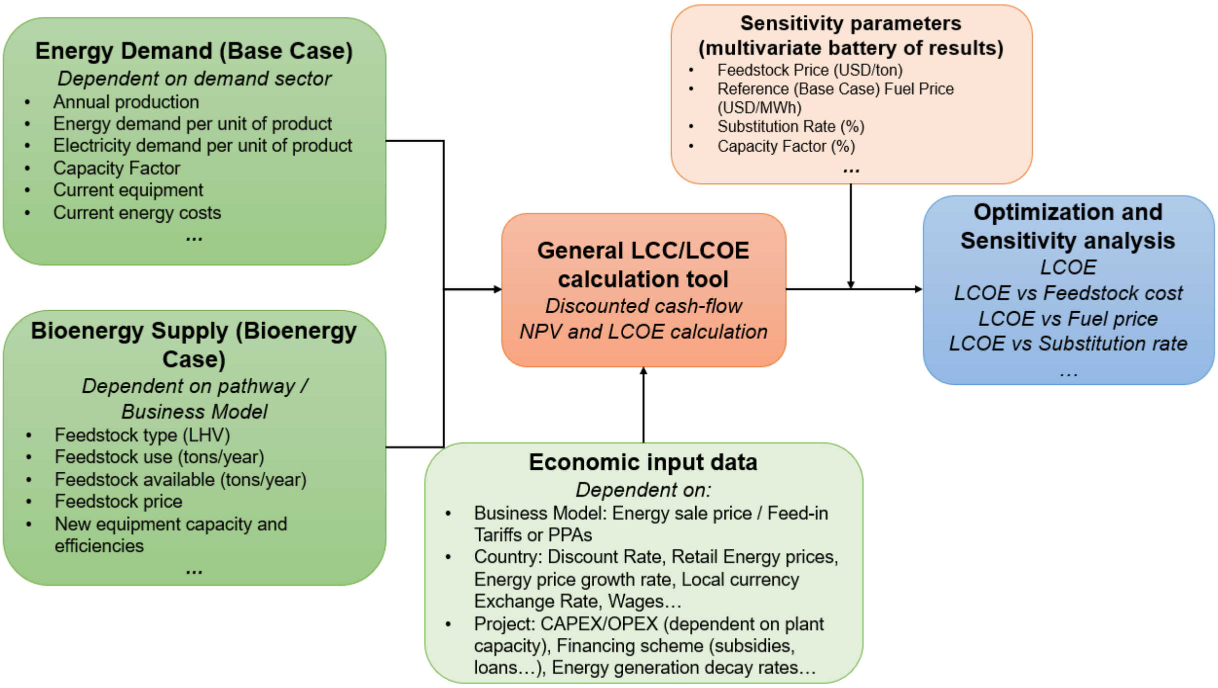

Bioenergy for Sustainable Local Energy Services and Energy Access in Africa

Life Cycle Costing (LCC) modelling tool
Methodology document

SEPTEMBER 2021

About the BSEAA2 Programme

NIRAS-LTS partnered with Aston University, E4tech and AIGUASOL to implement a two-year project entitled 'Bioenergy for Sustainable Local Energy Services and Energy Access in Africa - Phase 2' (BSEAA2). BSEAA2 was part of the Transforming Energy Access (TEA) programme, which is funded with UK aid from the UK government. TEA is a research and innovation platform supporting the technologies, business models and skills needed to enable an inclusive clean energy transition. TEA works via partnerships to support emerging clean energy generation technologies, productive appliances, smart networks, energy storage and more. It increases access to clean, modern energy services for people and enterprises in sub-Saharan Africa (SSA) and South Asia, improving their lives, creating jobs and boosting green economic opportunities.

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Disclaimer

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CONTENTS

1 INTRODUCTION

The economic analysis within the Bioenergy for Sustainable Local Energy Services and Energy Access in Africa - Phase 2 (BSEAA2) project was carried out following a Life Cycle Cost (LCC) approach, assessing costs from the inception of a bioenergy project through to a selected time horizon. Input data from seven representative industries (or 'demand sectors') were introduced into an Excel-based tool that models the economic performance of bioenergy projects.

The seven Demand Sectors (DS) evaluated were:

- Cement manufacturing
- Tea processing
- Wood processing
- Palm oil processing
- Horticulture
- Dairy
- Sisal processing

A detailed cashflow analysis lies at the core of the LCC Modelling Tool, which considers two scenarios:

- a 'Base Case' scenario, which is the industry standard for energy use in the country and demand sector in question. It defines the Business as Usual (BAU) approach, i.e. the common practice for companies in the sector, and what a new developer or investor would most probably do. This will often mean meeting energy demand with grid electricity or fossil-fuel based energy carriers.
- a 'Bioenergy Case' scenario, representing a new proposal for the adoption of one of the investigated bioenergy generation technologies, either based on combustion or anaerobic digestion (AD)', depending on the demand sector.

From an economic point of view, the comparison between the Base Case and the Bio-energy Case provides a before-and-after assessment to highlight the costs and benefits of adopting bioenergy for the production of heat, power or combined heat and power (CHP).

In order to properly deal with uncertainties and critical parameters, the LCC toolkit allows sensitivity analysis to be carried out on relevant input parameters, based on a multivariate analysis approach considering all possible combinations and ranges of the selected variables.

