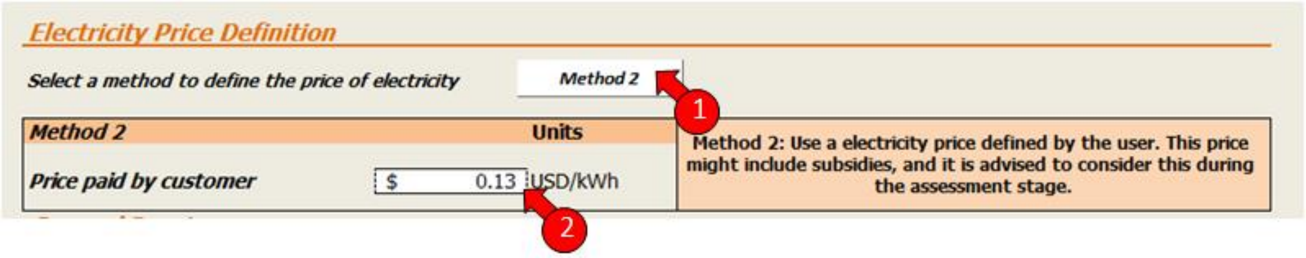
Comparative Production Cost of Electricity	$ 1.87	USD/kWh

Figure 11: Electricity Price Definition - Method 1

B. Method 2: Use an electricity price identified by the user. The user identifies a price of electricity in unit of USD/kWh. This price can be the current price from the national grid or the price of electricity that is generated from decentralized energy options, e.g. solar energy, mini-small hydro power, etc. To run this analysis, the user has to:

1. Select “Method 2” to define the price of electricity (Figure 12, label 1).
2. Enter the price of electricity paid by the customer (Figure 12, label 2).

Note: This price might include subsidies. It is advised to take this into consideration and carefully assess the likelihood that this price reflects the true price paid by rural consumers.



Electricity Price Definition

Select a method to define the price of electricity Method 2

Method 2		Units
Price paid by customer	$ 0.13	USD/kWh

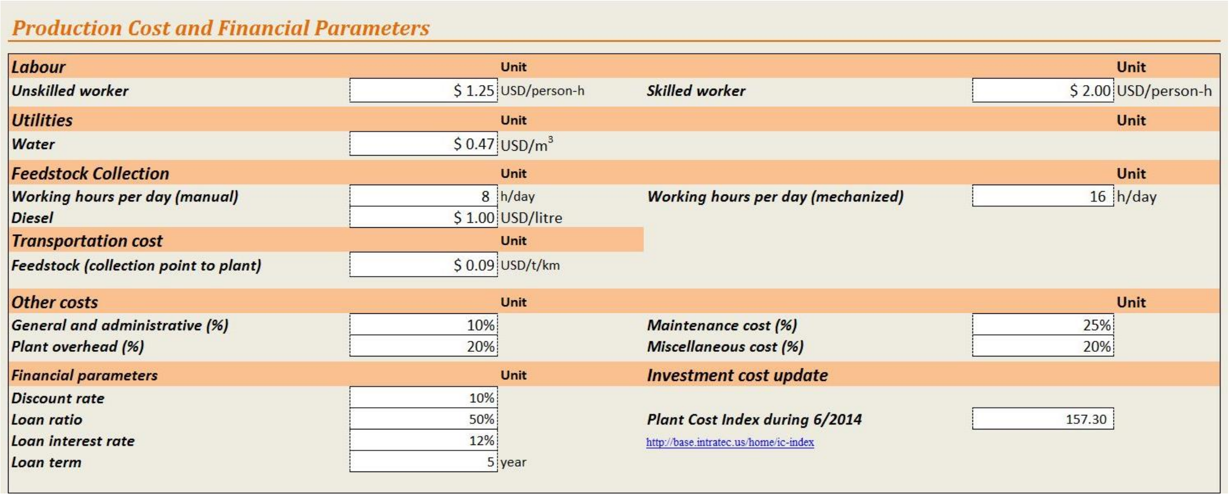
Method 2: Use a electricity price defined by the user. This price might include subsidies, and it is advised to consider this during the assessment stage.

Figure 12: Electricity Price Definition - Method 2

For this example, the user can use the minimum price of electricity paid by customers, which is 1.87 USD/kWh (result of Method 1 as shown in Figure 11) or 0.13 USD/kWh (Method 2 for defining the price paid by customer as shown in Figure 12) for further analysis.

5.4 Step 4: Production cost and financial parameters

General inputs required to run the operations are shown in Figure 13. The user will need to provide data on:



Production Cost and Financial Parameters

Labour		Unit			Unit
Unskilled worker	$ 1.25	USD/person-h	*Skilled worker*	$ 2.00	USD/person-h
Utilities		Unit			Unit
Water	$ 0.47	USD/m^3			
Feedstock Collection		Unit			Unit
Working hours per day (manual)	8	h/day	*Working hours per day (mechanized)*	16	h/day
Diesel	$ 1.00	USD/litre			
Transportation cost		Unit			
Feedstock (collection point to plant)	$ 0.09	USD/t/km			
Other costs		Unit			Unit
General and administrative (%)	10%		*Maintenance cost (%)*	25%	
Plant overhead (%)	20%		*Miscellaneous cost (%)*	20%	
Financial parameters		Unit	*Investment cost update*		
Discount rate	10%				
Loan ratio	50%		*Plant Cost Index during 6/2014*	157.30	
Loan interest rate	12%		http://base.intratec.us/home/ic-index		
Loan term	5	year			

Figure 13: General Inputs

1. **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 2.B) and the labour cost of the combustion process.
2. **Utilities cost**: the price of water (USD/m^3).
3. **Feedstock collection:** these parameters are required to calculate the feedstock price as explained in Step 2.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. **Transportation cost of feedstock (USD/t/km):** cost of transportation of feedstock from collection point to the combustion plant. The user will need to:
   - Identify the current methods of transportation to move agriculture commodities within the country.
   - Define the current transportation prices associated to the transportation method identified above in unit of USD per tonne per km.

Guidance: This can be based on unprocessed agricultural goods.

