BIOENERGY AND FOOD SECURITY
RAPID APPRAISAL (BEFS RA)

User Manual

CHP (Cogeneration)

BEFS Rapid Appraisal

Energy End Use Options Module

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Heat and Power Sub-Module

Section 1: CHP (Cogeneration)

User Manual

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II. Country Status Module

III. Natural Resources Module

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    - Section 1: Crop Production Tool
    - Section 2: Crop Budget Tool
2. Agricultural Residues
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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.

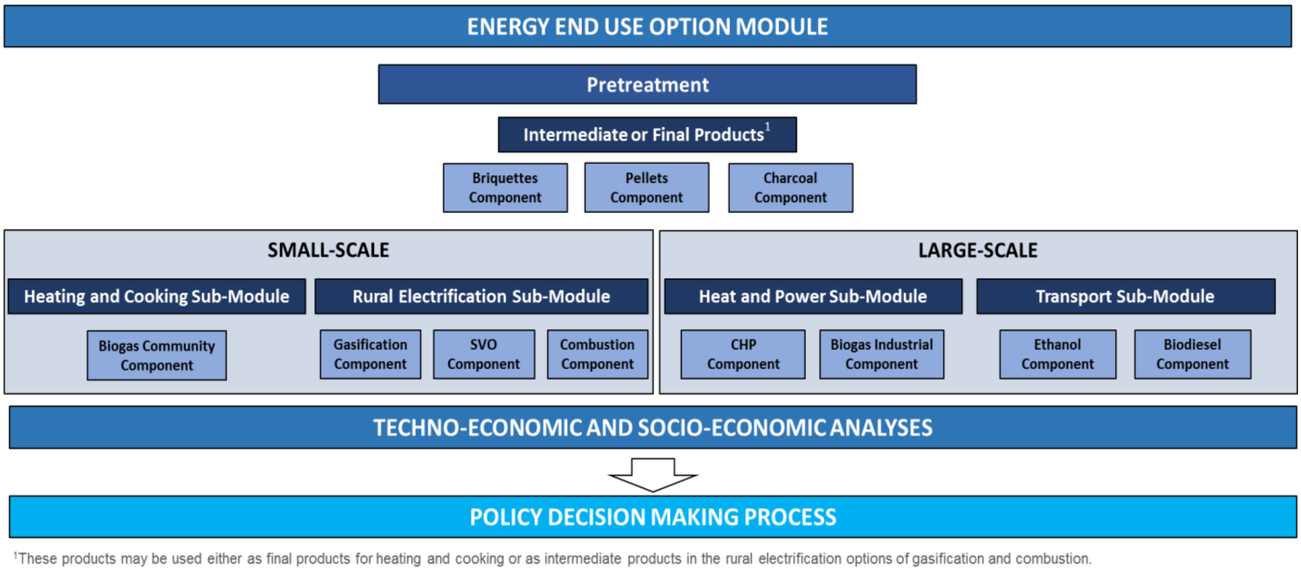


Figure 1: The Structure of the Energy End Use Option Module

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 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 *Cogeneration Component*

The *Cogeneration Component* is designed to assist the user in evaluating the potential to develop biomass cogeneration to supply electricity and/or heat at the industrial level. The boundary of the cogeneration 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.

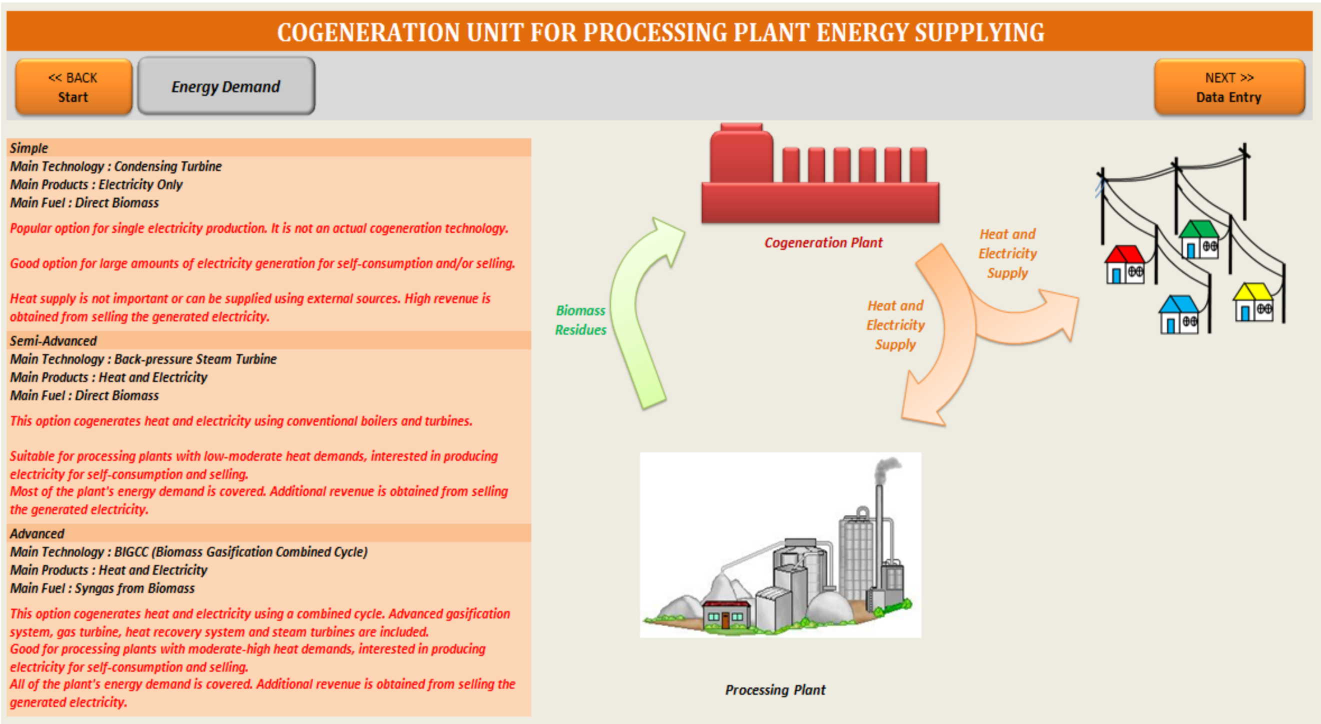
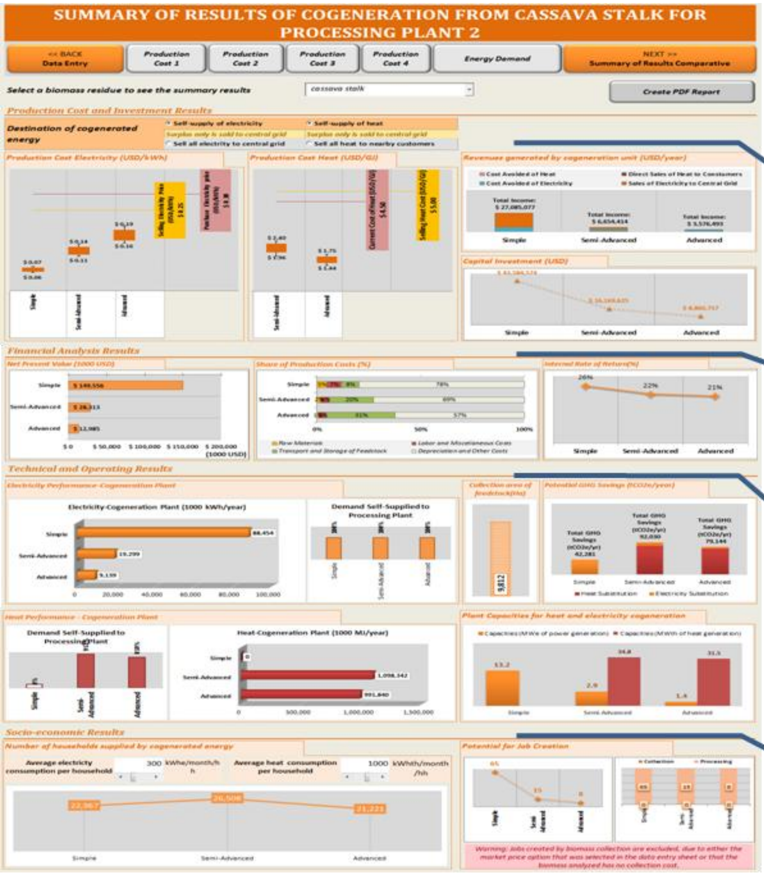


Figure 2: Biomass Cogeneration System for Heat and Power at the Industrial Level

After completing the analysis, the user will have an indication on: 1) the biomass consumption and area required to set up the various technologies of biomass cogeneration plants; 2) the potential number of biomass sustainable cogeneration plants that can be developed in the country; 3) the investment cost and production cost per kWh and MJ for each technology; 4) the number of households that could be supplied with electricity; and 5) the employment generation potential and financial viability associated to each technology as shown in Figure 3. The user will also be able to compare across different biomass types (feedstock) and cogeneration technologies 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.