The results from the toolkit's costings and sensitivity analyses can be used not only to determine whether a project will result in cost-savings on energy after the adoption of the specified bioenergy technology, but also to identify those parameters that have the greatest impact on the economic outcome of a project, and to identify target values for prices and other parameters to improve economic viability or profitability.

2 LCC METHODOLOGY

2.1 GENERAL LCC FRAMEWORK

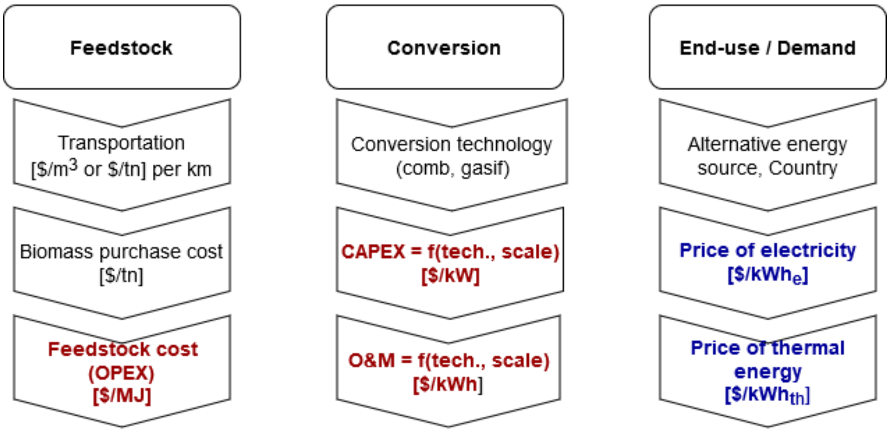
The overall goal of the cost analysis performed by the LCC tool is to model two headline economic metrics – Life Cycle Costs (LCC) and Levelized Cost of Energy (LCOE) - for a chosen bioenergy pathway, as represented by particular demand sector.

The LCC of a venture is derived from CAPEX (upfront investment and other amortizable costs) and OPEX (personnel, consumables and operating costs) as follows:

$$LCC\,[\$] = CAPEX\left[\frac{\$}{kW}\right]\cdot P_n\,[kW] + \sum_i \frac{\left(OPEX\left[\frac{\$}{kWh}\right]\cdot E_{prod}\left[\frac{kWh}{year}\right] + OPEX\left[\frac{\$}{year}\right]\right)\cdot years}{(1+DR)^i} \tag{1}$$

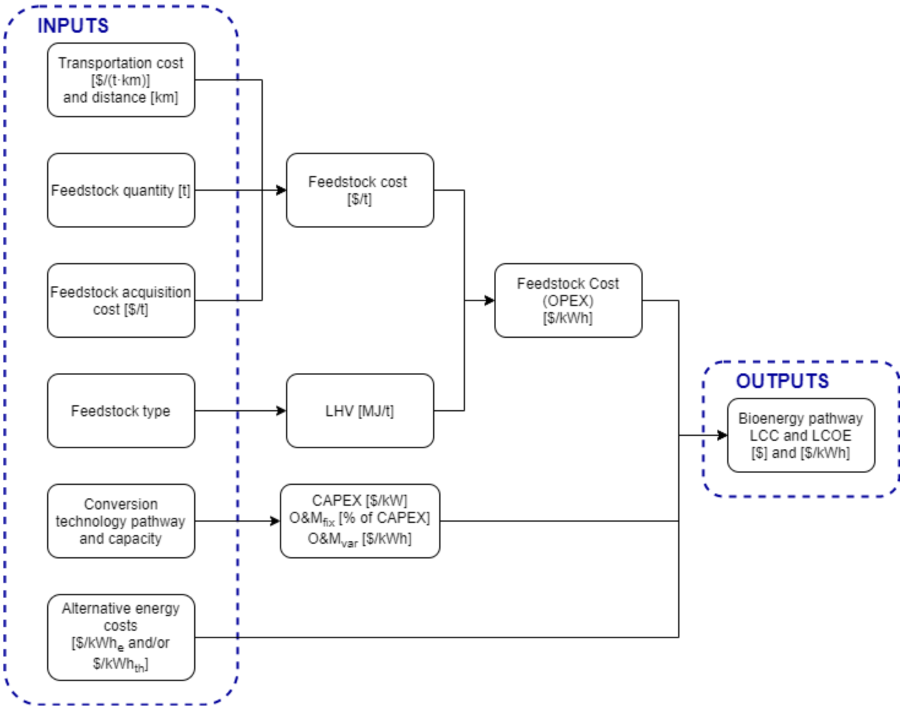
The relevant pathway costs from feedstock to end-use are presented in Figure 1.

Figure 1: Relevant pathway costs



The cost terms most relevant for the analysis are the upfront investment costs, i.e the CAPEX for adapting the project to use bioenergy; and two types of OPEX: fuel costs and operation & maintenance (O&M) costs (mainly personnel and consumables). The cost modelling considers the parameters specified in Figure 2.

Figure 2: Summary of bioenergy pathway cost modelling



2.2 Key Performance Indicators

The calculation engine of the LCC Tool is a detailed cashflow analysis that is carried out for the Base Case and the Bioenergy Case scenarios. The differential cashflow arising from the two scenarios is used to determine the main economic Key Performance Indicators (KPI) and the economic viability of the proposed bioenergy investment.

