POTENTIAL OF SMALL SCALE BIOREFINERIES IN TROPICAL COUNTRIES

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Project Partners

Outline

- Introduction
- Integrated Biorefinery based on plantain
    - Plantain Pseudostem Biorefinery
    - Plantain Peel Biorefinery
- Integrated biorefinery based on amazon feedstocks
    - Aguaje
    - Macambo
    - Cedar
- Final Remarks

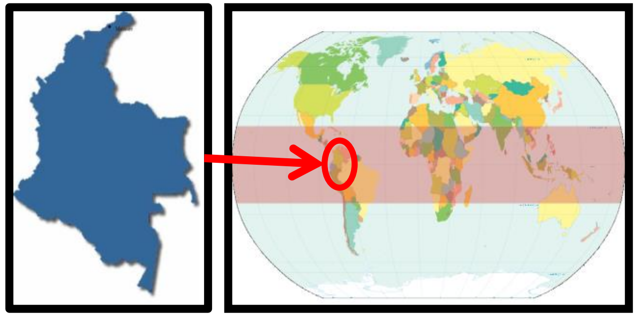
1. INTRODUCTION.

TROPICAL REGIONS

Tropical regions have an important production of renewable raw materials (mostly second generation feedstocks). A lot of direct or indirect added value products are losen

For the extraction of these important compounds it is necessary to carry out different operations such as extraction, concentration, purification, among others.

Small-scale biorefinery design



COLOMBIA is located in a tropical region.

SCALE OF THE BIOREFINERIES

Sell prices per kilo or kWh:

Ethanol. 0.5 to1.5 dollars

Biopolymers. 10-100 dollars

Electricity 0.1 to 1 dollar

Biodiesel. 0.5 to 1.3 dollars

Antioxidants 40 to 2000 dollars

Food and food additives 1 to 500 dollars

Small-Scale Biorefineries

The small-scale biorefineries are the new trend in design because these operations sometimes are unfeasible in large scale due to its production cost or market restrictions in quantity.

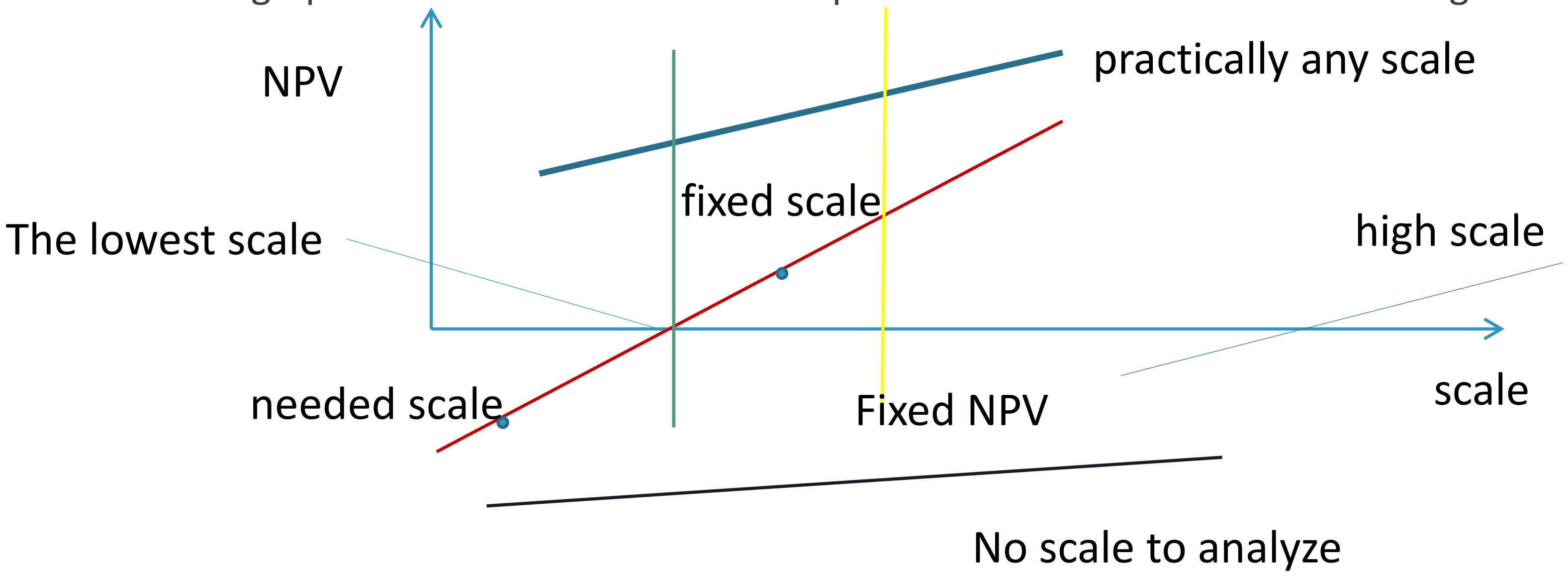
Small-scale biorefineries are affected by external factors such as:

- ✓Government policies.
- ✓Environmental considerations.
- ✓Market conditions.
- ✓Transportation and Distribution costs.