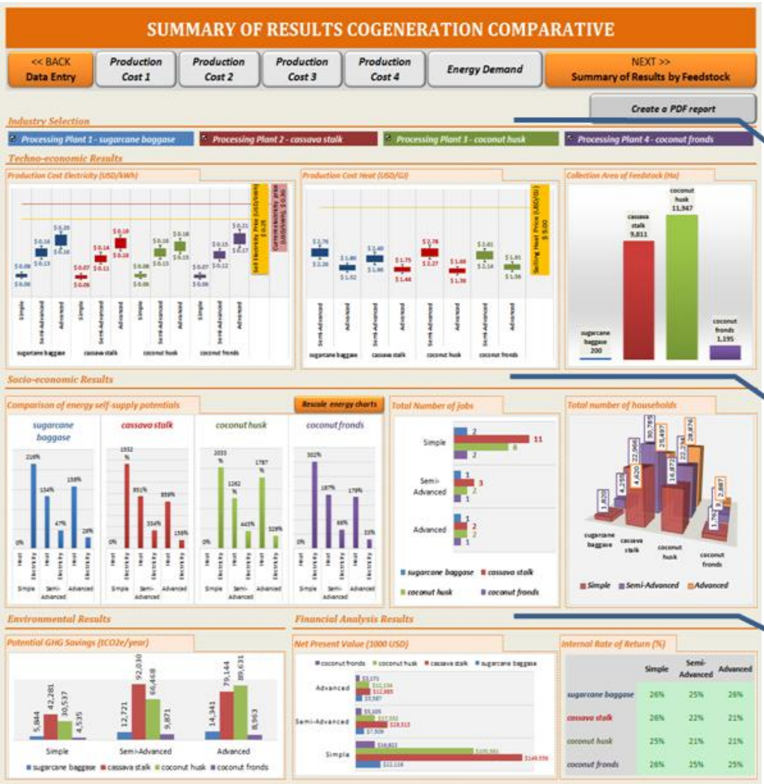
General Outputs by Feedstock

Production Costs and Investment Results: Cost of production of electricity, Cost of production of heat, Revenues generated , Capital investment

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

Operating Results: Electricity and heat performance, Demand of heat and electricity self-supplied to processing plant, Collection area of feedstock, Potential GHG savings, Plant capacities for CHP

Socio-economic Results: Net Present Value (NPV) and Internal Rate of Return (IRR)



Comparative Outputs by Capacity

Techno-Economic Results: Production cost of electricity, Production cost of heat, Collection area of feedstock

Socio-Economic Results: Energy self-supply potentials, Total number of jobs created, Total number of households supplied

Environmental Results & Financial Analysis-Before Taxes: Potential GHG savings, Net Present Value (NPV) and Internal Rate of Return (IRR)

Figure 3: Layout of the Cogeneration Results Sheets

3 Terms and Definitions Used in the *Cogeneration Component*

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

- **Condensing turbine** is a type of steam turbine where the steam is condensed below atmospheric pressure so as to gain the maximum amount of energy from it. In condensing turbines, substantial quantities of cooling water are required to carry away the heat released during condensation. Condensing turbines can condense at pressures of 90 to 100 kilopascals (13 to 14.5 pounds per square inch) below atmospheric pressure.
- **Back-pressure steam turbine (BST)** can be counted among the most employed systems for bioelectricity production. Biomass is first dried and then burned on a grate or furnace, fixed, moving, or fluidized. In the combustion chamber, biomass exothermically reacts with excess air, leading to high reaction rates and high released heat. From an energy generation point of view this reaction allows for the conversion of the chemical energy stored in biomass into usable energy, which is used to generate high pressure steam. This steam passes through a turbine connected to a generator, producing electricity and low pressure steam (see Figure 2). Steam can be used to satisfy part of the heating requirements of the facility (U.S. Department of Energy 2004).
- **Biomass Integrated Gasification Combined Cycle Technology (BIGCC):** Basic elements of BIGCC system include biomass dryer, gasification chamber, gas turbine and heat steam recovery generator (HRSG). Gasification is a thermo-chemical conversion technology of carbonaceous materials (coal, petroleum coke and biomass), to produce a mixture of gaseous products (CO, CO_2, H_2O, H_2, CH_4) known as syngas added to small amounts of char and ash. Gasification temperatures range between 875-1275 K (Ahmed and Gupta 2011). The gas properties and composition of syngas changes according to the gasifying agent used (air, steam, steam-oxygen, oxygen-enriched air), gasification process and biomass properties (Ahmed and Gupta 2011). Syngas is useful for a broader range of applications, including direct burning to produce heat and power or high quality fuels production or chemical products such as methanol (Rincón, Hernandez, and Cardona 2014; Quintero, Rincón, and Cardona 2011). A gas turbine is a rotator engine that extracts energy from a flow combustion gas. It is able to produce power with an acceptable electrical efficiency, low emission and high reliability. The gas turbine is composed by three main sections: compression (air pressure is increased, aimed to improve combustion efficiency), combustion (adiabatic reaction of air and fuel to convert chemical energy to heat) and expansion (obtained pressurized hot gas at high speed passing through a turbine generating mechanical work) (Rincón, Hernandez, and Cardona 2014; Quintero, Rincón, and Cardona 2011). The HRSG is a high efficiency steam boiler that uses hot gases from a gas turbine or engine to generate steam, in a thermodynamic Rankine Cycle. This system is able to generate steam at different pressure levels. According to process requirements a HSRG system can use single, double or even triple pressure levels.
- **Steam** is technical name for vaporized water. Steam has different applications as a means for energy transportation. Steam has the following advantages: low toxicity, ease of transportability, high efficiency, high heat capacity, and relatively low costs. 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).

4 Scope and Objective of the *Cogeneration Component*

The aim of the *Cogeneration Component* is to assess the feasibility to develop biomass cogeneration systems to supply electricity and/or heat at the industrial level. It provides the user with a technical foundation to perform an analysis of biomass cogeneration systems for the production of electricity and steam for three technologies: simple, semi-advanced and advanced from an assortment of biomass sources. The results of the analysis can be used to identify the viability of electricity and heat production from cogeneration 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 cogeneration systems at the industrial level.

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

Figure 4: Rapid Appraisal Tool Electricity and/or Heat

5 Running the *Cogeneration Component*

The flow of analysis within the *Cogeneration Component* and the inter-linkages with the 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 *Cogeneration Component* relies on the information generated in the *Natural Resources* module and information can be cross-reference 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.

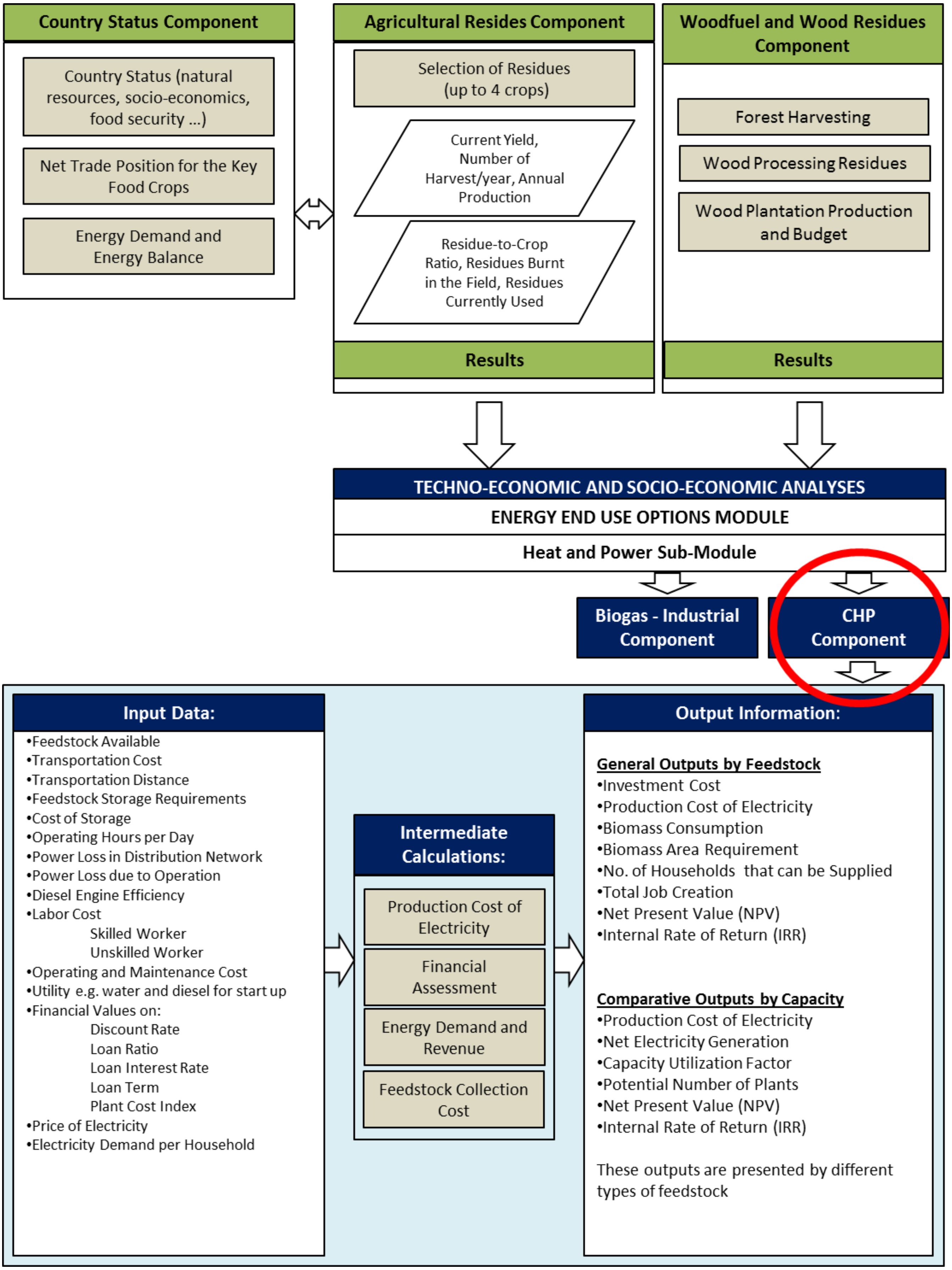


Figure 5: *Cogeneration Component*: Flow of Analysis and Inter-linkages with BEFS RA Modules and Components

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 cogeneration system to generate electricity and heat for food processing industries interested on self-supplying of energy and/or selling to central grid. All input parameters are based on a generic situation.

5.1 Step 1: Energy Demand

Depending whether the cogeneration system is connected to a processing plant (attached production) or is stand-alone, the user may or may not need to define the industrial energy demand.

In this tool, stand-alone refers to a cogeneration plant that produces energy to sell to clients. Therefore, the user does not need to define the industrial energy demand, as the plant is not consuming heat or electricity (Figure 6).