The main economic KPI used to assess economic performance is the LCOE, in USD/MWh. LCOE is calculated for both the Base Case and the Bioenergy Case, and is split between CAPEX and OPEX, in order to identify the life cycle stage where the majority of costs are located. The results of the LCOE analysis comprise the following items:

- LCOE of CAPEX
- LCOE of ABEX
- LCOE of OPEX
  - Personnel costs
  - O&M costs (fuel excluded)
  - Fuel + electricity costs

LCOE is calculated separately for heat and electricity or - in the case of CHP applications - is split between electricity and heat.

Other KPIs can be extracted from the tool for further reference:

- CO_2 emissions avoided during the project's service life
- USD invested per tonne of CO_2 emissions avoided.

2.3 General economic parameters

The modelling tool is based on a combination of general economic parameters for the country and sector in question, and energy parameters that are specific to each Demand Sector.

The following general modelling parameters are applied:

- Cashflow analysis is carried out on an annual basis.
- The United States Dollar (USD) is the default currency.
- Discount rates (DR) for each of the ten SSA countries scoped within the BSEAA2 project were sourced from CIA World Factbook, National Central Banks and International Monetary Fund (IMF) databases. For Ethiopia these sources lacked comparable data and Trading Economics[1] was used instead. DR is assumed to correspond to the National Bank interest rate (IR), in the absence of more specific information.
- The Consumer Price Index (CPI) is included as indicator of the general growth rate. Data from the CIA World Factbook is again used. CPI is applied for modelling the evolution of all non-fuel and non-energy operating costs, namely consumables, personnel, future capital investments (e.g. boiler or turbine overhauls) and abandonment expenditures (ABEX).
- The energy price growth rate is assumed to mirror the general growth rate, in the absence of more specific data, and is applied to all fuel and energy costs.

[1] https://tradingeconomics.com/ethiopia/interest-rate

- Electricity Retail prices in each country are those charged to commercial or industrial consumers by the relevant national utility.
- Annualised salaries are those for high-skilled workers, using data from Trading Economics[2].
- Currency exchange rates considered are 3-year average values published by National Central Banks. Personnel costs, feedstock costs and other operating costs are usually entered in USD, but are converted from local currency using the applicable exchange rates.

2.4 Comparative Cashflow analysis

As previously introduced, the backbone of the KPI calculation is a differential cash-flow analysis between an industry standard 'Base Case' scenario (or Business as Usual/BAU) and a 'Bioenergy Case' scenario focused on the use of different feedstocks and energy production, depending on the specific Demand Sector being addressed. Data from real world 'flagship projects' was used to characterise these bioenergy scenarios in terms of technology prices, feedstock costs, sizing of the project and type of business model.

The LCC analysis was tailored to include an estimate of the Base Case costs and the Bioenergy Case costs for each Demand Sector. For instance, capital investment costs for the cement industry assume the acquisition and installation of rotary kilns as joint energy and clinker production devices, whereas for the tea or wood processing industries, an internal cost database of boilers is used to characterise the CAPEX. Similarly, for AD-based projects, the costs of the digester and linked reciprocating engine are considered in the internal cost database.

2.5 Annualization

Two of the main KPIs to model the economic performance of a project are the LCOE and the Net Present Value (NPV). Both KPIs are based on the concept of **cost annualization**. This cost annualization is based on the following modelling assumptions:

- Energy costs (both electrical and thermal) rise annually following the Energy Price Inflation Rate or IR (generally speaking, the CPI).
- O&M costs also rise annually in lined with the CPI.
- Fossil fuel costs also increase on an annual basis following the general inflation rate, i.e. the CPI.
- Feedstock costs are considered to increase on an annual basis following the DR, which indirectly represents the general economic growth rate of the country.

For LCC the following terms are considered:

- Cost of Primary Energy Savings (CPES)

$$CPES = \frac{C_{an,bio} - C_{an,base\_case}}{PE_{ref} - PE_{base\_case}} \tag{2}$$

- LCOE for only one energy carrier:

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[2] https://tradingeconomics.com/

$$LCOE = \frac{\sum_{t=1}^{n} \frac{C_t}{(1+DR)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+DR)^t}(1+IR)^t} \quad (3)$$

The LCOE can be calculated for the final energy consumption of electricity and heat, thus generating both a $LCOE_{electricity}$ and $LCOE_{heat}$.

2.6 Sensitivity analysis

The sensitivity analysis allows the investigation of the influence on LCOE of selected parameters, that can be chosen by the tool user, together with their range of maximum and minimum values. This runs all possible combinations of values for the selected variables over a certain number of iterations that the user can also define.

3 Input data

Cells within the tool are colour-shaded to indicate the degree to which the user can enter, adjust or over-ride the specified values:

Type of cell	Cell shading
Default	These cells have a default value that can be overwritten. The default value is reset when the corresponding drop-down list is re-selected.
User-defined	These cells must be filled in by the user and are critical for the results.
Blocked	These cells cannot be modified.
Warning	If this colour appears, there is a warning.

All data input cells show the applicable units. The user is advised to be mindful of the units when entering data.

The following are the key steps involved in using the tool

1. Enter data in the two main data tabs of the tool:
   - **Tab 1 – "Input technical data"**
   - **Tab 2 – "Input economic data".**

   An example of appropriate input for Tab 1 is provided in Figure 3.
2. Check the results in **Tab 4 "Results".**
3. (Optional) Perform a sensitivity analysis by selecting the desired sensitivity parameters in **Tab 3 "Sensitivity analysis"** and setting minimum and maximum values for each parameter and the number of iterations desired for the analysis. An example is provided in Figure 4. The results can be seen in **Tab 5 "Sensitivity results"**.