How to define the small or high scale biorefinery. A technical approach.

Algorithm

1. Calculate your desired biorefinery at any scale.
2. Analyze the production costs, profit and net present value (NPV)
3. Develop the point 2 at different scales and fix the profit or NPV you want.
4. Define in the obtained graphic the cases below the fixed profit or NPV as “small scale” and higher as “high scale”.



How to define the small or high scale biorefinery. A technical approach.

Algorithm (cont)

5. Based on conceptual design, transform the lower profit or NPV for small scale biorefineries as a challenge for your design: How can we make these small scale cases as profitable?:

Integration

Increase the number or fraction of high value added products

Technology changes

6. Redefine your problem or target as needed and repeat points 1-4.

Methodology

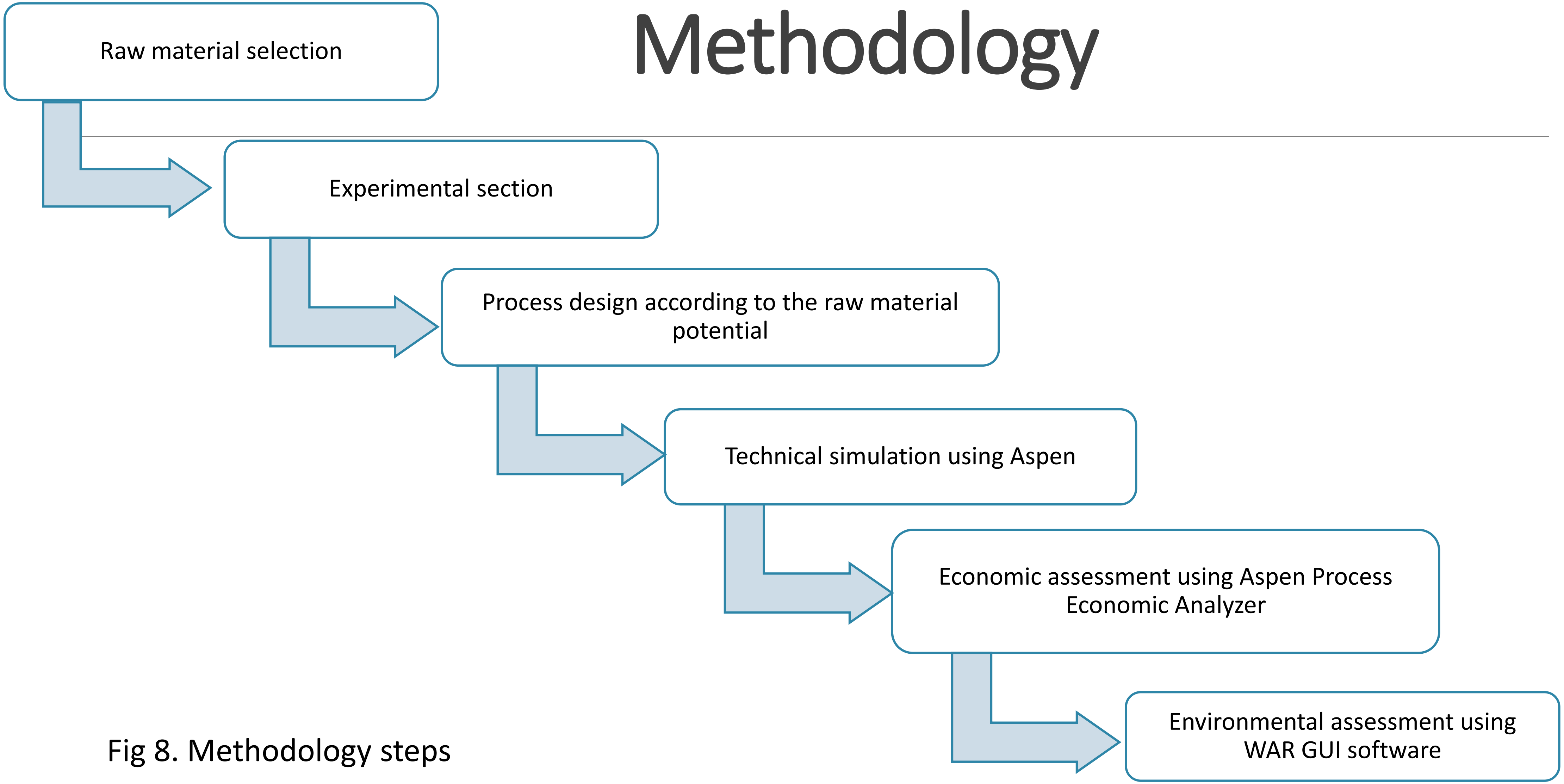


Fig 8. Methodology steps

Plantain Pseudostem (PP)

The plantain pseudostem is the non-edible part of the plantain plant, it represent the 50 % of total biomass

7.3 million tons of plantain pseudostem wes produced in 2014

Plantain Pseudostem is used for nutrient assistance of new plants. But also in the paper fabrication and currently, as raw material for the production of sugars to obtain other added-value products

Figure 2. Plantain Pseudostem

Table 1. Chemical Composition PP

Component	% dry basis
Cellulose	43.46
Hemicellulose	33.77
Lignin	20.14
Extractives	2.5
Ash	0.14

Plantain Peel

Figure 3. Plantain Peel

Represents between 30% and 40% of the total fruit weight

Approximately 1 kilogram of plantain bunches produces 360 grams of plantain peel

Applications studies → Starch extraction for the food industry, extraction of phenolic compounds and antioxidants

Table 2. Chemical Composition Plantain Peel

Component	% dry basis
Cellulose	27.7
Hemicellulose	22.7
Lignin	27.9
Crude Protein	7.4
Extractives	7.9
Ash	6.4

Plantain Pseudostem Biorefinery

Acid Hydrolysis
Sulfuric Acid 2%w/w
Temperature = 122°C
Water to Solid Ratio (WSR) = 8g/g

Detoxification
Overliming with Lime
Temperature = 60°C

Alkaline treatment
NaOH 2 %w/v
Temperature = 120°C
Water to Solid Ratio = 10 g/g

Enzymatic Saccharification
Celluclast 1.5L
Temperature = 45°C
Biomass to Enzyme Ratio = 2% w/v