Guidance: If the method of transportation is by person or bike, then it is recommended that the user estimates 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 as given in the following equation:

$$\text{Transportation cost (USD/tonne/km)} = \frac{\text{Hourly wages (USD/hour/person)} \times \text{Working time (hours)}}{\text{Transportation distance (km)} \times \text{Feedstock transport (tonne/person)}}$$

Alternatively, the user can include this cost in the collection cost of feedstock by adding this to the number of workers in **Step 2.B** (estimate price of feedstock) and then inputting zero costs for the transportation of feedstock from the collection point to the plant.

5. **Other costs (%):** The user enters the percentage of:
    - General and administrative cost,
    - Plant overhead,
    - Maintenance cost and
    - Miscellaneous cost.

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

6. **Financial parameters**: The user identifies the values for the following financial parameters:
    - Discount rate (%),
    - Loan ratio (%),
    - Loan interest rate (%),
    - Loan term (years) and
    - Plant Cost Index.

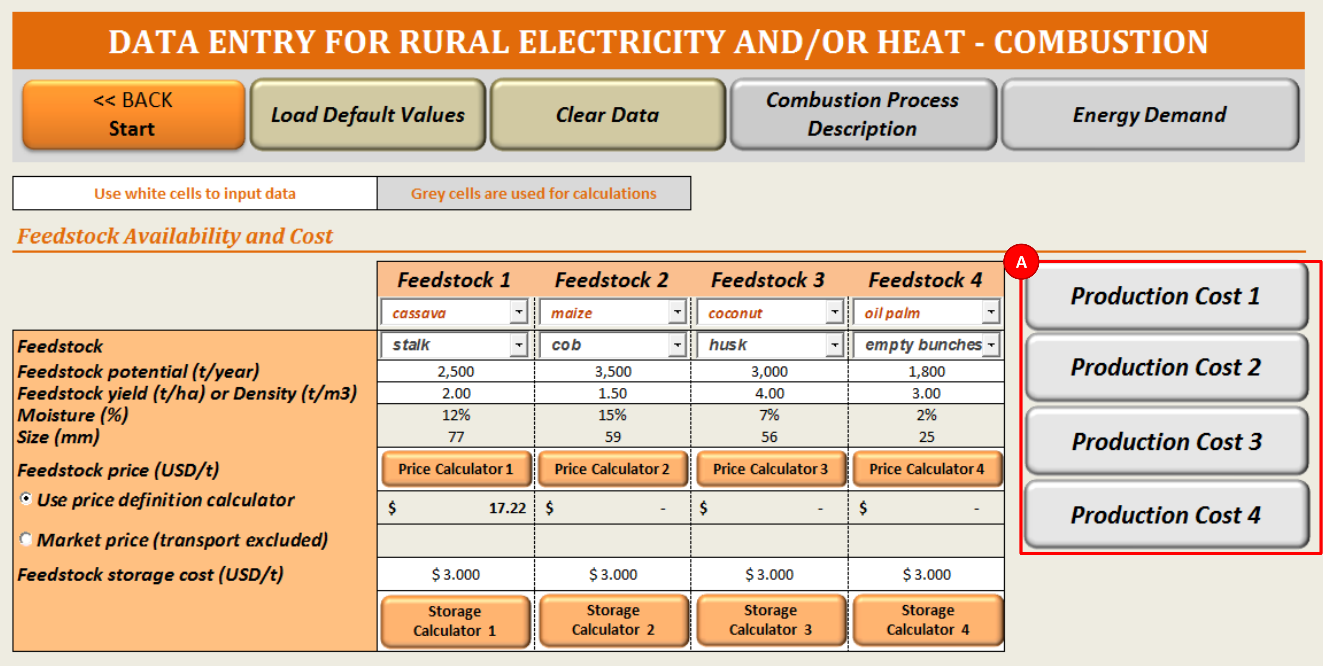
The plant cost index data for equipment cost is obtained from technical literature and based on past technical and economic conditions. Therefore, the Intratec Chemical Plant Construction Index (IC), a dimensionless index used as a proxy to update the capital cost of a chemical plant, which accounts 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 13 were used to carry out the analysis.

5.5 Step 5: Calculation of the production cost of electricity

After entering the data in Steps 1 to 4, the user can click on any of the "Production Cost" buttons (Figure 14, 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).