Figure 3: Example of suitable data for Tab 1 "Input Data" – Demand Sector 5, AD in Horticulture

General project data		
Parameter	**Drop-down list**	**Description**
Country	Kenya	The country choice sets default values for discount rate and electricity retail price, as listed at the beginning of the **Input Economic Data** tab. If you select 'other', please fill the values manually.
Demand sector	Fruit & Vegetables	This parameter sets some default values such as specfic waste generation, specific heat consumption and specific electricity consumption. If you select 'other', please fill the values manually.

Base Case (prior situation)			
Baseline characteristics			
Parameter	**Value**	**Units**	**Description**
Plant Nominal Capacity	4000.00	industrial process units	Annual nominal production of the plant
Plant Nominal Capacity Factor (CF)	90%	%	Percentage of total production over total nominal plant capacity
CF growth rate	0%	tonne of fresh fruit	Annual increment of the capacity factor
Baseline genset	**1**		**Select 1 genset, 2 gensets or no genset in the base case**
Reference fuel type for genset 1	Diesel		Select the reference fuel for genset 1. Note that some default values (LHV, emission factor, efficiency and genset utilization rate) will appear in green cells, this values can be overwritten. If the reference fuel is selected again, the default values from database tab will appear again.
LHV 1	0.04	GJ/L	This is a reference value for T=30ºC, and P=20 bars.
Emission factor 1	0.07	tCO2/GJ	This is a reference value for T=30ºC, and P=20 bars.
Fuel cost 1	0.95	USD/L	Write the cost of Diesel fuel for genset 1. This is a critical parameter for the results.
Genset utilisation rate (grid backup system) 1	10%	%	Write the percentage of failure of the grid, as an example a 10% means that 10% of the time that the demand should be covered by the grid, the grid is not available.
Rated power 1	500.00	kWe	Write the rated power of genset 1. This is a critical parameter for the results.
Efficiency 1	35%	%	Write the electrical efficiency of genset 1. This is a critical parameter for the results.
Baseline boiler	**No**		**Select 1 boiler, 2 boilers or no boiler in the base case**
Baseline combined heat and power (CHP)	**No**		**Select 1 CHP, 2 CHP or no CHP in the base case**
Waste Treatment cost	24.80	USD/tonne of waste	

Industrial process energy demand			
Plant production	3600.00	tonne of fresh fruit	
Specific waste generation	1.80	tonne of waste/ tonne of fresh fruit	
Annual waste generation	6480.00	tonne of waste/year	
Specific heat consumption	0.0000	MWhth/ tonne of fresh fruit	
Specific electricity consumption	0.1023	MWhel/ tonne of fresh fruit	
Thermal energy demand	0.00	MWhth/year	
Electricity demand	368.10	MWhe/year	
Industrial process energy consumption and self-production			
Baseline genset			
Genset electricity self-production 1	36.81	MWhel/year	Annual electricity self-production of the genset 1.
Genset fuel consumption 1	10517.14	L	Annual fuel consumption of genset 1.
Baseline grid			
Grid electricity consumption	331.29	MWhe/year	
Baseline total energy self-production			
Total electricity self-production	36.81	MWhe/year	
Total thermal energy self-production	0.00	MWhth/year	

Figure 4: Sensitivity parameters to be defined at the bottom of Tab 1 "Input Data"

Optional - **SENSITIVITY ANALYSIS**

Sensitivity analysis

Number of steps required for the sensitivity analysis					3
Parameter	**Value**	**Maximum**	**Minimum**	**Units**	**Include in sensitivity?**
Plant Nominal Capacity Factor (CF)	90%	100%	10%	%	Yes
Baseline Genset 1 - Reference Fuel (or Feedstock) Costs	0.95	1.5	0.5	USD/L	Yes
Baseline Genset 1 - utilisation rate (grid backup system)	10%	20%	1%	%	Yes
Waste Treatment Costs	24.80	0	0	USD/tonne of waste	No
Bienergy Subsidy to CAPEX	0%	0%	0%	%	No
Electricity Export Price / Feed-in Tariff	100.00	150	0	USD/MWhe	Yes

Simulation progress counter **0 of 81**

RESULTS | **Click once to run SENSITIVITY** | **RESET WORKBOOK**

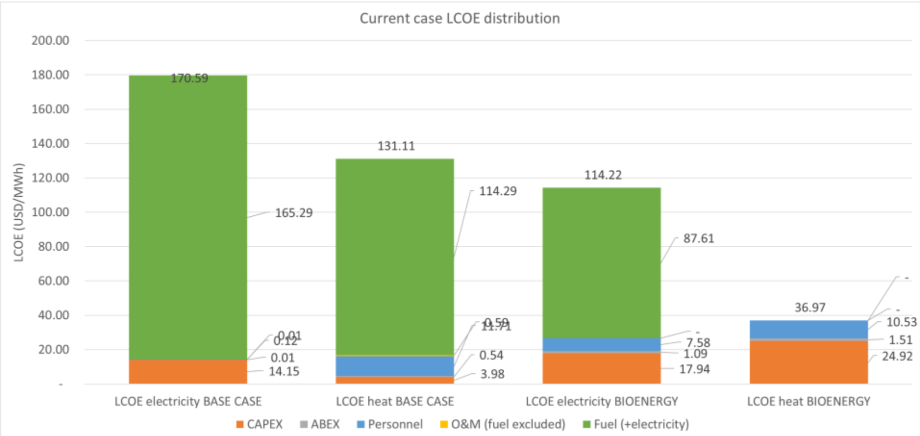
4 GRAPHICAL OUTPUTS

The results from the modelling tool are graphically plotted to facilitate interpretation and help extract conclusions. The model generates LCOE plots of both the 'Current Case' (which provides a comparison between the Base Case scenario and the Bioenergy Case scenario under the reported operational conditions at the sites analysed) and of the sensitivity analysis results.