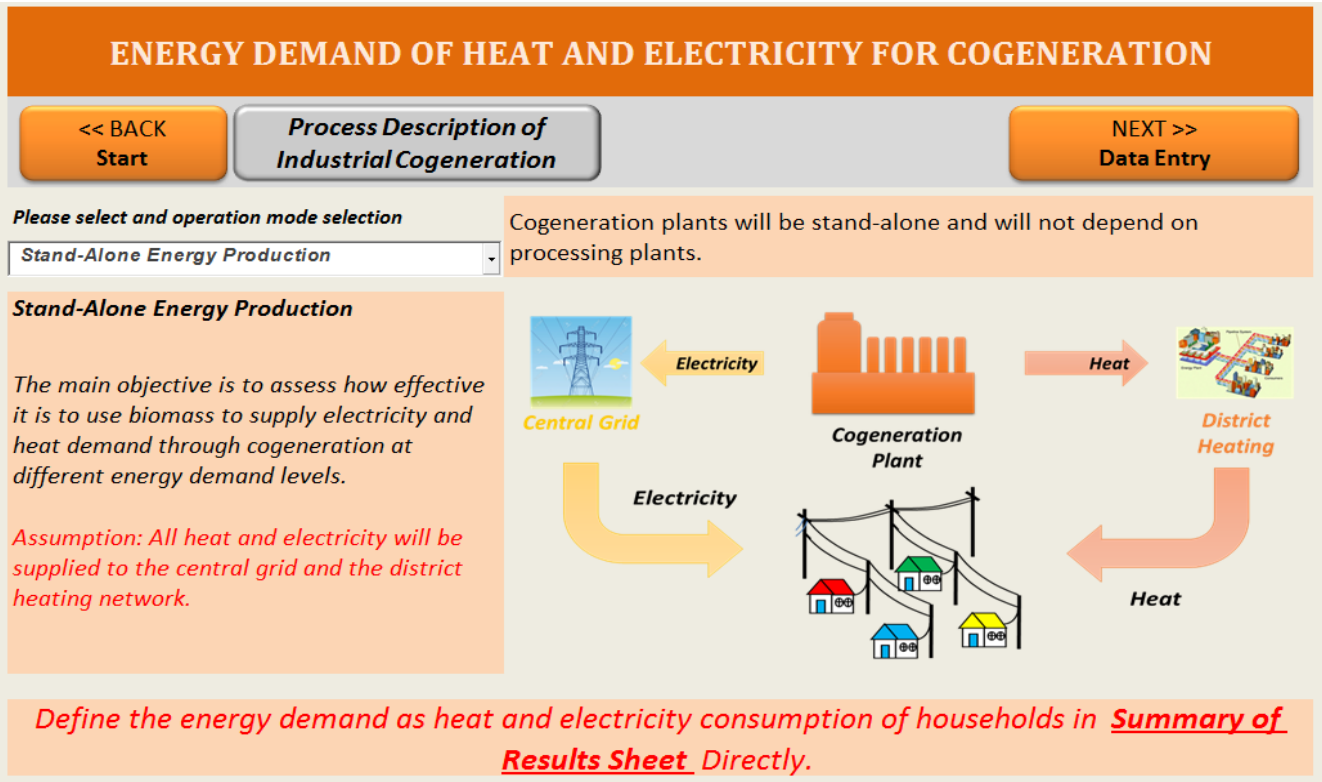


Figure 6: Stand-Alone Energy Production

For the case of a cogeneration system that is connected to a processing plant (attached production), the electricity and heating consumption at the industrial level must be defined, as this type of plant supplies energy for the industry first with any excess then being sold to clients (Figure 7).

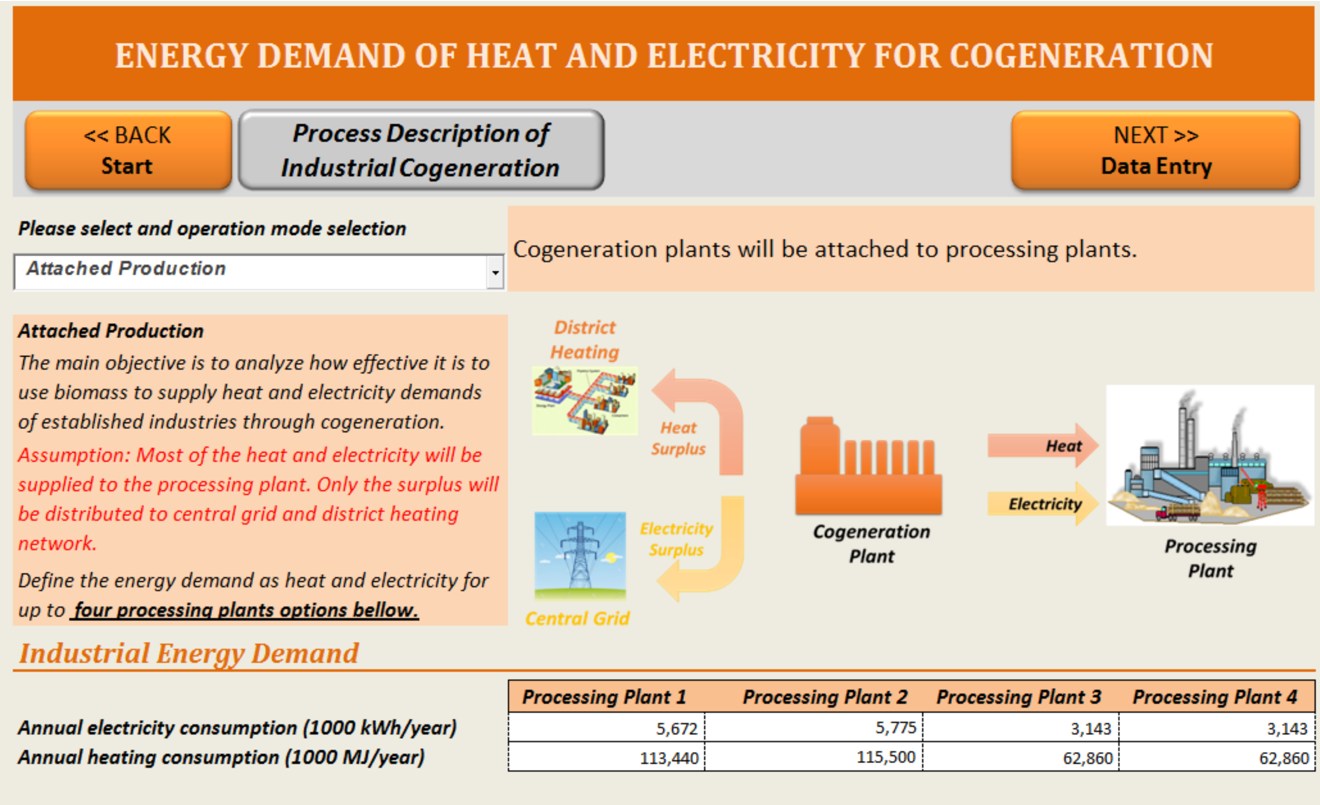


Figure 7: Attached Production - Energy Demand

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 "Load Default Values" button as shown in Figure 8, label A.

Step 2.A Selection of the feedstock

The user will:

1. Select the crop(s) and the residue(s) from the dropdown menu associated with each processing plant. The list includes 15 key food/cash crops, 2 types of wood processing residues and briquettes/pellets (Figure 8, label 1). Up to four crop residues can be analysed at the same time.

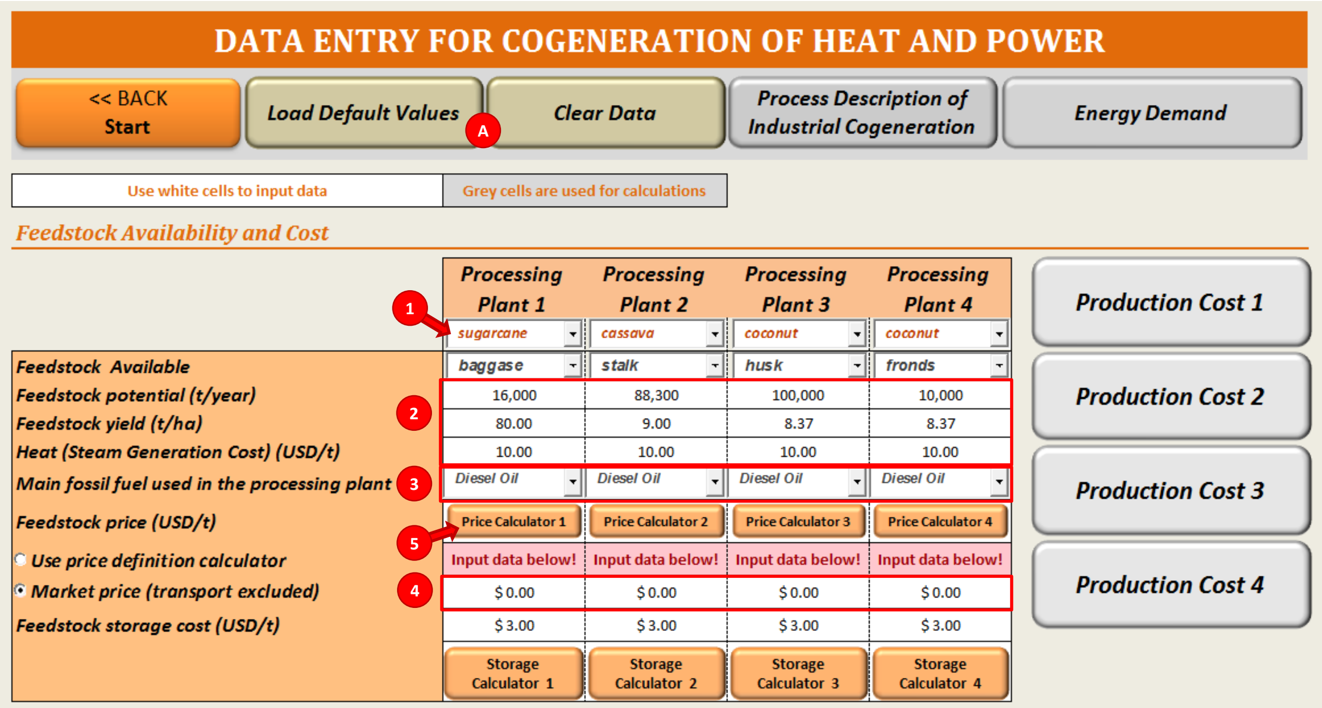


Figure 8: Feedstock Selection

2. Enter data on feedstock available (t/year) and yield (t/ha) of the selected crop residues (Figure 8, label 2). *This information is generated in the Natural Resources module*.
3. Enter data on the heat cost (USD/t) of the selected crop residues (Figure 8, label 2).
4. Select the current fuel used in boilers for each selected feedstock (Figure 8, label 3).

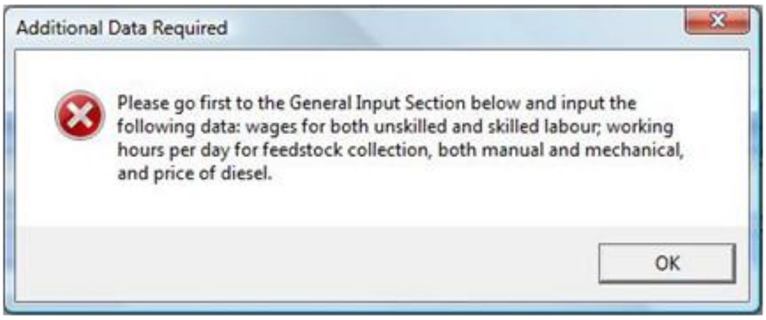
For this example the following were selected: Feedstock 1 "Sugarcane bagasse", Feedstock 2 "Cassava stalk", Feedstock 3 "Coconut husk", and Feedstock 4 "Coconut fronds" (Figure 8).