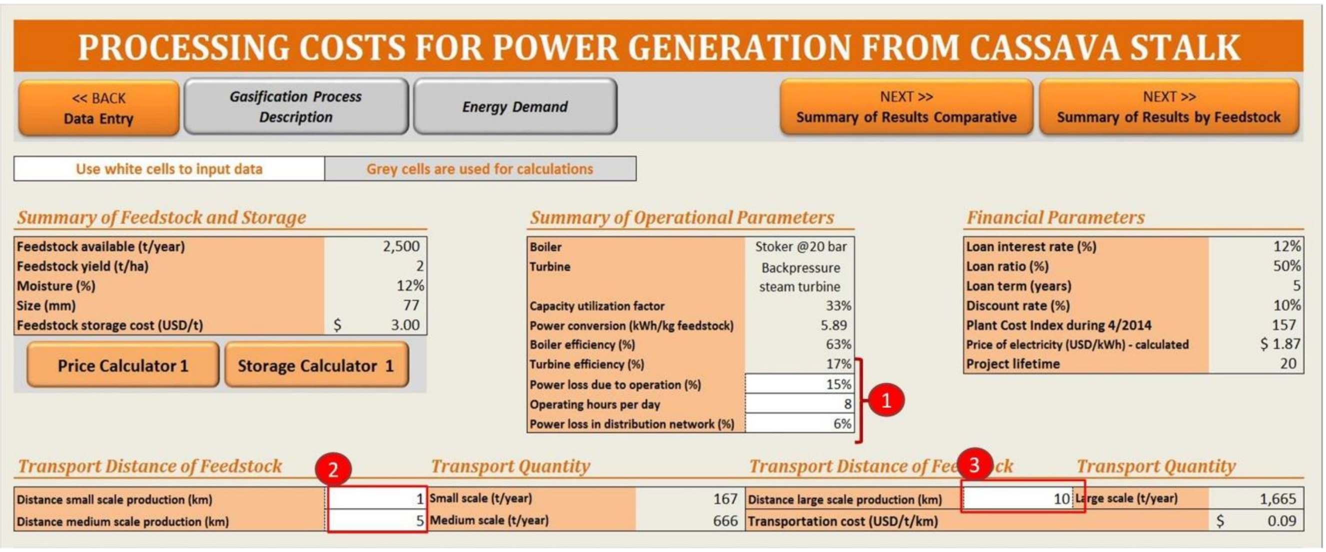


Feedstock Availability and Cost

	Feedstock 1	Feedstock 2	Feedstock 3	Feedstock 4
	cassava	maize	coconut	oil palm
Feedstock	stalk	cob	husk	empty bunches
Feedstock potential (t/year)	2,500	3,500	3,000	1,800
Feedstock yield (t/ha) or Density (t/m3)	2.00	1.50	4.00	3.00
Moisture (%)	12%	15%	7%	2%
Size (mm)	77	59	56	25
Feedstock price (USD/t)				
● Use price definition calculator	$ 17.22	$ -	$ -	$ -
○ Market price (transport excluded)				
Feedstock storage cost (USD/t)	$ 3.000	$ 3.000	$ 3.000	$ 3.000

Figure 14: Production Cost Calculation

This will take the user to the budget processing section for the selected feedstock (Figure 15).



Summary of Feedstock and Storage

Feedstock available (t/year)	2,500
Feedstock yield (t/ha)	2
Moisture (%)	12%
Size (mm)	77
Feedstock storage cost (USD/t)	$ 3.00

Summary of Operational Parameters

Boiler	Stoker @20 bar
Turbine	Backpressure steam turbine
Capacity utilization factor	33%
Power conversion (kWh/kg feedstock)	5.89
Boiler efficiency (%)	63%
Turbine efficiency (%)	17%
Power loss due to operation (%)	15%
Operating hours per day	8
Power loss in distribution network (%)	6%

Financial Parameters

Loan interest rate (%)	12%
Loan ratio (%)	50%
Loan term (years)	5
Discount rate (%)	10%
Plant Cost Index during 4/2014	157
Price of electricity (USD/kWh) - calculated	$ 1.87
Project lifetime	20

Transport Distance of Feedstock / *Transport Quantity*

Distance small scale production (km)	1	Small scale (t/year)	167
Distance medium scale production (km)	5	Medium scale (t/year)	666

Transport Distance of Feedstock / *Transport Quantity*

Distance large scale production (km)	10	Large scale (t/year)	1,665
Transportation cost (USD/t/km)			$ 0.09

Figure 15: Processing Costs for Power Generation

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

1. **Power losses due to operation (%):** losses due to inappropriate operation of the combustion-engine system. These losses are assumed to be 15%. However, a parameter can be entered directly by the user (Figure 15, label 1).

Note: These could be due to a lack of control and monitoring of units measuring gas pressure, gas composition, air leakage, or temperatures, etc. These lead to lower power outputs than the installation capacity.

2. **Operating hours per day:** The user enters the operating hours per day to run the combustion system[6]. The daily operating hours are used to compute the total annual operating hours and the capacity factor, assuming the combustion system runs 365 days per year (Figure 15, label 1).

Guidance: The operating hours should be related to electricity demand in a given rural location. For example, operate six hours per day in the evening to meet the lighting demand in rural area A.

3. **Power losses in distribution network (%):** The user identifies the power loss (%) in the distribution network. If this information is not readily available, the following database can be used: http://data.worldbank.org/indicator/EG.ELC.LOSS.ZS (The Wold Bank, n.d.) (Figure 15, label 1).

Guidance: The power loss in distribution from the current electric grid could be used as proxy.

4. **The transportation distance of feedstock to combustion 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 15, labels 2 and 3).

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.

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 feedstock.

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[6] Nouni, Mullick, & Kandpal, 2007

For this example, the "Production Cost 1" is "Cassava stalk". The values that were used to carry out the analysis are:

Power losses due to operation (%):	**15%**
Operating hours per day:	**8**
Power losses in distribution network (%):	**6%**
The transportation distance of feedstock to combustion plant:	
Distance for small scale plant:	**1 km**
Distance for medium scale plant:	**5 km**
Distance for large scale plant:	**10 km**
The transportation quantities are automatically generated:	
Small scale plant:	**167 t per year**
Medium scale plant:	**666 t per year**
Large scale plant:	**1,665 t per year**

These parameters are used for further analysis.

6 Assumptions and Limitations of the *Combustion 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 *Combustion Component* are:

1. Three combustion capacities are considered: 10kW, 40kW and 100kW.
2. 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.