4.1 CURRENT CASE CHART

The Current Case LCOE analysis and comparison plot shows the $LCOE_{electricity}$ and $LCOE_{heat}$ for both the Base Case and the Bioenergy Case scenarios, and illustrates the trade-offs of the bioenergy project implementation compared with the BAU approach.

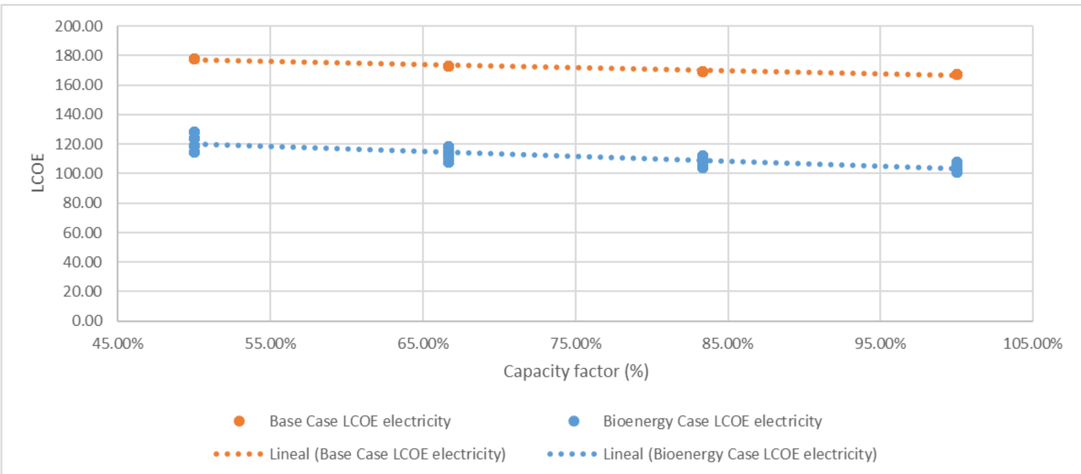
Figure 5: Current Case LCOE analysis chart



4.2 SENSITIVITY ANALYSIS CHARTS

The sensitivity analysis generates different charts that illustrate the relationships and influence of the dependent variables and input parameters that the user wishes to analyse (based on the selections made in the sensitivity analysis input data table). The sensitivity results are shown via scatter plots and best fit lines, for which an example is provided in Figure 6.

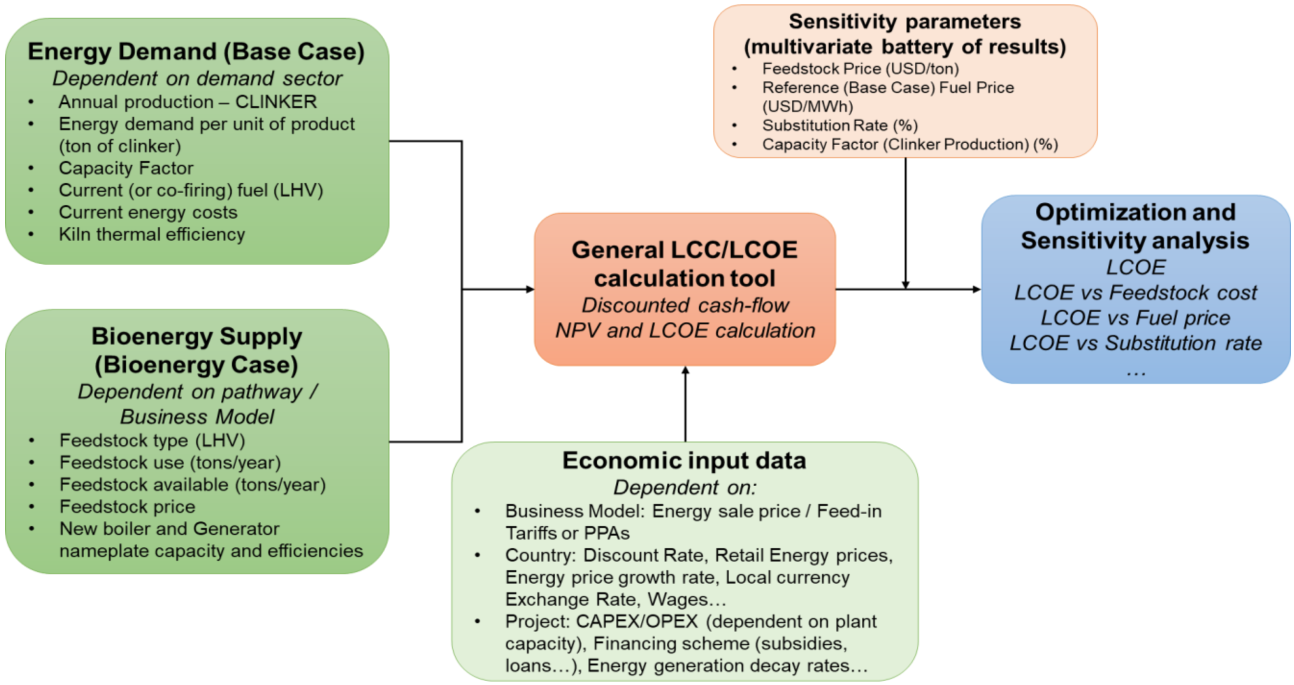
Figure 6: Sensitivity analysis results chart