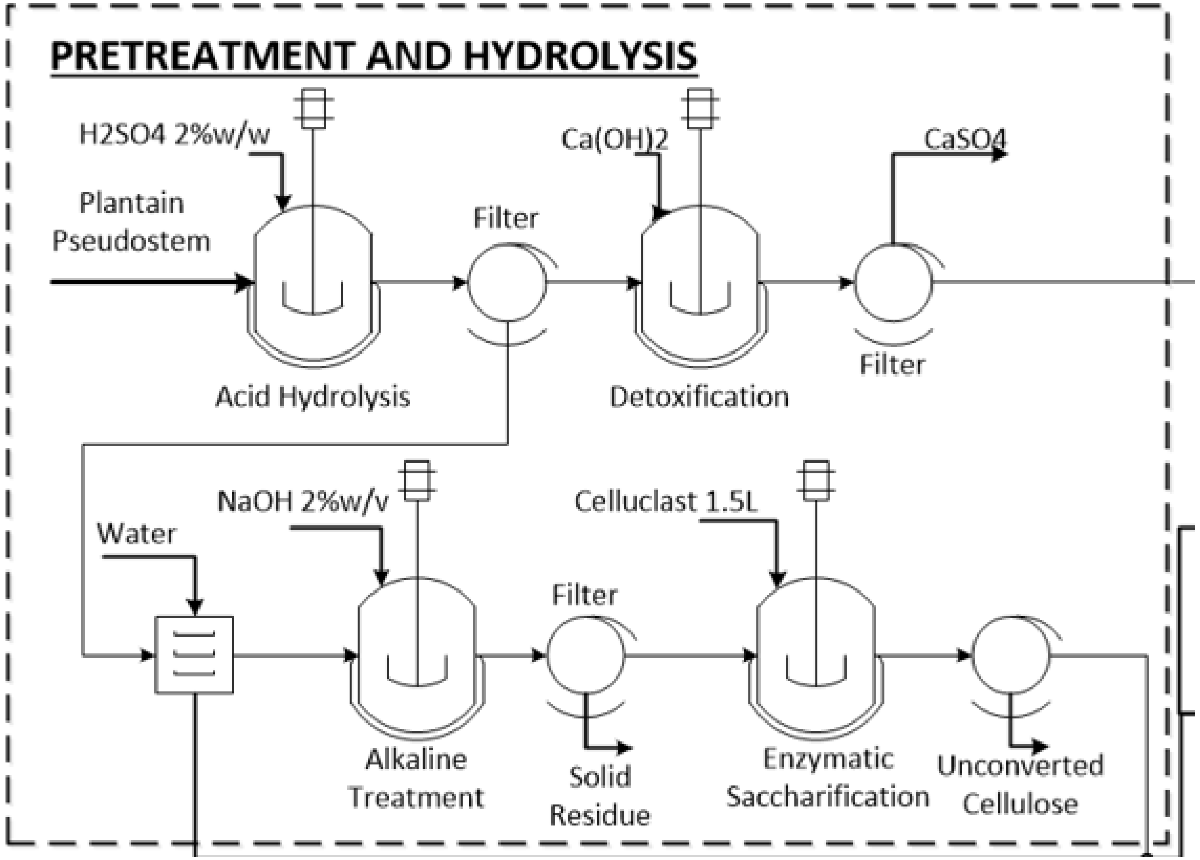


Figure 4. Pretreatment Process Scheme

Plantain Pseudostem Biorefinery

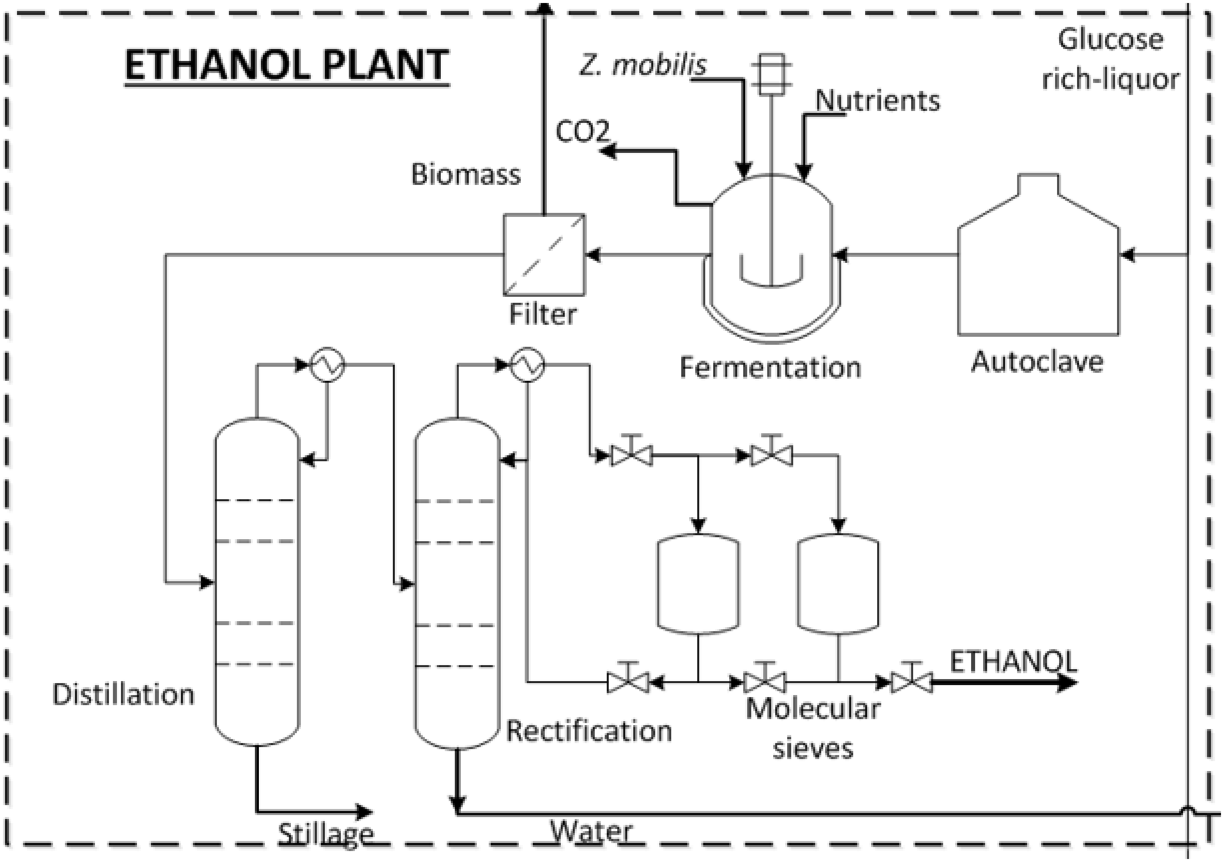


Figure 5. Ethanol Process Scheme

Fermentation
Microorganism = *Z. mobilis*
Temperature = 30°C

Downstream
Distillation column = Ethanol 50-55%wt.
Rectification column = 96%wt.
Molecular Sieves = 99.7%wt.