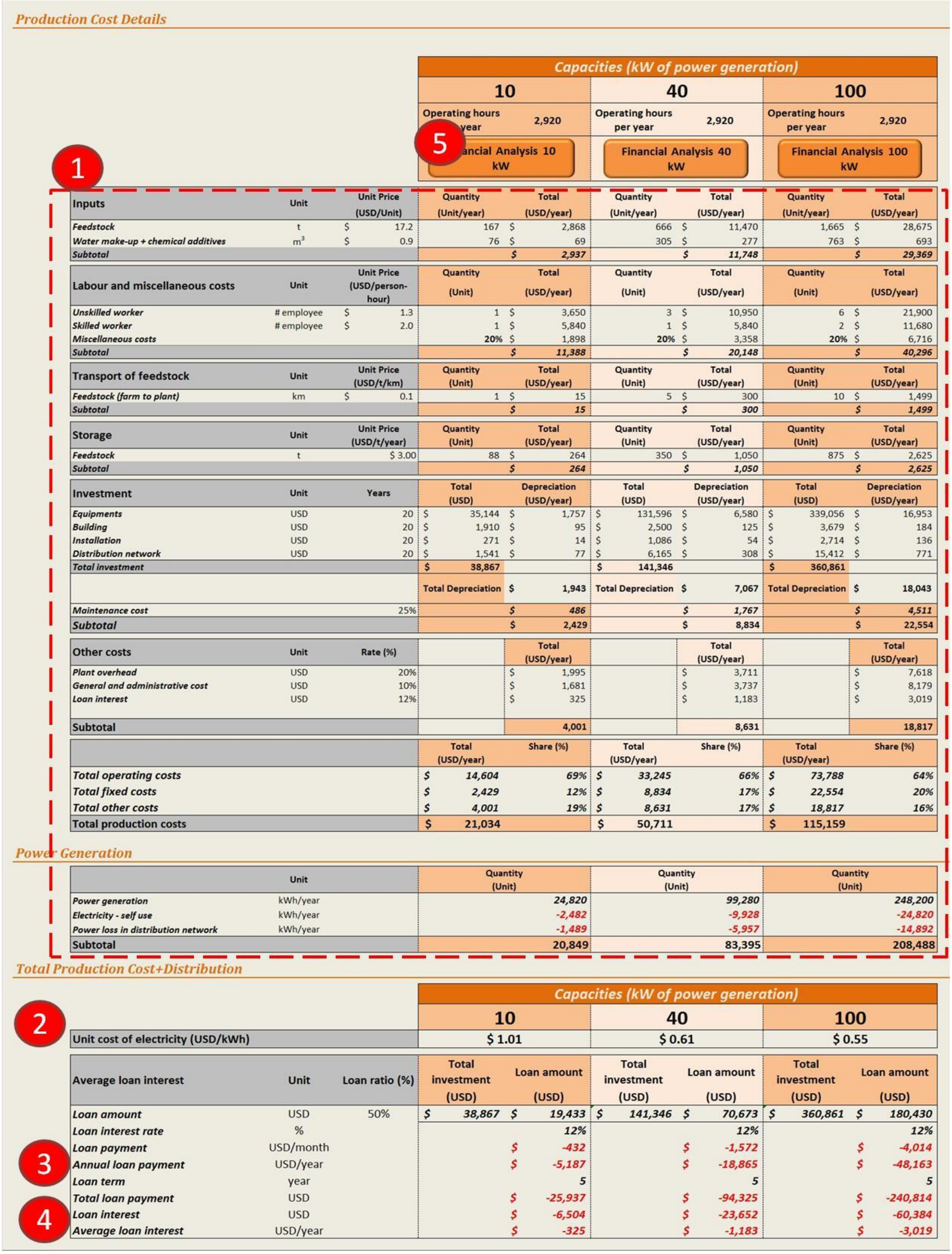
7 The Results of the *Combustion Component*

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 16. There are five main sections in this worksheet as explained below.

- **PART 1** (Figure 16, label 1) shows the distribution of production cost along the following categories: inputs, labour, transportation of feedstock, storage, investment, plant overhead, general and administrative cost, loan interest, and income tax. The total production costs (USD/year) of the three power generation capacities (10kW, 40kW and 100kW) are presented for comparative analysis.
- **PART 2** (Figure 16, label 2) shows the total power generation, which is the electricity in unit of kWh per year (note that the self-consumption, used to run the operation and power loss in transmission and distribution network, has been subtracted). These values are used to calculate the revenue of biomass combustion for the power generation system. The results are presented for all three power generation capacities.
- **PART 3** (Figure 16, label 3) shows the unit cost of electricity (USD/kWh) for all three power generation capacities.
- **PART 4** (Figure 16, label 4) summarizes the loan details, e.g. loan amount, loan interest, annual loan payment, etc., for financial analysis.

- **PART 5** (Figure 16, label 5) the “Financial Analysis” buttons will open the worksheet with the details on the financial analysis for each power generation system.



Production Cost Details

	Capacities (kW of power generation)		
	10	40	100
	Operating hours year 2,920	Operating hours per year 2,920	Operating hours per year 2,920

Inputs	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	$ 17.2	167	$ 2,868	666	$ 11,470	1,665	$ 28,675
Water make-up + chemical additives	m^3	$ 0.9	76	$ 69	305	$ 277	763	$ 693
Subtotal				*$ 2,937*		*$ 11,748*		*$ 29,369*

Labour and miscellaneous costs	Unit	Unit Price (USD/person-hour)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)
Unskilled worker	# employee	$ 1.3	1	$ 3,650	3	$ 10,950	6	$ 21,900
Skilled worker	# employee	$ 2.0	1	$ 5,840	1	$ 5,840	2	$ 11,680
Miscellaneous costs			20%	$ 1,898	20%	$ 3,358	20%	$ 6,716
Subtotal				*$ 11,388*		*$ 20,148*		*$ 40,296*

Transport of feedstock	Unit	Unit Price (USD/t/km)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)
Feedstock (farm to plant)	km	$ 0.1	1	$ 15	5	$ 300	10	$ 1,499
Subtotal				*$ 15*		*$ 300*		*$ 1,499*

Storage	Unit	Unit Price (USD/t/year)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)
Feedstock	t	$ 3.00	88	$ 264	350	$ 1,050	875	$ 2,625
Subtotal				*$ 264*		*$ 1,050*		*$ 2,625*

Investment	Unit	Years	Total (USD)	Depreciation (USD/year)	Total (USD)	Depreciation (USD/year)	Total (USD)	Depreciation (USD/year)
Equipments	USD	20	$ 35,144	$ 1,757	$ 131,596	$ 6,580	$ 339,056	$ 16,953
Building	USD	20	$ 1,910	$ 95	$ 2,500	$ 125	$ 3,679	$ 184
Installation	USD	20	$ 271	$ 14	$ 1,086	$ 54	$ 2,714	$ 136
Distribution network	USD	20	$ 1,541	$ 77	$ 6,165	$ 308	$ 15,412	$ 771
Total investment			$ 38,867		$ 141,346		$ 360,861	
			Total Depreciation	$ 1,943	Total Depreciation	$ 7,067	Total Depreciation	$ 18,043
Maintenance cost		25%		*$ 486*		*$ 1,767*		*$ 4,511*
Subtotal				$ 2,429		$ 8,834		$ 22,554

Other costs	Unit	Rate (%)		Total (USD/year)		Total (USD/year)		Total (USD/year)
Plant overhead	USD	20%		$ 1,995		$ 3,711		$ 7,618
General and administrative cost	USD	10%		$ 1,681		$ 3,737		$ 8,179
Loan interest	USD	12%		$ 325		$ 1,183		$ 3,019
Subtotal				4,001		8,631		18,817

	Total (USD/year)	Share (%)	Total (USD/year)	Share (%)	Total (USD/year)	Share (%)
Total operating costs	*$ 14,604*	*69%*	*$ 33,245*	*66%*	*$ 73,788*	*64%*
Total fixed costs	*$ 2,429*	*12%*	*$ 8,834*	*17%*	*$ 22,554*	*20%*
Total other costs	*$ 4,001*	*19%*	*$ 8,631*	*17%*	*$ 18,817*	*16%*
Total production costs	$ 21,034		$ 50,711		$ 115,159	