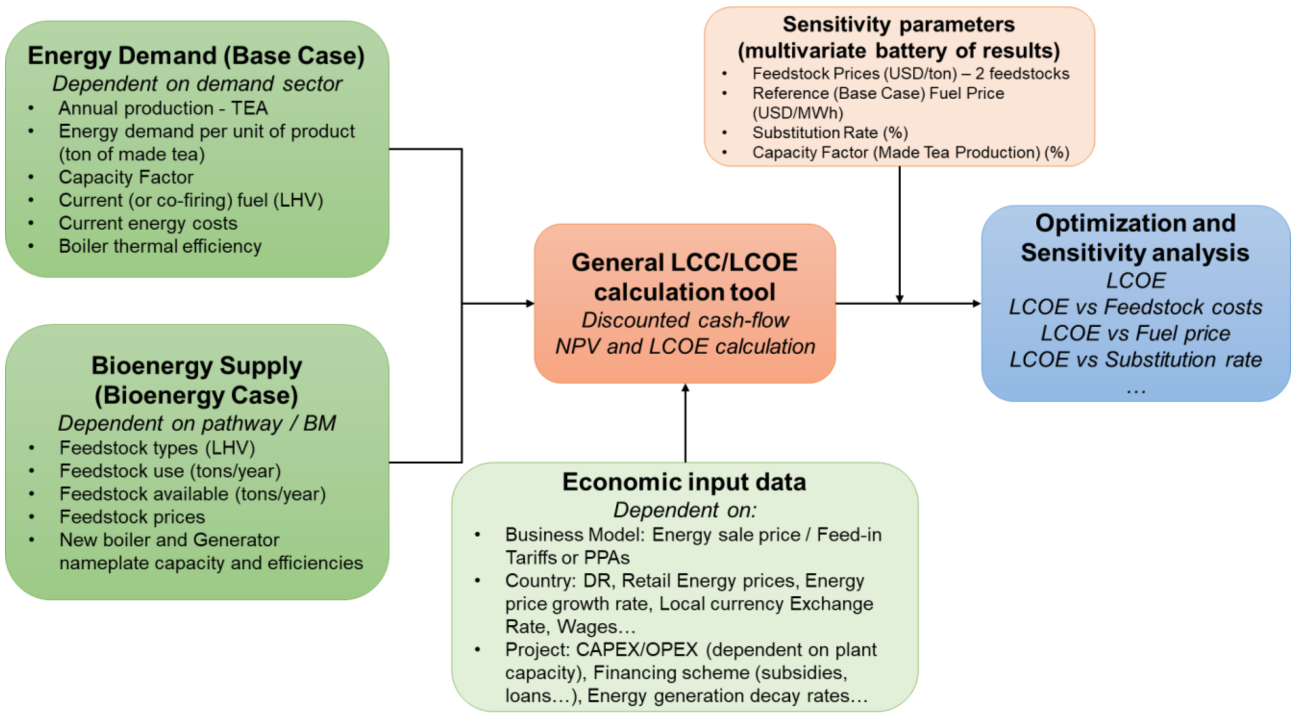
ANNEX: LCC MODELS ADAPTED TO EACH DEMAND SECTOR

This Annex presents the flow diagrams of the LCC toolkit functions adapted to each of the 7 Demand Sectors explored in this project.