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 8, 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 price by clicking on the "Use Price Definition Calculator" and selecting the "Price Calculator" (Figure 8, label 5).



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 "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 9) assists the user in estimating the potential feedstock price based on the source and collection method of the feedstock.

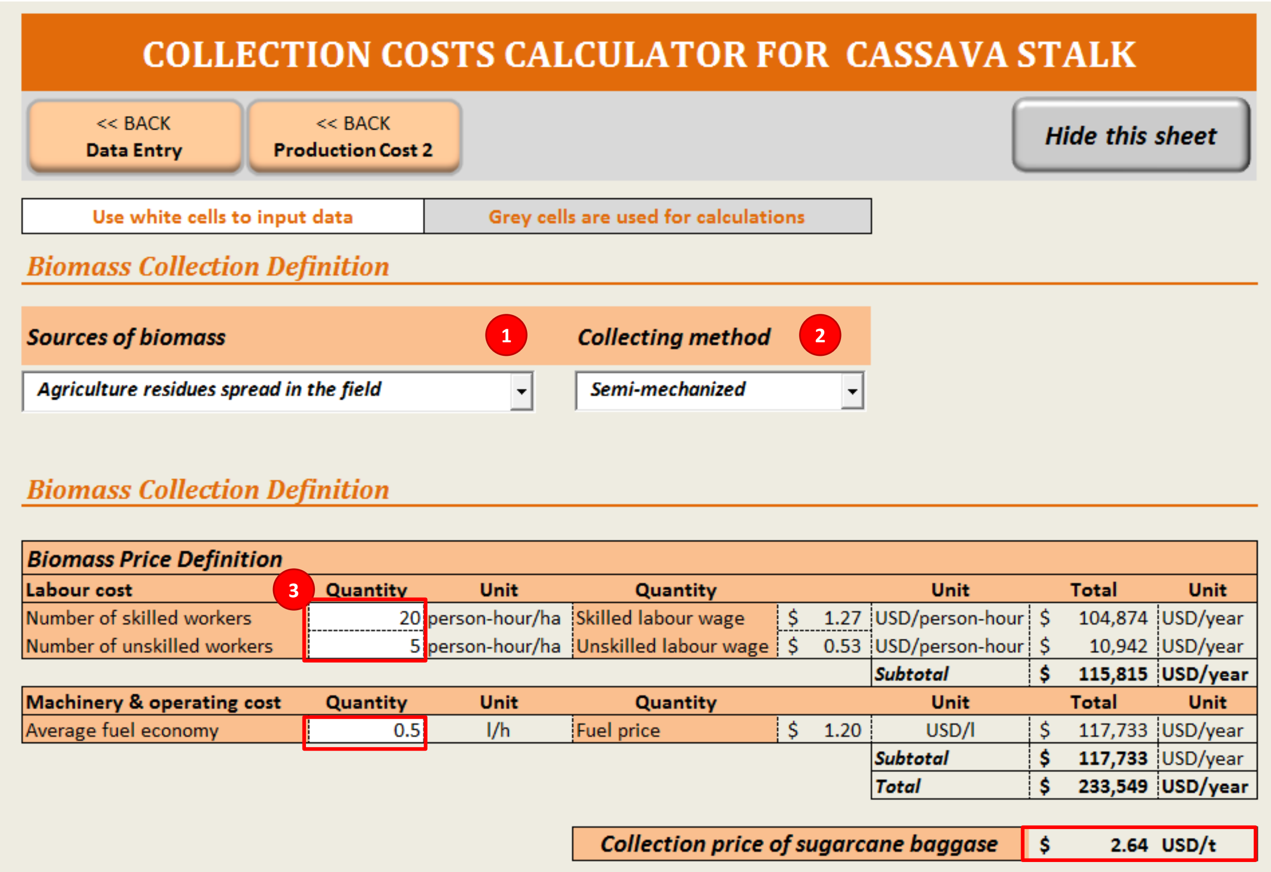


Figure 9: Feedstock Price Calculation based on the Collection Method and Source

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

1. Identify the *biomass source* from one of the following options (Figure 9, 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* (Figure 9, label 2) from the following options:
   - manual
   - semi-mechanized
   - mechanized

Guidance: The collection 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 9, label 3). To return to 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 9, red box), 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 2 "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 the diesel price is 1.20 USD per litre, a proxy price of feedstock is calculated at 2.64 USD/t (Figure 9).

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 in 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: Estimate Cost of Storage

Estimate 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 10, label 1).

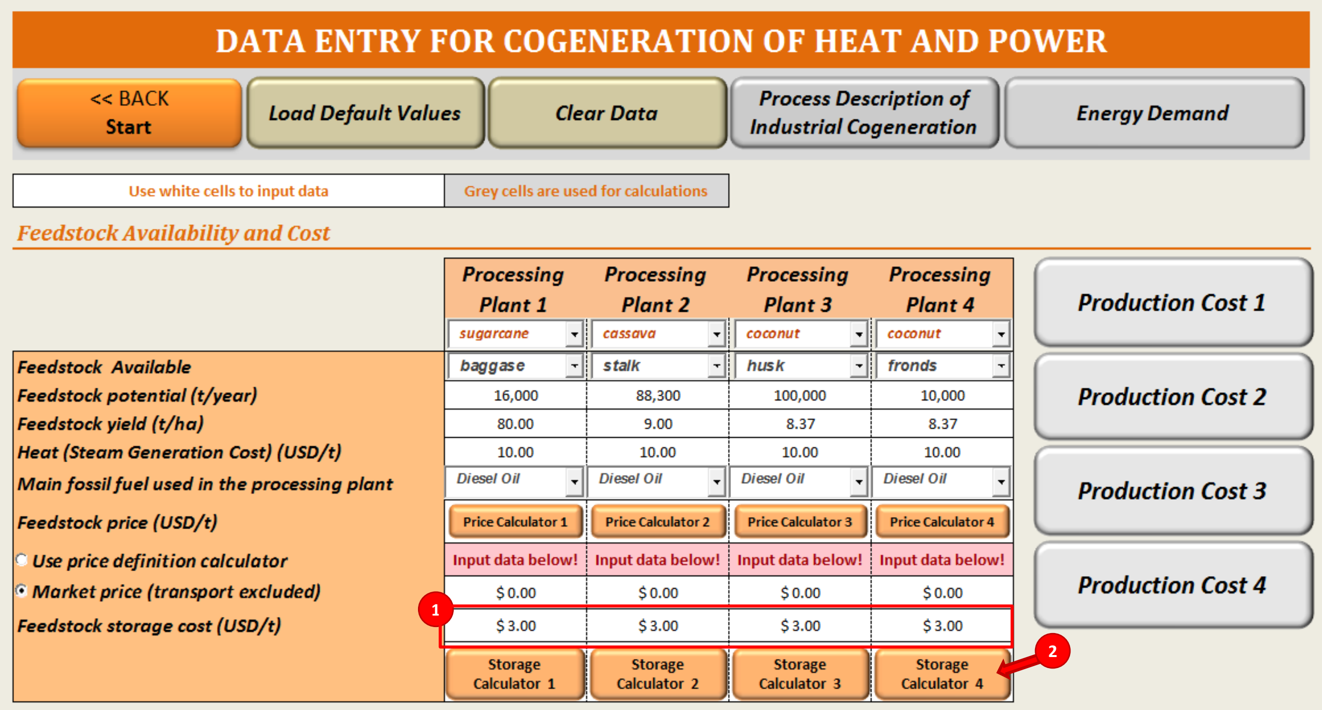


Figure 10: Feedstock Storage Cost

Step 2.C.3 In order to calculate the storage capacity needs, the user needs to click on the "Storage Calculator" (Figure 10, label 2). This will take the user to the Biomass Storage Calculator (Figure 11). In this worksheet, the user will need to:

1. Selects the harvesting month(s) of the crop (Figure 11, 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 11, label 2).
3. Click on "Calculate" (Figure 11, 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 11, label 4).
4. Clicks "OK" to return to the Data Entry Needs sheet (Figure 11, label 5).
5. Repeat the same steps for all feedstock.

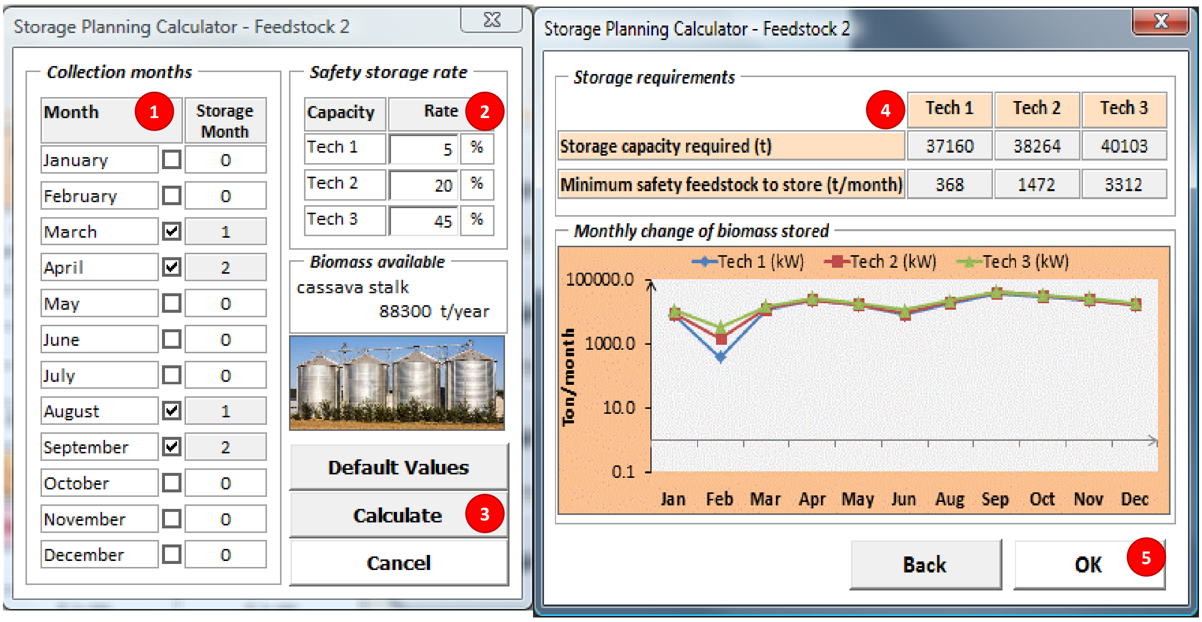


Figure 11: Storage Calculator of Feedstock

For this example, Feedstock 1 is harvested in 4 months: March, April, August, and September. As a result, the storage capacity required is 37160 tonnes for the first production capacity. The minimum safety feedstock to store is 368 tonnes per month. For other pre-defined capacities please see Figure 11.