Plantain Pseudostem Biorefinery

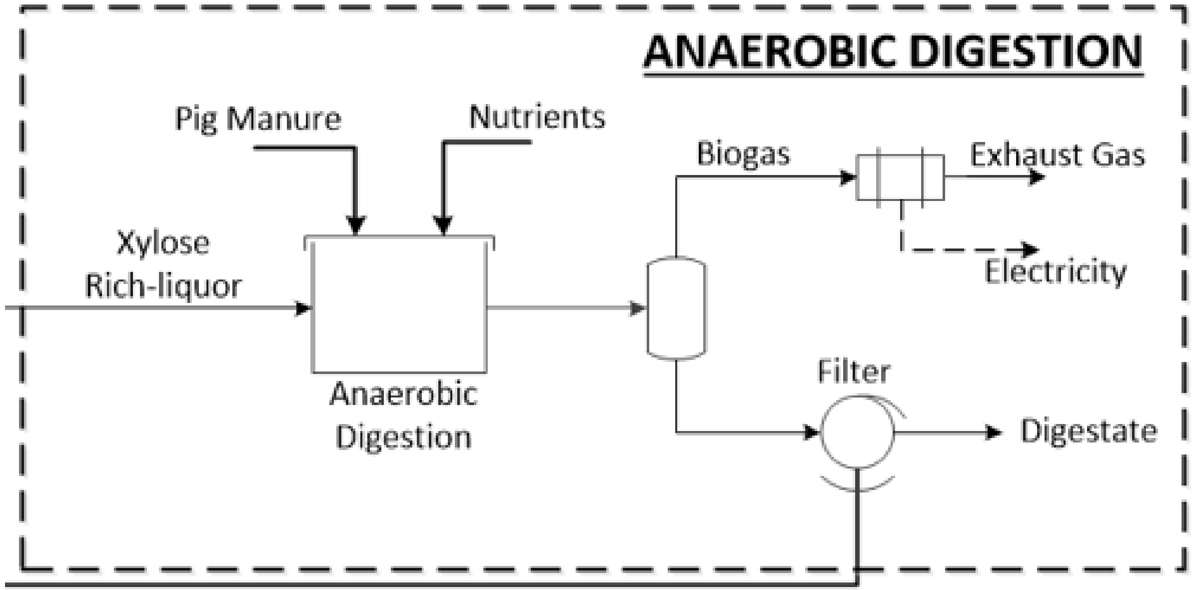


Figure 6. Anaerobic Digestion Process Scheme

Anaerobic Digestion

Inoculum = Pig Manure

Substrate to Inoculum Ratio = 1:2

Temperature = 37°C

Electricity generation from biogas = 1.7 kWh/cum biogas

Plantain Peel Biorefinery

Acid Hydrolysis
Sulfuric Acid 2%w/w
Temperature = 122°C
Water to Solid Ratio (WSR) = 10 g/g

Detoxification
Overliming with Lime
Temperature = 60°C

Alkaline treatment
NaOH 1 %w/v
Temperature = 121 °C
Water to Solid Ratio (WSR) = 8 g/g