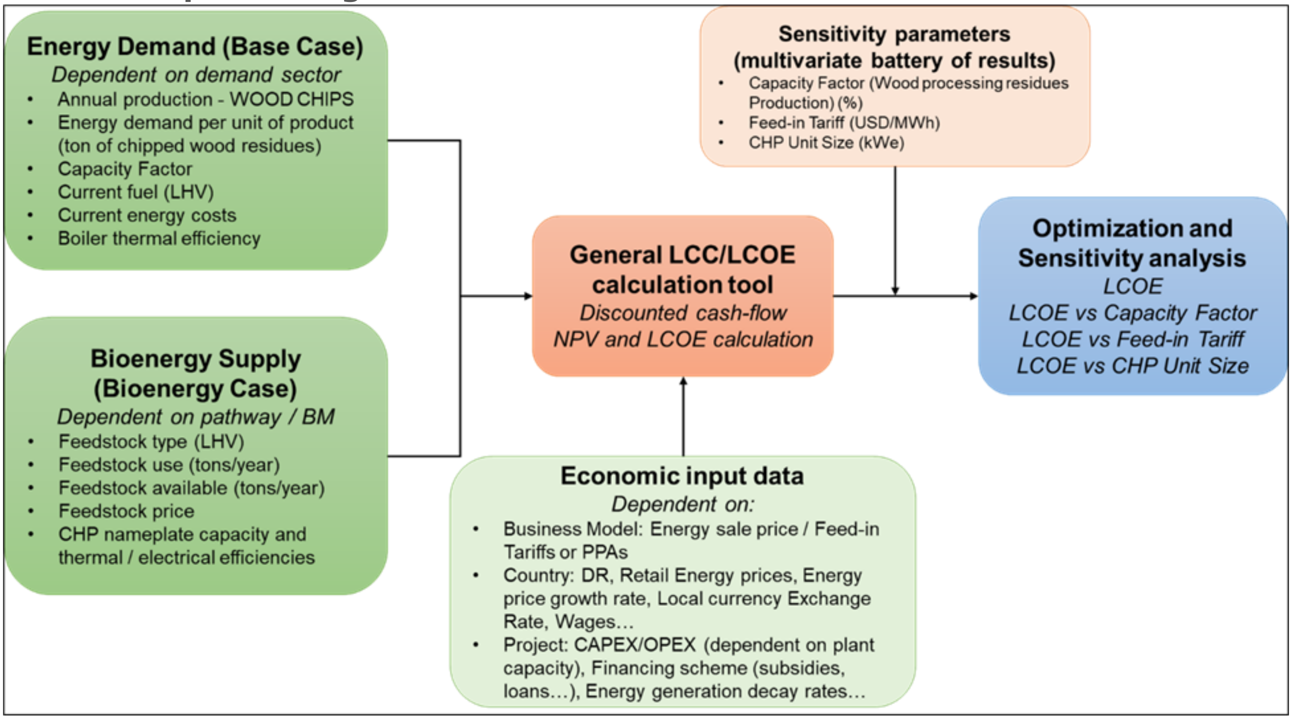
DS1 Cement manufacturing



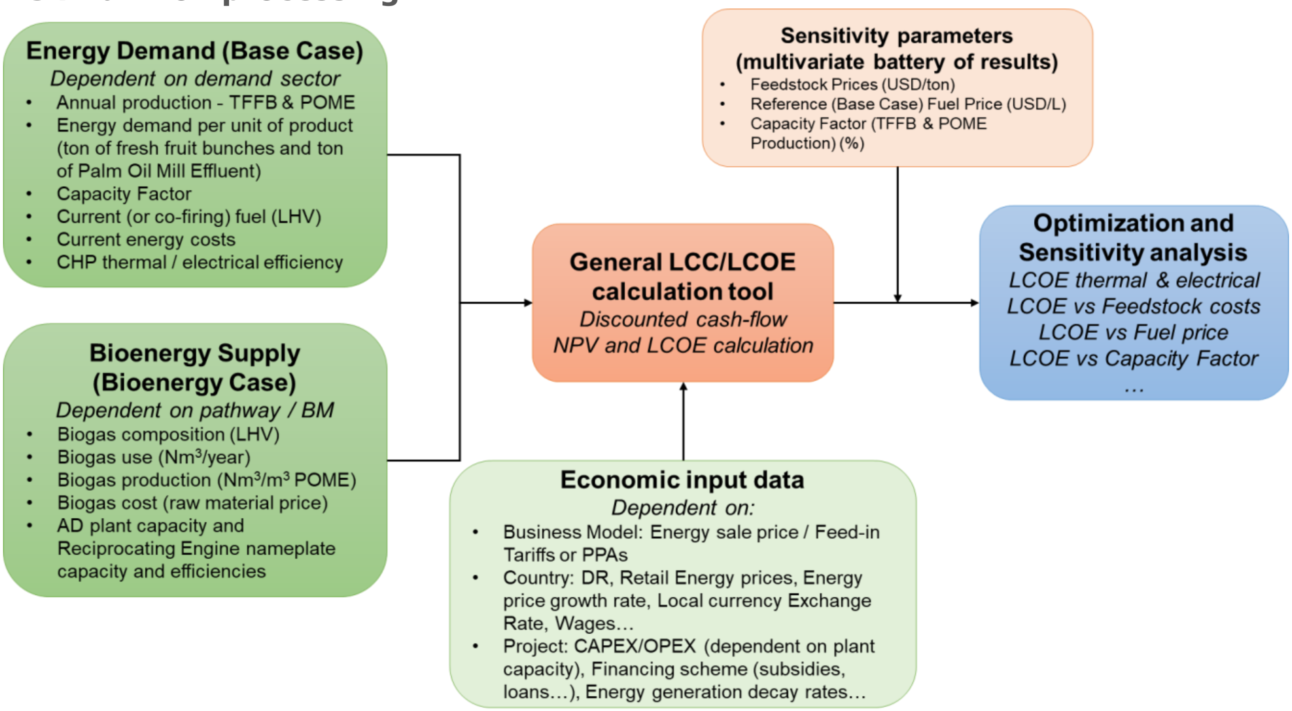
DS2 – Tea processing



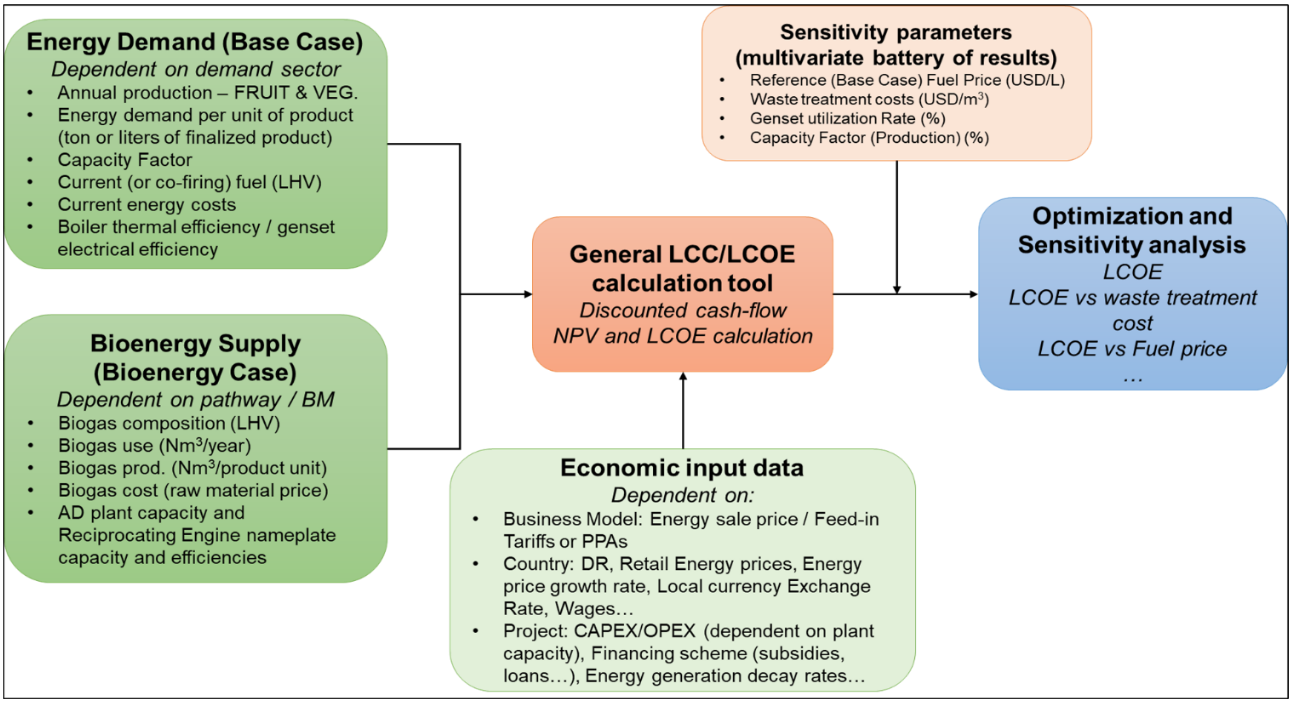