Power Generation

	Unit	Quantity (Unit)	Quantity (Unit)	Quantity (Unit)
Power generation	kWh/year	*24,820*	*99,280*	*248,200*
Electricity - self use	kWh/year	*-2,482*	*-9,928*	*-24,820*
Power loss in distribution network	kWh/year	*-1,489*	*-5,957*	*-14,892*
Subtotal		20,849	83,395	208,488

Total Production Cost+Distribution

	Capacities (kW of power generation)		
	10	40	100
Unit cost of electricity (USD/kWh)	$ 1.01	$ 0.61	$ 0.55

Average loan interest	Unit	Loan ratio (%)	Total investment (USD)	Loan amount (USD)	Total investment (USD)	Loan amount (USD)	Total investment (USD)	Loan amount (USD)
Loan amount	USD	50%	*$ 38,867*	*$ 19,433*	*$ 141,346*	*$ 70,673*	*$ 360,861*	*$ 180,430*
Loan interest rate	%			*12%*		*12%*		*12%*
Loan payment	USD/month			*$ -432*		*$ -1,572*		*$ -4,014*
Annual loan payment	USD/year			*$ -5,187*		*$ -18,865*		*$ -48,163*
Loan term	year			*5*		*5*		*5*
Total loan payment	USD			*$ -25,937*		*$ -94,325*		*$ -240,814*
Loan interest	USD			*$ -6,504*		*$ -23,652*		*$ -60,384*
Average loan interest	USD/year			*$ -325*		*$ -1,183*		*$ -3,019*

Figure 16: Detail of Production Costs of Electricity by Power Generation Capacity

For this example, the total production cost of electricity when using cassava stalk to run a 10kW capacity is 21,034 USD/year and the unit cost of electricity is estimated at 1.01 USD/kWh. Moreover, the total power generation is 20,849 kWh/year (Figure 16).

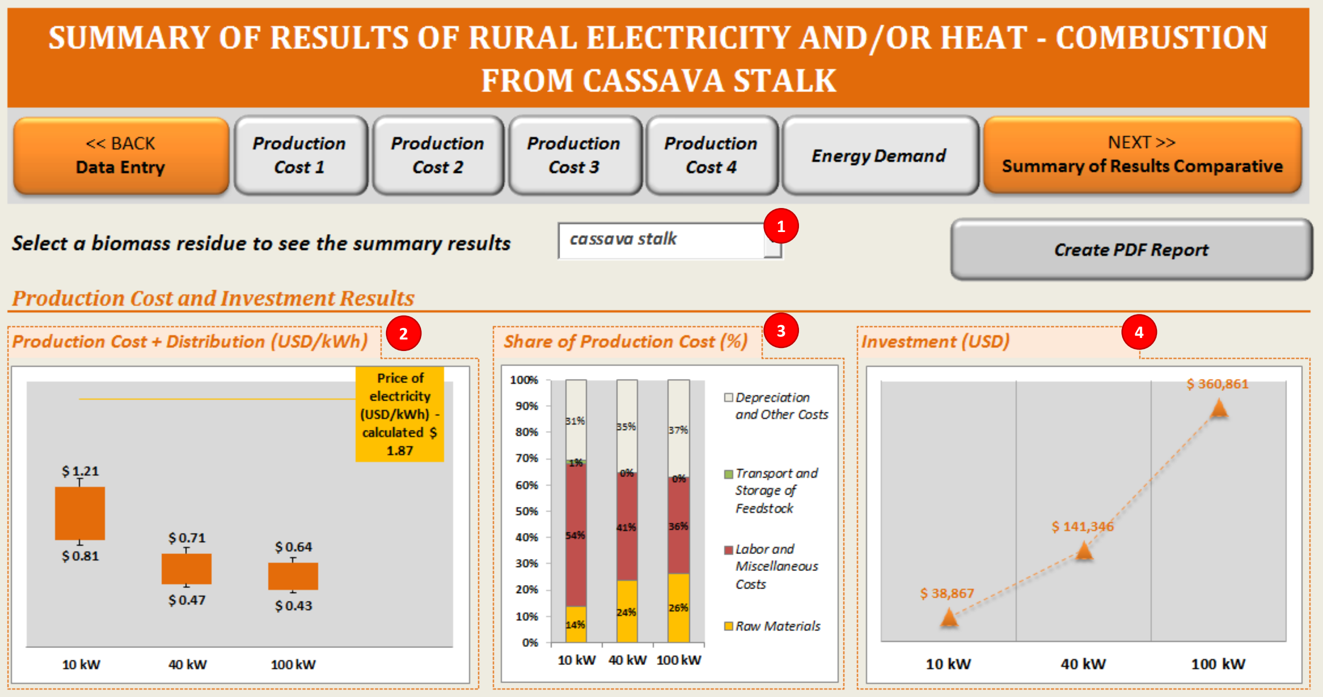
7.2 The summary results by feedstock

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

- What are the investment and production costs per kWh 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 combustion systems?
- How many potential combustion plants can be developed based on the availability of biomass?
- How many households can gain access to electricity through biomass combustion?
- How many jobs can be created through biomass combustion?
- Which type of feedstock is more suitable and could be promoted for the combustion system?
- What is the financial viability of the combustion system?

Results for the *Combustion Component* are divided along three main categories: Production Cost and Investments; Plant Operating; and Financial Analysis.

1. The user first selects the feedstock from the dropdown menu that he/she wants to review (Figure 17, label 1). The results for that specific feedstock will be generated.
2. The production cost and investments results are presented as follows:
    - Cost of production and distribution of electricity (USD per kWh) (Figure 17, label 2). The user can compare the production cost to the price of electricity (according to the method selected in Step 3).
    - Share of production cost (%) (Figure 17, label 3).
    - Total investment cost (USD) of the combustion system according to power generation capacity (Figure 17, label 4).