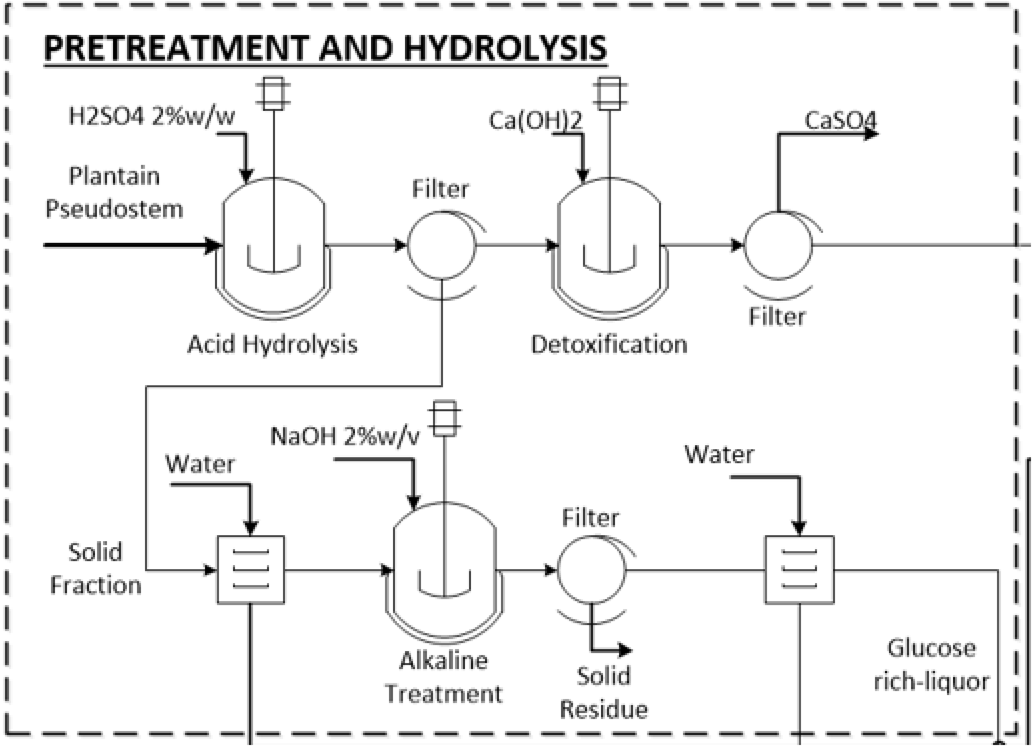


Figure 7. Pretreatment Process Scheme

Plantain Peel Biorefinery

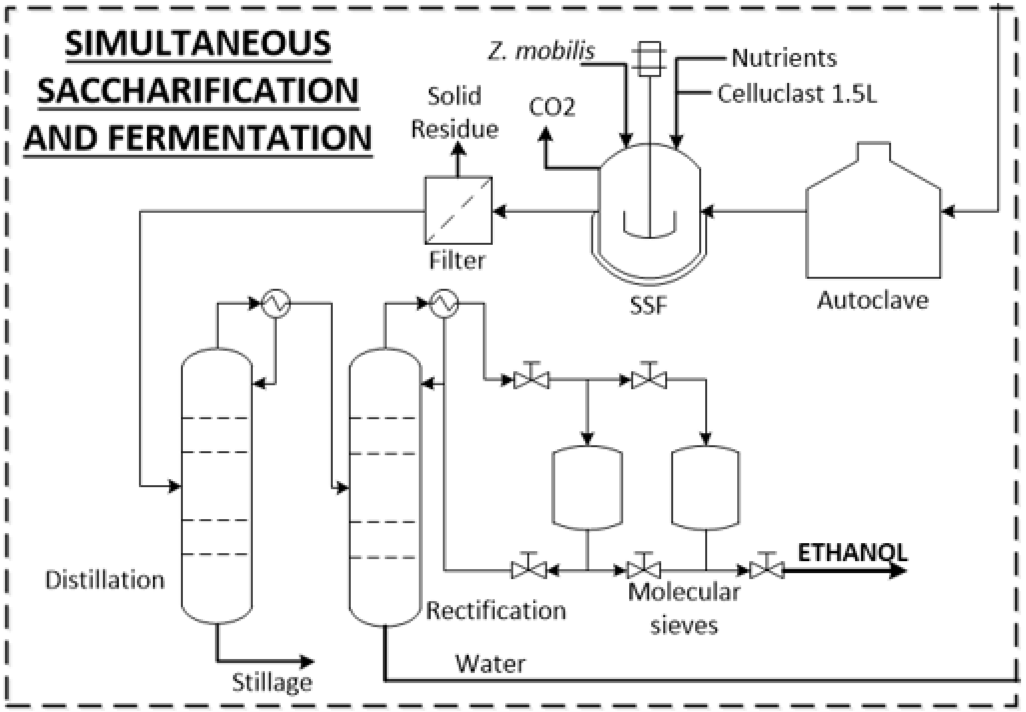


Figure 8. Simultaneous saccharification and fermentation Process Scheme

Simultaneous saccharification and fermentation
Enzyme = Celluclast 1.5L
Temperature = 40°C
Biomass to Enzyme Ratio = 2% w/v
Microorganism (ethanol) = Saccharomyces Cerevisiae