5.3 Step 3: Defining the energy price

The user needs to specify (Figure 12):

- Purchase Electricity Price
- Selling Electricity Price
- Country of Origin of Electricity
- Selling Heat Price

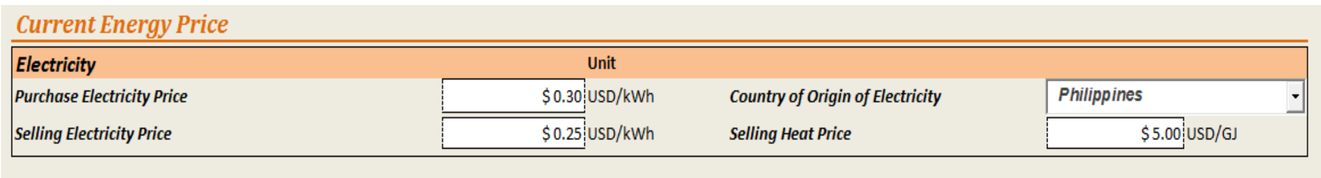


Figure 12: Energy Prices

5.4 Step 4: Operation Mode of Cogeneration

There are two modes of cogeneration: electricity tracking and thermal tracking. The user chooses one of these two depending on his/her central economic and/or technical objective. If the user is mainly interested in producing electricity, then he/she will select electricity tracking, whereas, if the user is primarily interested in producing heating, then he/she will select thermal tracking. The plant sizes will adjust according to the tracking option selected.

For stand-alone energy production, if electricity tracking is selected, electricity will be produced and heat wastes will be used to generate additional electricity. If thermal tracking is selected, then plants will produce heat, and heat wastes will again be used to generate electricity (Figure 13).

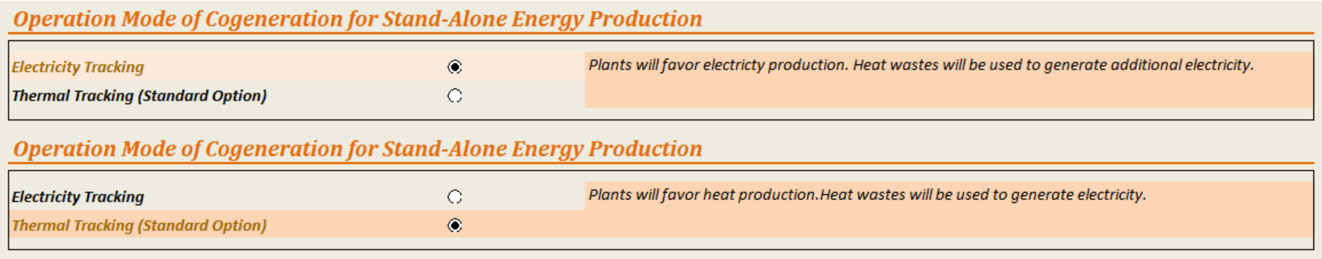


Figure 13: Operation Mode of Cogeneration - Stand-Alone Production

For attached production, if electricity tracking is selected, only electricity will be produced and there will be no surplus as production is based on the specific demand of the processing plant. If thermal tracking is selected, cogeneration plants will produce heat. For this option, if there is enough feedstock available, then heat surplus might be obtained (Figure 14).

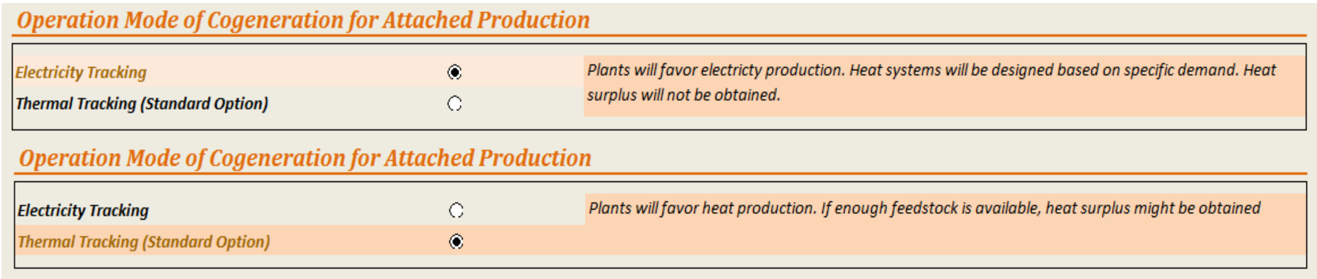


Figure 14: Operation Mode of Cogeneration – Attached Production

5.5 Step 5: General inputs

General inputs required to run the operations are shown in Figure 15. The user will need to provide data on:

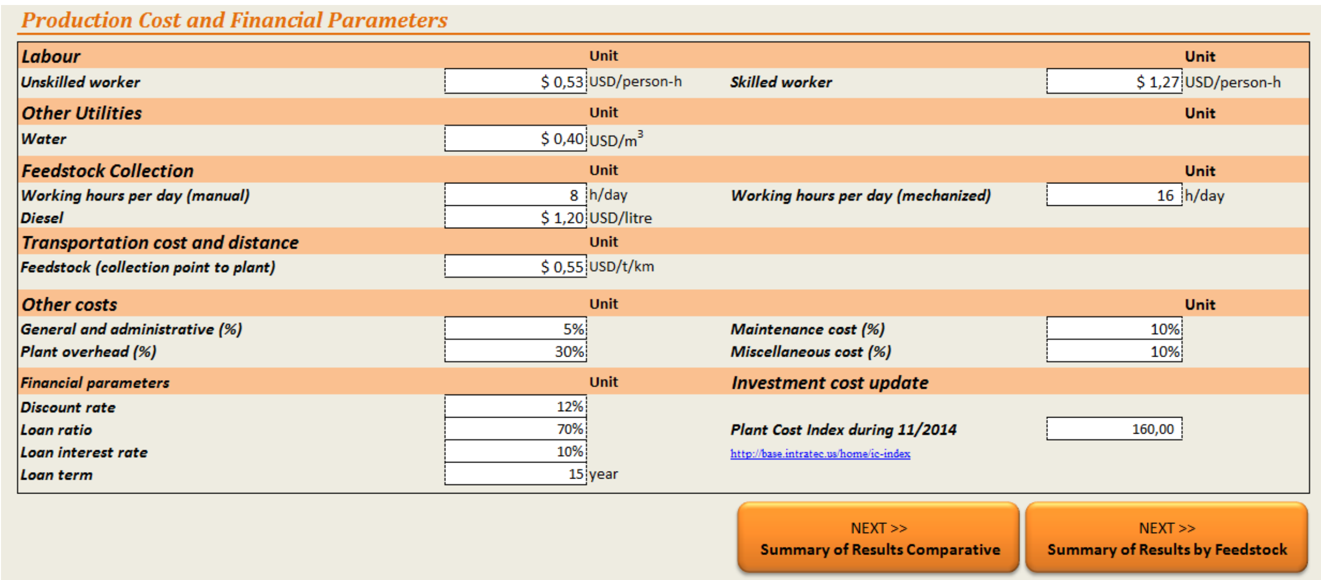


Figure 15: General Inputs

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 cogeneration 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 cogeneration 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:

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 cost 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 15 were used to carry out the analysis.

5.6 Step 6: Calculation of the production cost of electricity

After entering the data in Steps 1 to 5, the user can click on any of the "Production Cost" buttons (Figure 16, 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).

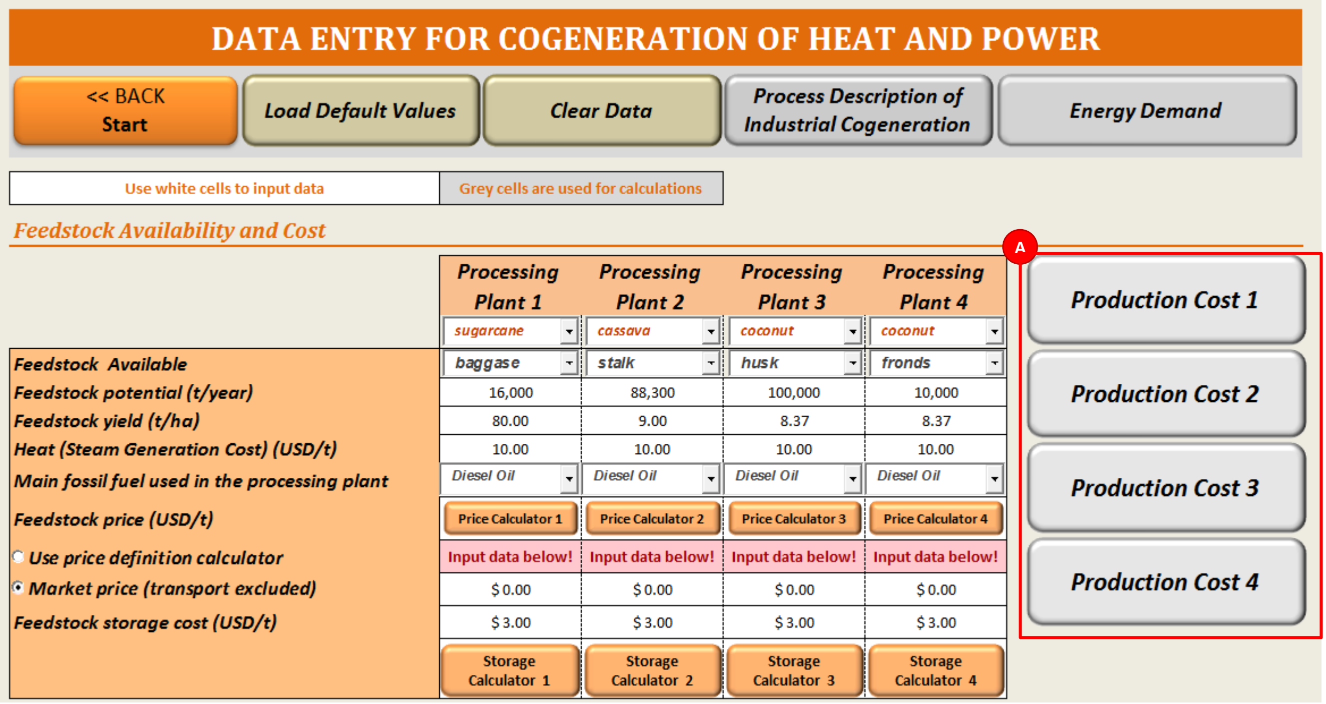


Figure 16: Production Cost Calculation

This will take the user to the budget processing section for the selected feedstock (Figure 17).