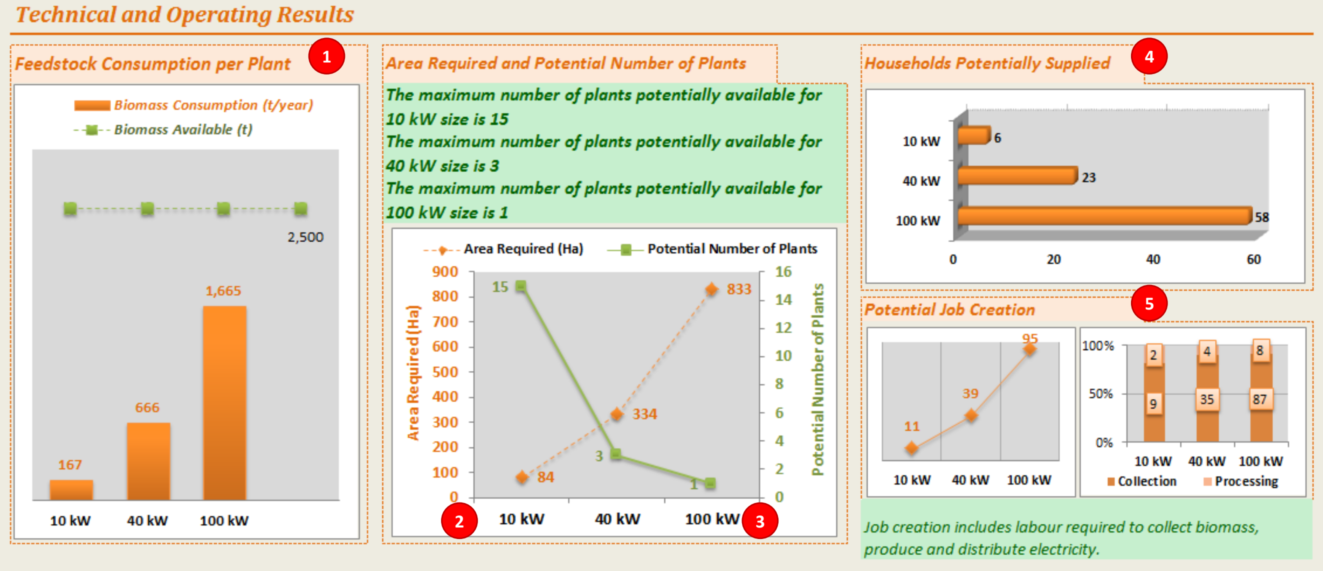


Select a biomass residue to see the summary results cassava stalk

Figure 17: Production Cost and Investment Results

For the example for cassava stalk, the production cost plus the distribution cost of 10kW ranged between 0.81-1.21 USD per kWh. These unit costs are lower than the electricity price 1.87 USD/kWh (Method 1 in Step 3 was selected). Therefore, this plant is feasible and an attractive investment, compared to the possibility of running a plant based on diesel. The total investment cost of 10kW is 38,867 USD. For other pre-defined capacities refer to Figure 17.

3. The technical and operating results are presented as follows:
    - Feedstock required to operate each of the production capacities (t per year) (Figure 18, label 1).
    - Feedstock area required to produce enough biomass to run the operation (hectare) (Figure 18, label 2).
    - Number of combustion plants that can be developed based on the availability of feedstock (Figure 18, label 3).
    - Number of households which can be supplied by the different electrification systems (Figure 18, label 4).
    - Total number of jobs that can be created through the implementation of each of the pre-defined combustion systems (Figure 18, label 5).



The maximum number of plants potentially available for 10 kW size is 15
The maximum number of plants potentially available for 40 kW size is 3
The maximum number of plants potentially available for 100 kW size is 1

Job creation includes labour required to collect biomass, produce and distribute electricity.

Figure 18: Operating Results

In the example of cassava stalk, the feedstock available is 2,500 t per year, which is sufficient to supply the feedstock needed for the three production capacities.
Considering the feedstock availability, 15 potential plants of 10kW capacity, which require 84 hectares of area of feedstock, can be developed. Up to 6 households could be supplied electricity from the 10kW plant. In addition, the potential job creation from the combustion plant with a 10kW capacity is a total of 11 jobs for the collection of feedstock and plant processing.
For other pre-defined capacities, refer to Figure 18.

4. The financial analysis (before tax return) results are presented as follows:
    - Net Present Value (NPV) (Figure 19, label 1)
    - Internal Rate of Return (IRR) (Figure 19, label 2)

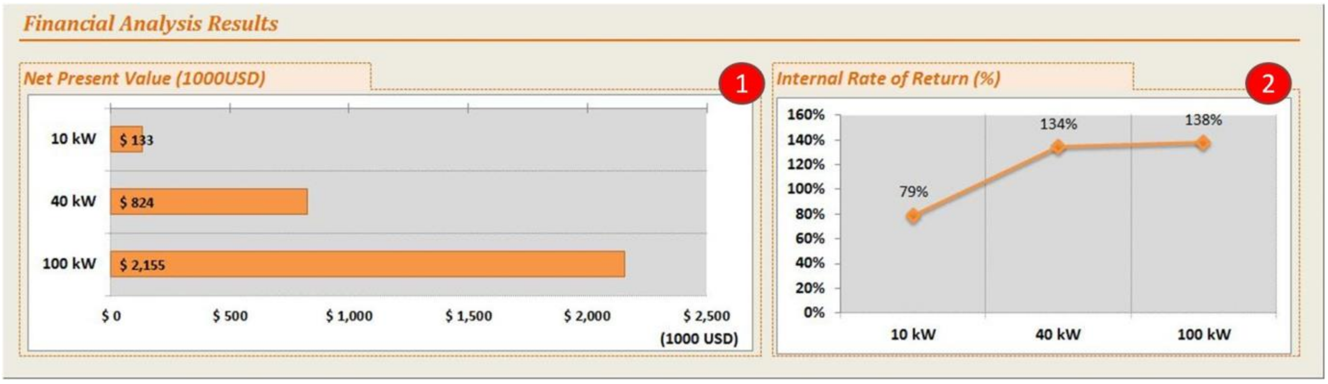


Figure 19: Financial Analysis Results

For the cassava stalk example, the net present value (NPV) and internal rate of return (IRR) for all plant capacities are positive as shown in Figure 19.

It can be concluded that cassava stalk is feasible for power generation at all plant capacities.

The user can save and print the results in PDF format by using “Create a PDF report” and following the instructions (Figure 17, label A).