Plantain Peel Biorefinery

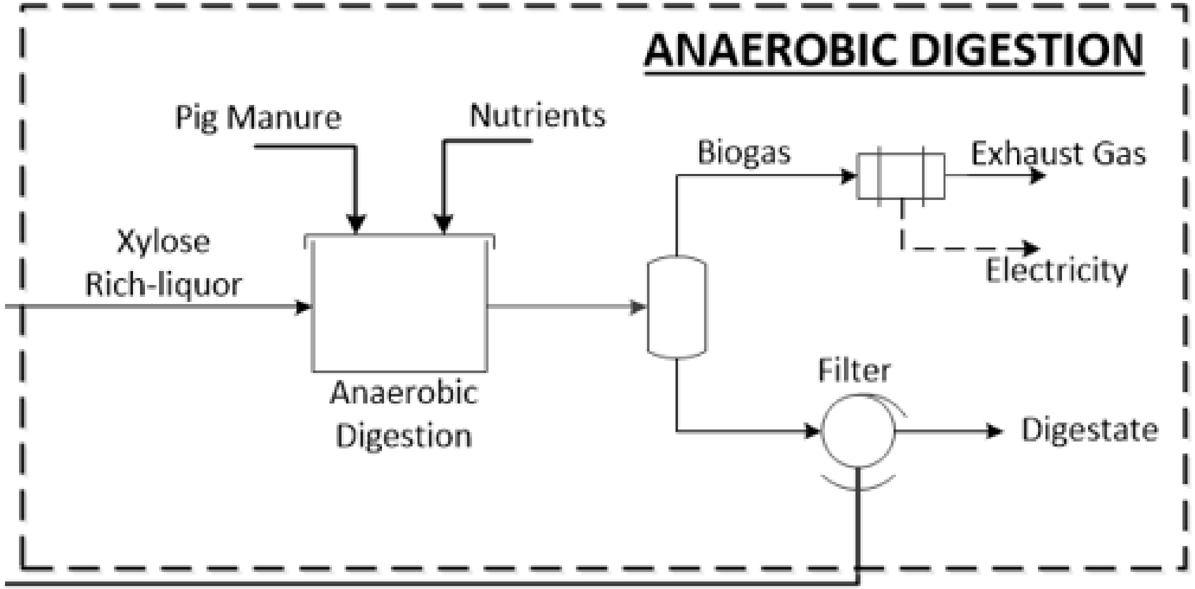


Figure 9. Anaerobic Digestion Process Scheme

Anaerobic Digestion
Inoculum = Pig Manure
Substrate to Inoculum Ratio = 1:2
Temperature = 37°C
Electricity generation from biogas = 1.7 kWh/cum biogas