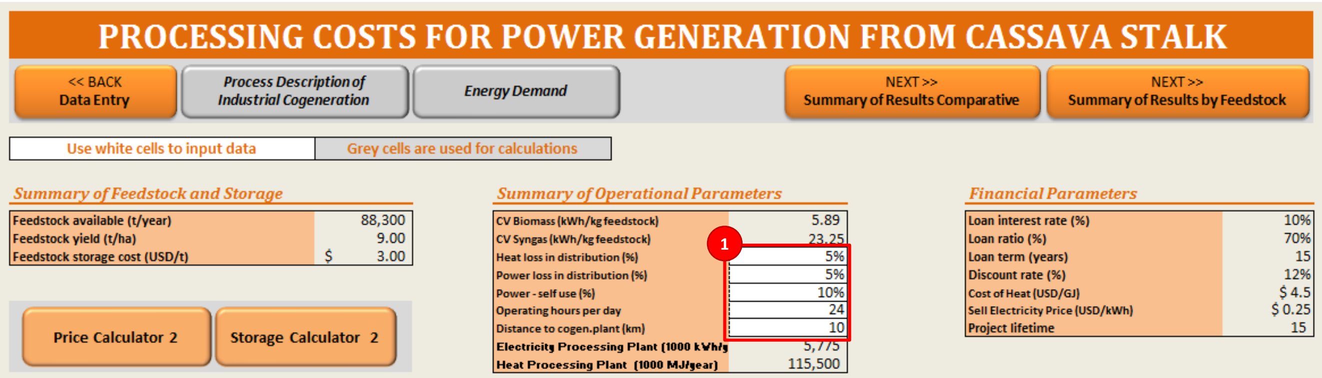


Figure 17: Processing Costs for Power Generation

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

1. **Heat losses due to distribution (%):** The user identifies the heat loss (%) in the distribution network. These losses are assumed to be 5%. However, a parameter can be entered directly by the user (Figure 17, label 1).

2. **Power losses in distribution network (%):** The user identifies the power loss (%) in the distribution network. These losses are assumed to be 5%. 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 17, label 1).

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

3. **Power – self use (%):** This is the electricity used in the cogeneration plant to supply the energy requirements. This value is assumed to be 15%. However, a parameter can be entered directly by the user (Figure 17, label 1).

4. **Operating hours per day:** The user enters the operating hours per day to run the cogeneration system[6]. The daily operating hours are used to compute the total annual operating hours and the capacity factor, assuming the cogeneration system runs 365 days per year (Figure 17, 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.

5. **The transportation distance of the feedstock to the cogeneration 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 17, label 1).

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.

For this example, the "Production Cost 2" is "Cassava stalk". The values that were used to carry out the analysis are:
Heat losses in distribution network (%): 5%
Power losses in distribution network (%): 5%
Power - self use (%): 10%
Operating hours per day: 24
The transportation distance of feedstock to cogeneration plant:
Distance to cogeneration plant: 10
These parameters are used for further analysis.

[6] Nouni, Mullick, & Kandpal, 2007

6 Assumptions and Limitations of the *Cogeneration Component*

Before starting the analysis, the user should get 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 *Cogeneration Component* are:

1. Three cogeneration technologies are considered: Simple, Semi-advanced and Advanced.
2. The business lifetime is considered to be 20 years for the financial analysis.
3. Heat distribution for district heating is not considered.
4. No distinction between heat and electricity tracking is considered.

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

7 The Results of the *Cogeneration Component*

7.1 Overview of the production cost calculation (optional)

After user inputs all required data (Steps 1 to 6), then the user has the option to review the detailed production cost as shown in Figure 18. There are five main sections in this worksheet as explained below.

- **PART 1** (Figure 18, 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 cogeneration technologies (Simple, Semi-advanced and Advanced) are presented for comparative analysis.
- **PART 2** (Figure 18, label 2) shows the total power generation, electricity-self use and power loss in distribution network in the unit of MWh per year. These values are used for calculating the revenue of biomass cogeneration for the power generation system. The results are presented for all three cogeneration technologies.
- **PART 3** (Figure 18, label 3) shows the total heat generation and heat loss in distribution network in the unit of GJ per year. These values are used for calculating the revenue of biomass cogeneration for the heat generation system. The results are presented for all three cogeneration technologies.
- **PART 4** (Figure 18, label 4) shows the unit cost of electricity (USD/kWh) and heat (USD/GJ) for all three cogeneration technologies.
- **PART 5** (Figure 18, label 5) summarizes the loan details e.g. loan amount, loan interest, annual loan payment, etc., for financial analysis.
- **PART 6** (Figure 18, label 6) the “Financial Analysis” buttons will open the worksheet with the details on the financial analysis for each cogeneration technology.

Production Cost Details

	Simple	Semi-Advanced	Advanced
Capacities (MW_e of power generation)	13.2	2.9	1.4
Capacities (MW_{th} of heat generation)	0.0	34.8	31.5
Operating hours per year	8,760	8,760	8,760
6	Financial Analysis Simple	Financial Analysis Semi-Advanced	Financial Analysis Advanced

1

Inputs	Unit	Unit Price (USD/Unit)	Simple Quantity (Unit/year)	Simple Total (USD/year)	Semi-Advanced Quantity (Unit/year)	Semi-Advanced Total (USD/year)	Advanced Quantity (Unit/year)	Advanced Total (USD/year)
Feedstock	t	$ -	88,300	$ -	88,300	$ -	88,300	$ -
Water make-up + chemical additives	m^3	$ 0.8	319,954	$ 268,313	47,470	$ 39,808	14,597	$ 12,241
Subtotal				***$ 268,313***		***$ 39,808***		***$ 12,241***

Labour and miscellaneous costs	Unit	Unit Price (USD/person-hour)	Simple Quantity (Unit)	Simple Total (USD/year)	Semi-Advanced Quantity (Unit)	Semi-Advanced Total (USD/year)	Advanced Quantity (Unit)	Advanced Total (USD/year)
Unskilled worker	#employee	$ 0.5	54	$ 250,711	12	$ 55,714	6	$ 27,857
Skilled worker	#employee	$ 1.3	11	$ 122,377	3	$ 33,376	2	$ 22,250
Miscellaneous costs			10%	$ 37,309	10%	$ 8,909	10%	$ 5,011
Subtotal				***$ 410,397***		***$ 97,998***		***$ 55,118***

Transport of feedstock	Unit	Unit Price (USD/t/km)	Simple Quantity (Unit)	Simple Total (USD/year)	Semi-Advanced Quantity (Unit)	Semi-Advanced Total (USD/year)	Advanced Quantity (Unit)	Advanced Total (USD/year)
Feedstock (farm to plant)	km	$ 0.6	10	$ 485,650	10	$ 485,650	10	$ 485,650
Subtotal				***$ 485,650***		***$ 485,650***		***$ 485,650***

Storage	Unit	Unit Price (USD/t/year)	Simple Quantity (Unit)	Simple Total (USD/year)	Semi-Advanced Quantity (Unit)	Semi-Advanced Total (USD/year)	Advanced Quantity (Unit)	Advanced Total (USD/year)
Feedstock	t	$ 3.00	37,160	$ 111,480	38,264	$ 114,792	40,103	$ 120,309
Subtotal				***$ 111,480***		***$ 114,792***		***$ 120,309***

Investment	Unit	Years	Simple Total (USD)	Simple Depreciation (USD/year)	Semi-Advanced Total (USD)	Semi-Advanced Depreciation (USD/year)	Advanced Total (USD)	Advanced Depreciation (USD/year)
Equipments	USD	20	$ 42,965,147	$ 2,148,257	$ 16,033,138	$ 801,657	$ 8,795,222	$ 439,761
Building	USD	20	$ 261,159	$ 13,058	$ 58,320	$ 2,916	$ 28,519	$ 1,426
Installation	USD	20	$ 358,267	$ 17,913	$ 78,167	$ 3,908	$ 37,016	$ 1,851
Total investment			$ 43,584,574		$ 16,169,625		$ 8,860,757	
			Total Depreciation	$ 2,179,229	Total Depreciation	$ 808,481	Total Depreciation	$ 443,038
Maintenance cost		10%		*$ 217,923*		*$ 80,848*		*$ 44,304*
Subtotal				$ 2,397,152		$ 889,329		$ 487,342

Other costs	Unit	Rate (%)		Simple Total (USD/year)		Semi-Advanced Total (USD/year)		Advanced Total (USD/year)
Plant overhead	USD	30%		$ 177,303		$ 50,981		$ 28,323
General and administrative cost	USD	5%		$ 53,697		$ 13,482		$ 6,999
Loan interest	USD	10%		$ 1,900,295		$ 704,998		$ 386,330
Subtotal				2,131,295		769,461		421,653

	Simple Total (USD/year)	Simple Share (%)	Semi-Advanced Total (USD/year)	Semi-Advanced Share (%)	Advanced Total (USD/year)	Advanced Share (%)
Total operating costs	*$ 1,275,840*	*22%*	*$ 738,248*	*31%*	*$ 673,318*	*43%*
Total fixed costs	*$ 2,397,152*	*41%*	*$ 889,329*	*37%*	*$ 487,342*	*31%*
Total other costs	*$ 2,131,295*	*37%*	*$ 769,461*	*32%*	*$ 421,653*	*27%*
Total production costs	$ 5,804,286		$ 2,397,039		$ 1,582,312	

Power Generation

2

	Unit	Simple Quantity (Unit)	Semi-Advanced Quantity (Unit)	Advanced Quantity (Unit)
Power generation	MWh/year	*104,063*	*22,705*	*10,752*
Electricity - self use	MWh/year	*-10,406*	*-2,270*	*-1,075*
Power loss in distribution network	MWh/year	*-5,203*	*-1,135*	*-538*
Subtotal		88,454	19,299	9,139

Heat Generation

3

	Unit	Simple Quantity (Unit)	Semi-Advanced Quantity (Unit)	Advanced Quantity (Unit)
Heat generation	GJ/year		*1,098,342*	*991,840*
Heat loss in distribution network	GJ/year		*-54,917*	*-49,592*
Subtotal			1,043,425	942,248