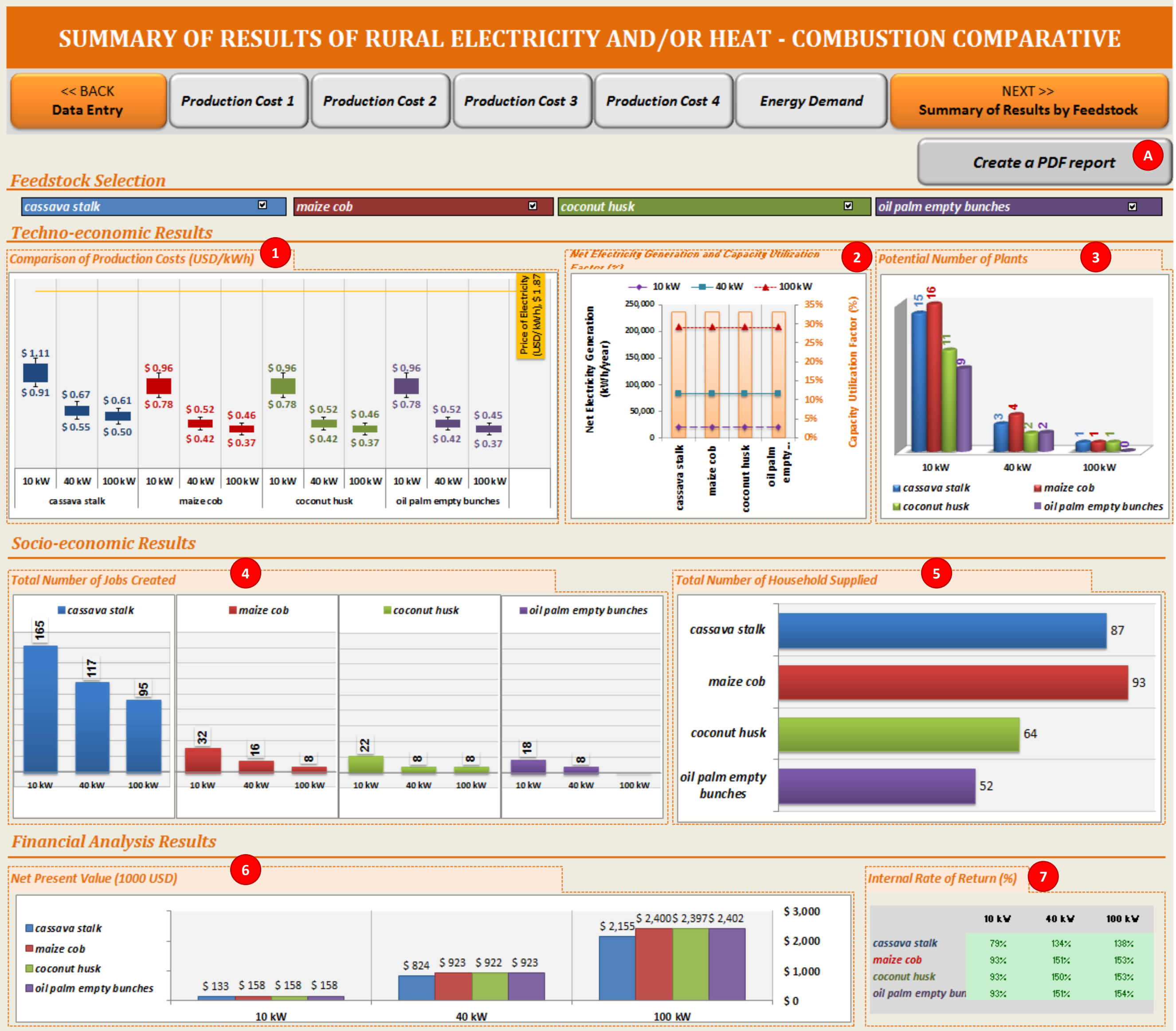
7.3 The summary of comparative results

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 feedstock, by clicking on it, that he/she wants to review. The results for that specific feedstock will be generated.
2. Comparison results are presented on:
    - Production costs according to feedstock (USD/kWh) (Figure 20, label 1)
    - Net electricity generation and the utilization capacity factor of the plant by feedstock (Figure 20, label 2)
    - Potential number of combustion plants which can be developed according to each feedstock (Figure 20, label 3)
    - Total number of jobs that can be created (Figure 20, label 4)
    - Total number of households that can be supplied (Figure 20, label 5)
    - Comparison of NPV (before taxes) across the selected feedstock options (Figure 20, label 6)
    - Comparison IRR (before taxes) across the selected feedstock options (Figure 20, label 7)

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 20, label A).



	10 kW	40 kW	100 kW
cassava stalk	79%	134%	138%
maize cob	93%	151%	153%
coconut husk	93%	150%	153%
oil palm empty bun	93%	151%	154%

Figure 20: Layout of Comparative Results

For this example, the production cost of electricity when using oil palm shell as feedstock is the lowest compared to the other feedstock for all plant capacities. Cassava stalk and maize cob have the highest production cost. Notably, all of the feedstock provide positive NPV and IRR as shown in Figure 20. From this analysis, the user can conclude that:

1. Cassava stalk, maize cob, coconut husk and oil palm shell are feasible options and are available for power generation at all capacities.
2. Given the feedstock availability, a large number of plants based on maize cob can be created, impacting positively on the number of households supplied in the country.
3. From a job generation perspective, cassava stalk is the best option.
4. Oil palm shell is feasible and available for power generation at 10kW or 40kW, but not sufficient for 100kW capacity.

8 Annex

8.1 Methodology and outputs

This section describes the methodologies integrated in the *Combustion 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 2.