DS3 Wood processing



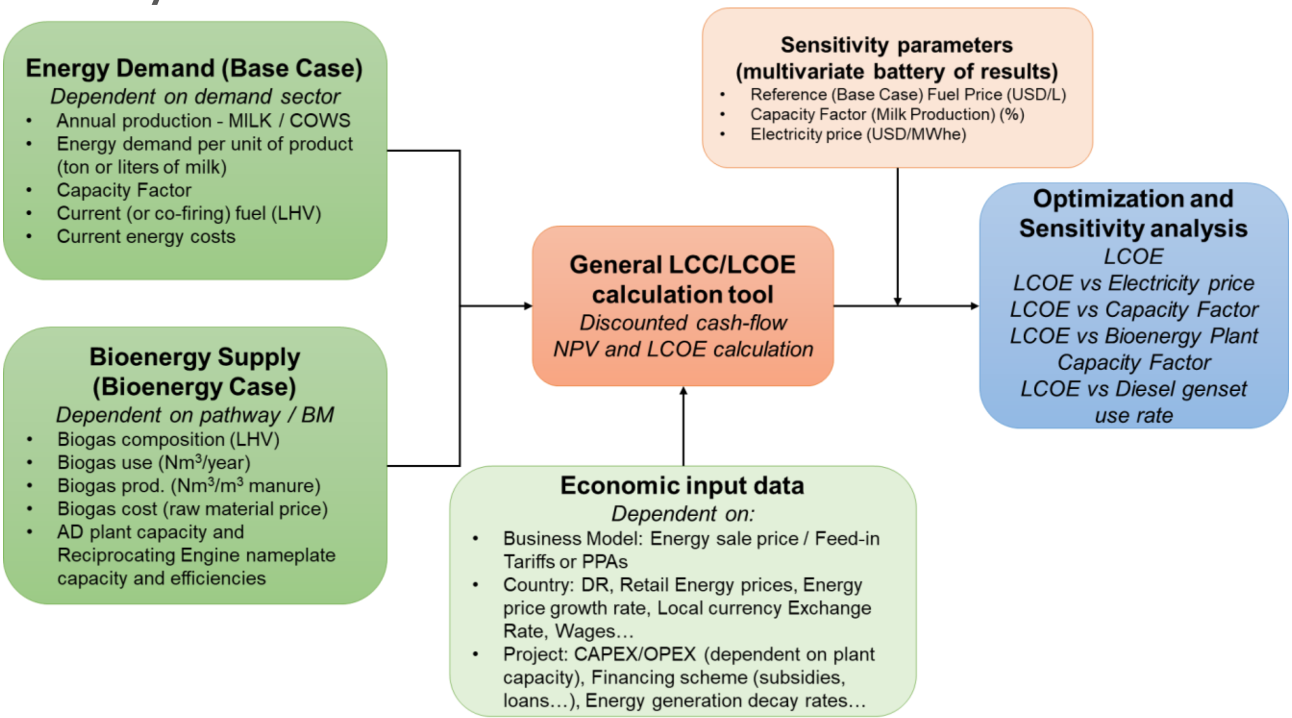
DS4 Palm oil processing



DS5 Horticulture



DS6 Dairy



DS7 Sisal processing