Total Production Cost

4

	Simple	Semi-Advanced	Advanced
Capacities (MW_e of power generation)	13	3	1
Unit cost of electricity (USD/kWh)	$ 0.07	$ 0.12	$ 0.17
Capacities (MW_{th} of heat generation)		35	31
Unit cost of Heat (USD/GJ)		$ 2.18	$ 1.60

5

Average loan interest	Unit	Loan ratio (%)	Simple Total investment (USD)	Simple Loan amount (USD)	Semi-Advanced Total investment (USD)	Semi-Advanced Loan amount (USD)	Advanced Total investment (USD)	Advanced Loan amount (USD)
Loan amount	USD	70%	*$ 43,584,574*	*$ 30,509,201*	*$ 16,169,625*	*$ 11,318,738*	*$ 8,860,757*	*$ 6,202,530*
Loan interest rate	%			*10%*		*10%*		*10%*
Loan payment	USD/month			*$ -327,853*		*$ -121,632*		*$ -66,653*
Annual loan payment	USD/year			*$ -3,934,241*		*$ -1,459,581*		*$ -799,832*
Loan term	year			*15*		*15*		*15*
Total loan payment	USD			*$ -59,013,619*		*$ -21,893,712*		*$ -11,997,486*
Loan interest	USD			*$ -28,504,418*		*$ -10,574,975*		*$ -5,794,956*
Average loan interest	USD/year			*$ -1,900,295*		*$ -704,998*		*$ -386,330*

Figure 18: Detail of Production Costs of Electricity and Steam by Cogeneration Technology

For this example, the total production cost of electricity by using cassava stalk for the simple cogeneration technology is 5,804,286 USD/year and the unit cost of electricity is 0.07 USD/kWh. Moreover, the total power generation is 88,454 kWh/year.

7.2 The summary results by feedstock

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

- What are the investment and production costs per MWh and GJ for the various configuration technologies and feedstock selections?
- How much biomass and area are required to secure the supply of biomass for the development of cogeneration systems?
- How many potential cogeneration plants can be developed based on the availability of biomass?
- How many jobs can be created through biomass cogeneration?
- Which type of feedstock is more suitable and could be promoted for the cogeneration system?
- What is the financial viability of the cogeneration system?

Results for the *Cogeneration Component* are divided along four main categories: Production Cost and Investments; Financial Analysis; Technical and Operating Results; and Socio-economic Results.

1. The user first selects the feedstock from the dropdown menu that he/she wants to review (Figure 19, label 1). The results for that specific feedstock will be generated.
2. If the cogeneration system is connected to a processing plant (attached production), then the user must select the destination of cogenerated energy. The tool provides various scenarios for final energy use and the user must decide what is best for his/her objectives. If the user decides to self-supply electricity and/or heat, then only the surplus will be sold to the central grid. On the other hand, the user can decide to sell all electricity to the central grid and/or heat to nearby customers, but must keep in mind that none of the energy generated will be supplied to the processing plant. In the example presented in the results section, attached production with thermal tracking is selected. Then, self-supply of electricity and heat is also selected as this is the standard method of cogeneration (Figure 19, label 2).
3. The production cost and investments results are presented as follows:
    - Production cost of electricity (USD per kWh) (Figure 19, label 3)
    - Production cost of heat (USD per GJ) (Figure 19, label 4)
    - Revenues generated by the cogeneration unit (USD/year) (Figure 19, label 5)
    - Capital investment (USD) (Figure 19, label 6)

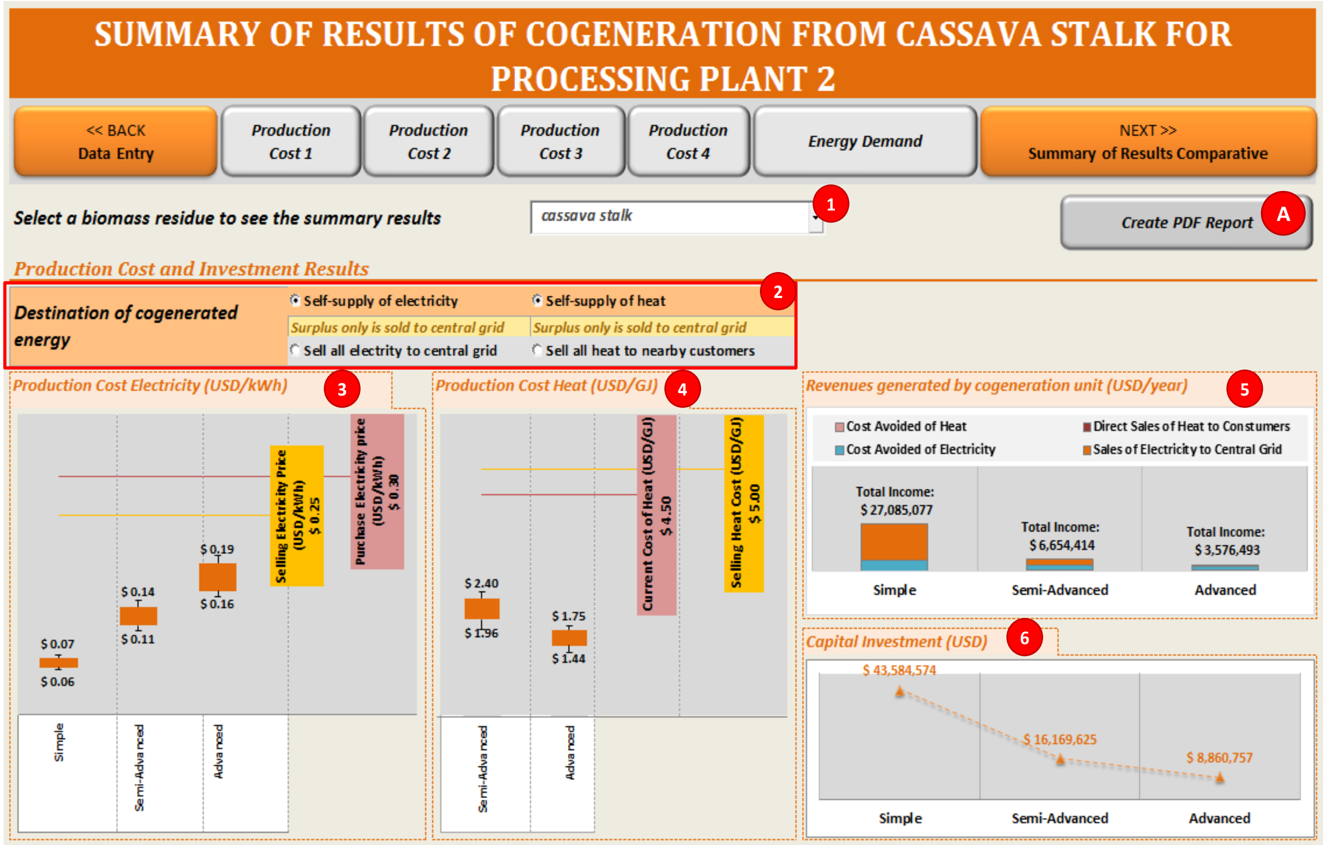


Figure 19: Production Cost and Investment Results

> **For the example of cassava stalk, the production cost plus the distribution cost of simple technology ranged between 0.06-0.07 USD per kWh. These unit costs are lower than the electricity price 0.25 USD/kWh. Therefore, this plant is feasible and an attractive investment, compared to the possibility of running a plant based on diesel. The total revenue generated with this technology is $27,085,077 USD/year and the capital investment is $43,584,574 USD. For other pre-defined technologies refer to Figure 19.**

4. The financial analysis (before tax return) results are presented as follows:
   - Net Present Value (NPV) (Figure 20, label 1)
   - Share of Production Costs (%) (Figure 20, label 2)
   - Internal Rate of Return (IRR) (Figure 20, label 3)

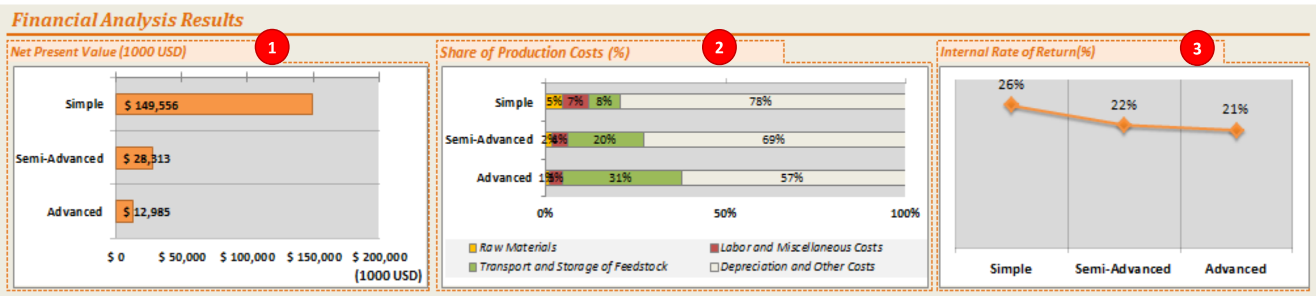


Figure 20: Financial Analysis Results

For the example of cassava stalk, the net present value (NPV) and internal rate of return (IRR) for all plant technologies are positive as shown in Figure 20.

It can be concluded that cassava stalk is feasible for power and steam generation at all cogeneration technologies.