Table 2: Inputs Cost Equations

Item	Equation and Assumption	Remark
Steam Production	ST = PG x 3,600/TE*(LW+SW)/OP Where: PG is Power generation rate (kWh) TE is Turbine Efficiency LW is Enthalpy of Vaporization of Water (MJ/kg) at 10 Bar SW is Enthalpy Change of Water (MJ/kg) from 1 Bar to 10 Bar OP is Operating hours period (hours per year)	Default value of OP is 2920 hours per year Default value of TE is assumed to be 17%
Quantity of feedstock	QF = HB x ST x 10 / [BE x PC x (1-Power losses due to operation)*3.6E6] Where: QF is Quantity of feedstock (tonne per year) HB is Combustion Heat in Boiler (MJ/kg) BE is Boiler Efficiency PG is Power generation (kWh per year) PC is Power conversion potential (kWh per kg of feedstock)	PC is varied depending on the type of feedstock A power loss due to operation is assumed at 15% Default value of HB is assumed as 63%.
Water Make-up	WM = MR x ST X OP/1000 Where: WM is Water Make-Up (m^3 per year) MR is Make-up rate (%) OP is Operating hours period (hours per year)	Default value of MR is assumed as 35%.
Total Inputs cost	TIC = (QF x Cf) + (WM x Cw) + (DC x Cd) Where: TIC is Total Inputs cost (USD per year) QF is Quantity of feedstock (tonne per year) WM is Water Make-up(m^3 per year) DC is Diesel consumption (litres per year) Cf is unit cost of feedstock (USD per tonne) Cw is unit cost of water (USD per m3) Cd is unit cost of diesel (USD per litre)	Cost of oxygen as gasifier agent and steam is not considered in this tool.
Power generation (PG) (kWh per year)	Power capacity (kW) x Operating hours per year Where, Operating hours per year= Operating hours per day x 365 days per year	Operating hours per year entered by the user.

To calculate the biomass consumption as feedstock

The quantity of feedstock is calculated based on the power generation in kWh per year and the power conversion of biomass to electricity through combustion system.

$$\text{Steam Production}\left(\frac{t}{\text{year}}\right)=\frac{\text{Power Generation Rate (kWh) x3600 }(\frac{\text{MJ}}{\text{kWh}})}{\text{Turbine Efficiency (\%) x }(\Delta Hvap+\Delta Hliq)\text{ x Operating hours}\left(\frac{\text{h}}{\text{year}}\right)}$$

Therefore, biomass consumption (kg/year) is calculated by

$$=\frac{\Delta\text{Hboiler x Steam Production}\left(\frac{\text{t}}{\text{year}}\right)\text{ x 10}}{\text{Boiler Efficiency (\%) x Power Conversion Potential}\left(\frac{\text{kWh}}{\text{kg biomass}}\right)\text{ x }(1-\text{Power lossses (\%)})}$$

However, to calculate the biomass consumption (kg/year) based on the actual power generation has to take “the power losses due to operation” into consideration. These losses are due to inappropriate operation of the combustion-engine system. These include lack of control and monitoring of units measuring gas pressure, gas composition, air leakage, or temperatures etc. Therefore, these causes lead to lower power output than the installation capacity. These losses are assumed to be 15%.

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 3.

Table 3: Labour and Miscellaneous Cost Equations

Item	Equation and Assumption	Remark
Number of unskilled labour	10kWcapacity is 1 person 40kWcapacity is 3 person 100kWcapacity is 6 person	[7] (Dasappa, Subbukrishna, Suresh, Paul, & Prabhu, 2011)
Number of skilled labour	10kWcapacity is 1 person 40kWcapacity is 1 person 100kWcapacity is 2 person	(Dasappa et al., 2011)
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 4.

Table 4: 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 5 presents the calculating equations for estimating the storage cost.

Table 5: Storage Cost Equations

Item	Equation and Assumption	Remark
Storage Capacity (tonne/year)	The estimate storage capacity in "Storage Calculator#" worksheet by pressing on the "Storage Calculator"	
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 6 presents the equations and assumptions applied to calculate the fixed cost and the depreciation cost.

Table 6: Fixed Cost Equations

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. The cost consists of Biomass pretreatment processes, Combustion system, Back-Pressure Turbine, and Generator. EC at current period = EC (base year) x [Plant Cost Index (current period) / Plant Cost Index (base year)]	(U.S. Department of Energy, 2012a - 2012j) 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)]	(U.S. Department of Energy, 2012a - 2012j) 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, 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)]	(Nouni et al., 2007) (Buchholz et al., n.d.) Plant cost index (current period) input by the user
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	(Bouffaron et al., 2012) (Wiskerke et al., 2010)
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 7 shows the equations for calculating the cost associated with plant overhead, general and administrative cost, average loan interest payment and corporate tax.

Table 7: 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 8 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 8: 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.

8.1.8 Project revenue calculation

Table 9 presents the equations for calculating the potential revenue of combustion system.

Table 9: Potential Revenue Equations

Item	Equation and Assumption	Remark
Potential revenue (USD per year)	[Power generation - Electricity self-use - Power loss in distribution network]x Price of electricity Where, Power loss in distribution network (%) x Power generation	Power generation same as in Table 3. Electricity self-use (kWh per year) assumed 10% of power generation. Power loss distribution entered by the user in Step 4.
Price of electricity (USD/kWh)	The user selects option: Method 1 or Method 2 to define the price of electricity paid by customer	Input data by the user in “Data Entry Needs”.

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).
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.
Feedstock safety stock rate (%)	The user defines this value by entering it in each biomass storage calculator. This value defines the percentage of biomass that should be reserved to operate the plant during shortage periods.

Data	**Definition and Sources**
The user selects the option to identify the price of electricity paid by customer (USD/kWh).	The price of electricity can be the price for the national grid or the price of electricity that is generated by other energy resources, e.g. diesel generator, solar energy, hydro power, natural gas, etc. To estimate the price of electricity by using a diesel generator, the user inputs the capacity of the diesel generator (kW), operating hour per day, operating day per year, transportation cost and transportation distance of diesel including labour and maintenance cost in the "Electricity price calculator".
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 combustion 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.
The transportation distance of feedstock to combustion plant in kilometres by power generation capacity	Transportation distance is determined based on the availability of biomass in a particular area in relation to the amount required to operate each of the power generation capacities.
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.
Power loss in distribution network (%)	This information can be the current loss in the national electric grid. Alternatively, a link is provided to a World Bank global database compiling national distribution losses. Please visit: http://data.worldbank.org/indicator/EG.ELC.LOSS.ZS

Data	**Definition and Sources**
Power loss due to operation (%)	The user estimates the losses due to operation. These losses are due to inappropriate operation of the combustion-engine system. These include lack of control and monitoring of units measuring gas pressure, gas composition, air leakage, or temperatures, etc.
Gas engine efficiency (%)	This parameter is provided by gas engine manufacturer.
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.

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