5. The technical and operating results are presented as follows:
   - Electricity performance of the cogeneration plant (kWh/year) and Demand self-supplied to the processing plant (%) (Figure 21, label 1)
   - Collection area of the feedstock (ha) (Figure 21, label 2)
   - Potential GHG savings (tCO2e/year) (Figure 21, label 3)
   - Demand self-supplied to the processing plant (%) and Heat performance of the cogeneration plant (MJ/year) (Figure 21, label 4)
   - Plant capacities for heat and electricity cogeneration (Figure 21, label 5)

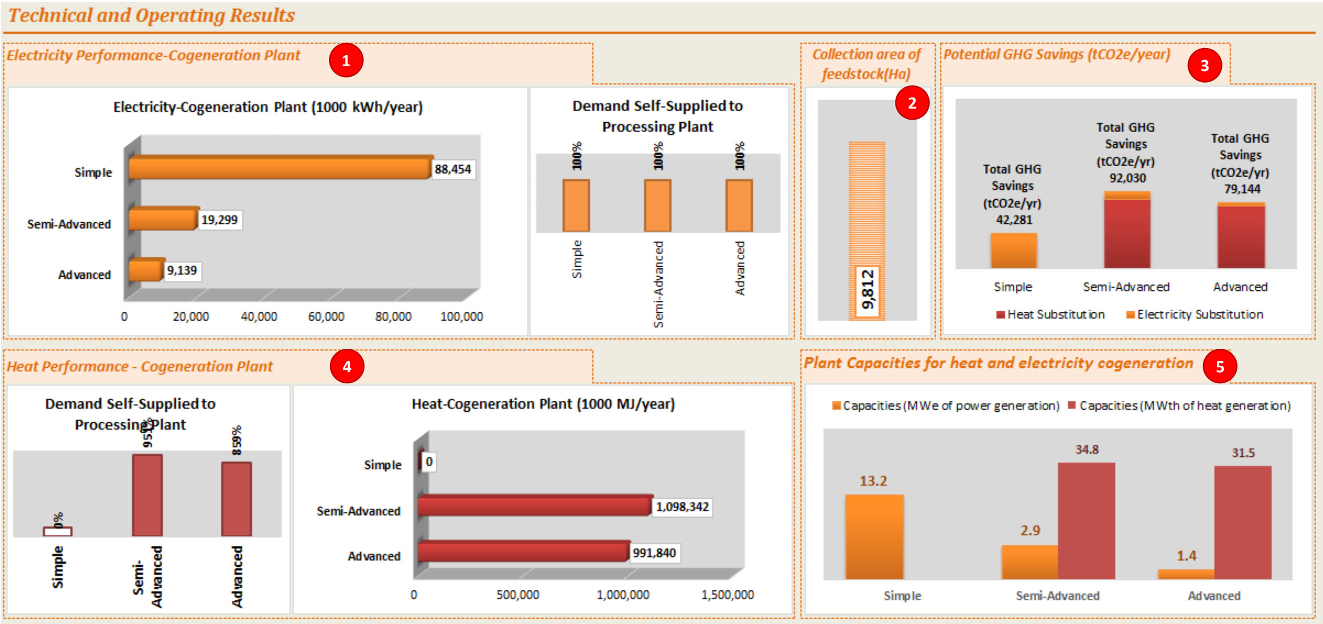


Figure 21: Technical and Operating Results

For the example of cassava stalk, the electricity and heat performances for the cogeneration plant are positives for semi-advance and advance technologies, while for the simple technology the electricity performance is positive and the heat performance is zero.
According to the electricity and heat performances, 9,812 hectares of collection area of feedstock are required. For simple technology, the GHG saving is 42, 281 tCO2e/year and the plant capacity is 13.2 MWe of power generation.

For other pre-defined technologies refer to Figure 21.

6. The socio-economic results are presented as follows:
   - Number of household that can be supplied by cogenerated energy (Figure 22, label 1)
     - The user must input the average electricity and heat consumption per household.
   - Total number and types of jobs that can be created through the implementation of the different cogeneration systems (Figure 22, label 2)

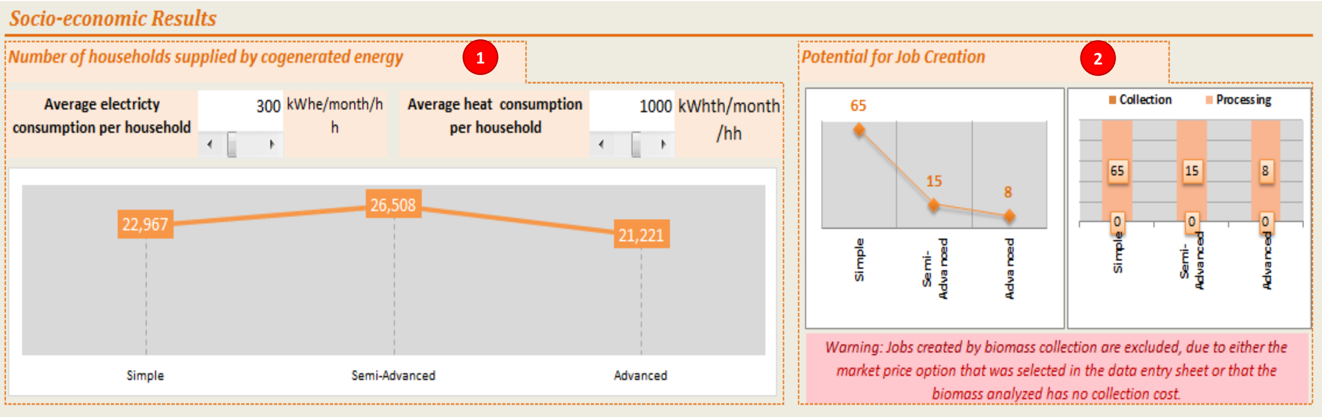


Figure 22: Socio-economic Results

For the example of cassava stalk, the number of households which can supplied by cogenerated electricity with simple technology is 22,967 if the average electricity consumption is 300 kWhe/month/household and for heat is 1000 kWth/month/household.

In addition, the potential job creation from a cogeneration plant of simple technology is 65 jobs of processing.

For other pre-defined technologies refer to Figure 22.

The user can save and print the results in PDF format by using "Create a PDF report" and following the instructions (Figure 19, 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 cogeneration for power and heat generation at the industrial level. 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 want to review. The results for that specific feedstock will be generated.
2. Comparison results are presented on:
   - Production costs of electricity according to feedstock (USD/kWh) (Figure 23, label 1)
   - Production costs of heat according to feedstock (USD/GJ) (Figure 23, label 2)
   - Collection area (ha) (Figure 23, label 3)
   - Energy self-supply potentials (Figure 23, label 4)
   - Total number of jobs that can be created (Figure 23, label 5)
   - Total number of households that can be supplied (Figure 23, label 6)
   - Potential GHG savings (tCO2e/year) (Figure 23, label 7)
   - Comparison of NPV (before taxes) across the selected feedstock options (Figure 23, label 8)
   - Comparison IRR (before taxes) across the selected feedstock options (Figure 23, label 8)

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

The user can save and print the results in PDF format by using "Create a PDF report" and following the instructions (Figure 23, label A).

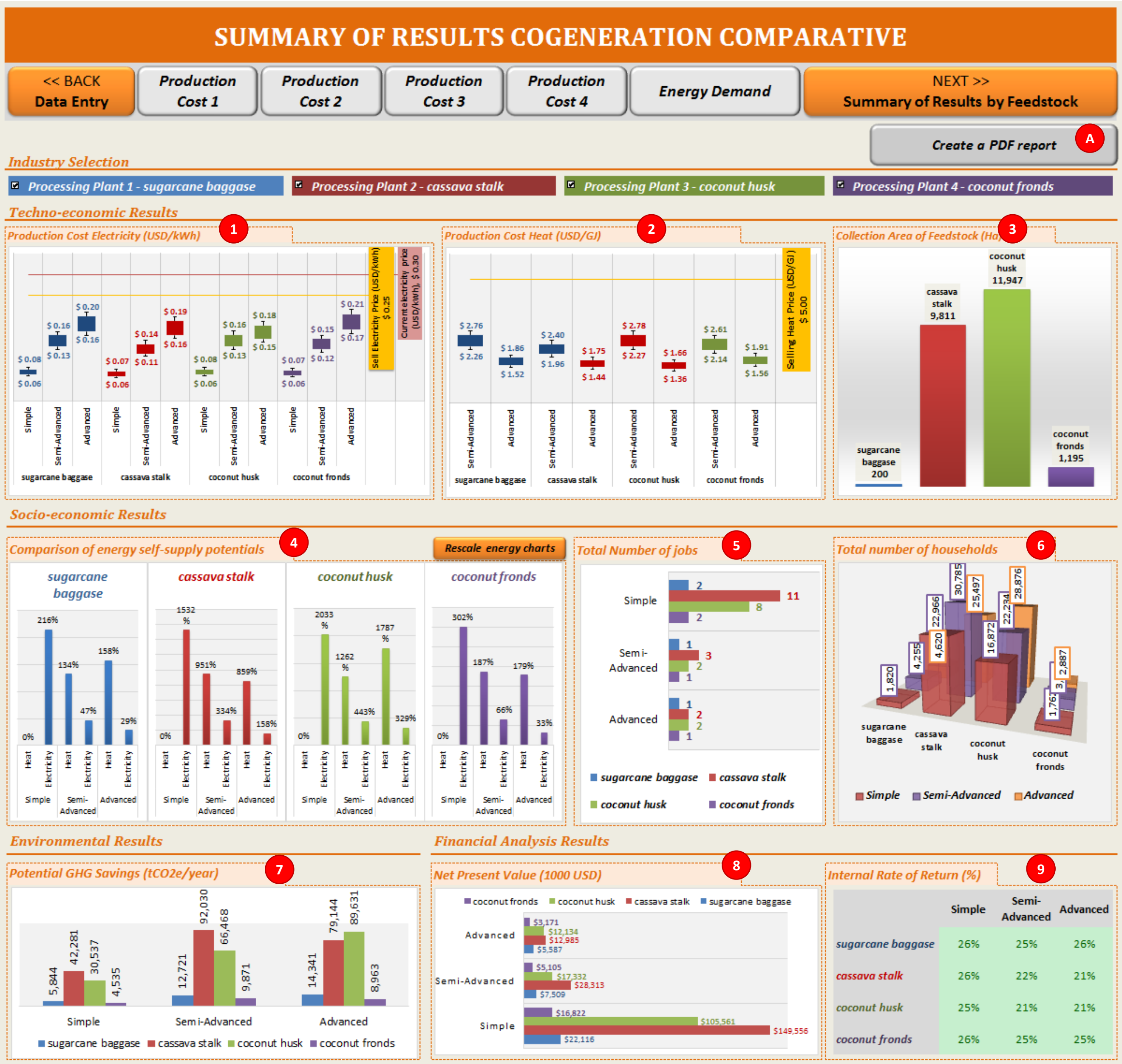


Figure 23: Layout of Comparative Results

For this example, the production cost of heat for semi-advanced cogeneration technology is lowest using cassava stalk as feedstock. However, for advanced cogeneration technology it is lowest using coconut husk as feedstock.

Importantly, all feedstock provide positive NPV and IRR as shown in Figure 23.

It can be concluded that:

1. Sugarcane bagasse, cassava stalk, coconut husk and coconut fronds are feasible options and are available for power generation at all technologies.
2. Sugarcane bagasse, cassava stalk, coconut husk and coconut fronds are feasible options and are available for steam generation at semi-advanced and advanced technologies.
3. Given the electricity performance, a large number of plants based on cassava stalk or coconut husk can be created, impacting positively on the number of households supplied in the country.
4. From a job generation perspective cassava stalk is the best option.

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