Plantain Peel Biorefinery

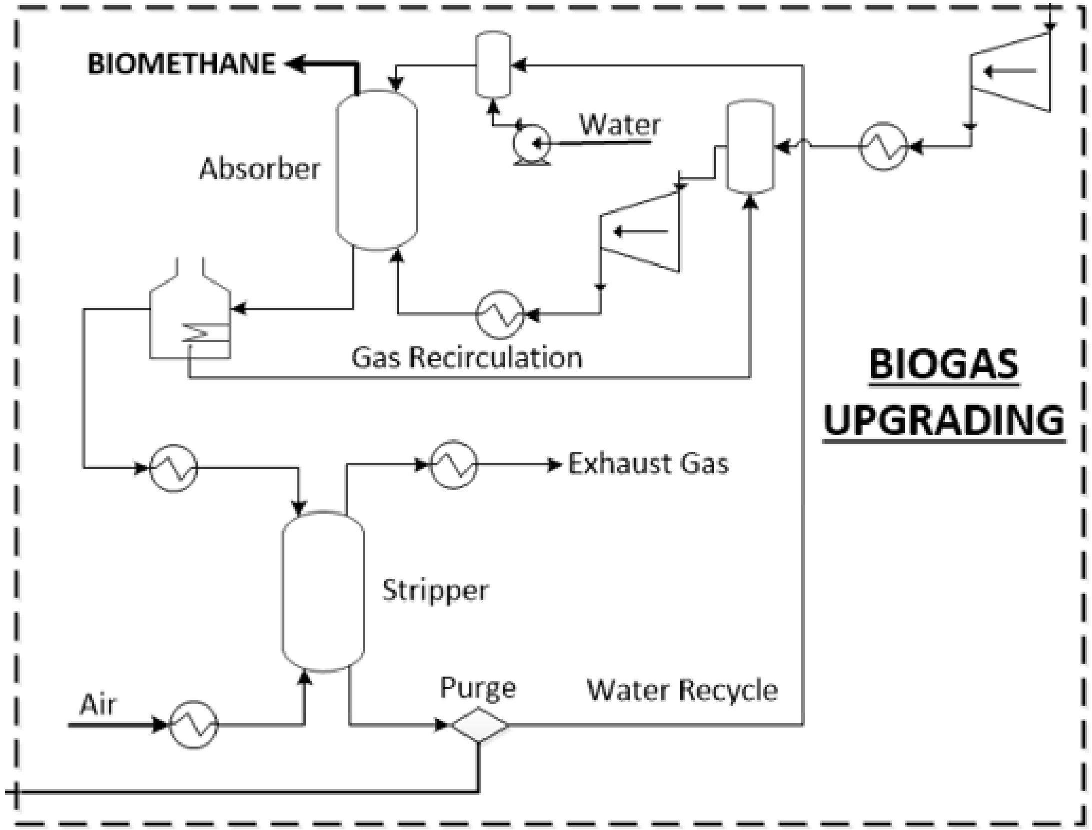


Figure 10. Biomethane Process Scheme

Biogas Upgrading (Absorption and Stripping)

Absorber
Pressure = 10 bar
Temperature = 20°C
Absorption agent = Water

Stripper
Pressure = 1 bar
Temperature = 20°C
Stripping Agent = Air

Biomass integrated gasification combined cycle (BIGCC)

Biomass dryer, gasification chamber, gas turbine and heat steam recovery generator (HRSG)

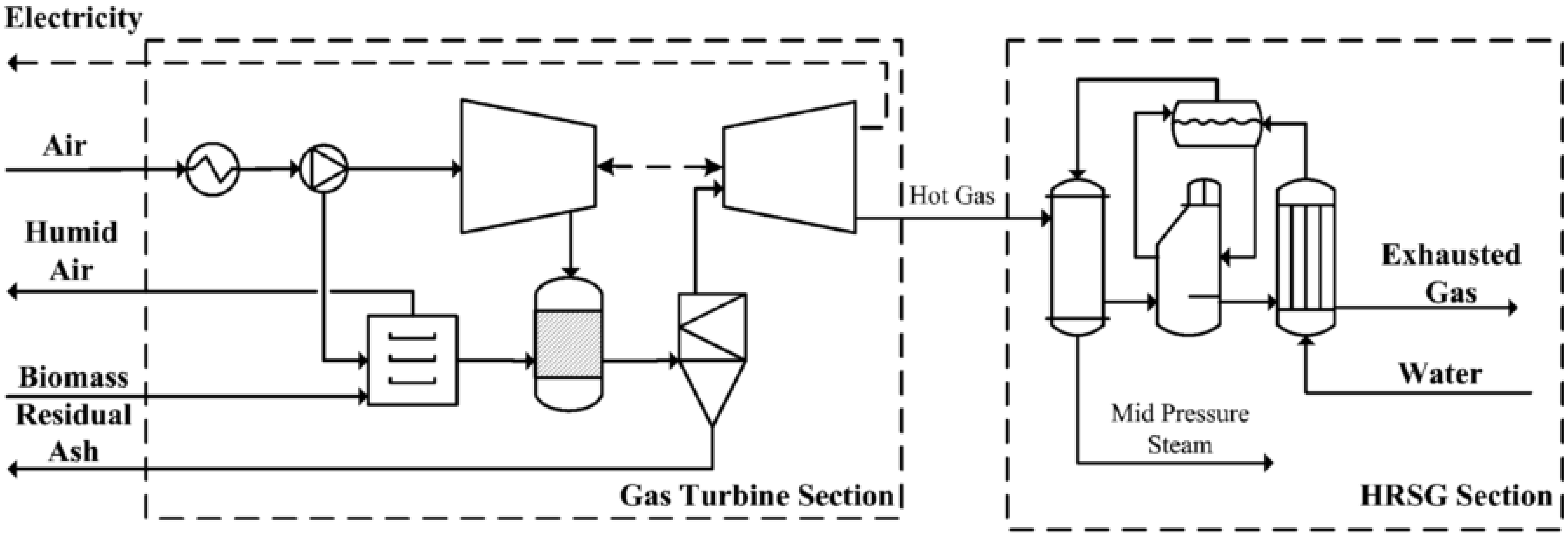


Figure 11. Cogeneration Process Scheme

Process Simulation plantain

Table 3. Bioethanol productivity and yield of the integrated biorefinery

Products	Productivity		Yield	
	Value	Unit	Value	Unit
Plantain Pseudostem	148.31	m^3/day	102.85	L/ton
Plantain Peel	17.62	m^3/day	0.29	L/ton

Economic Assessment

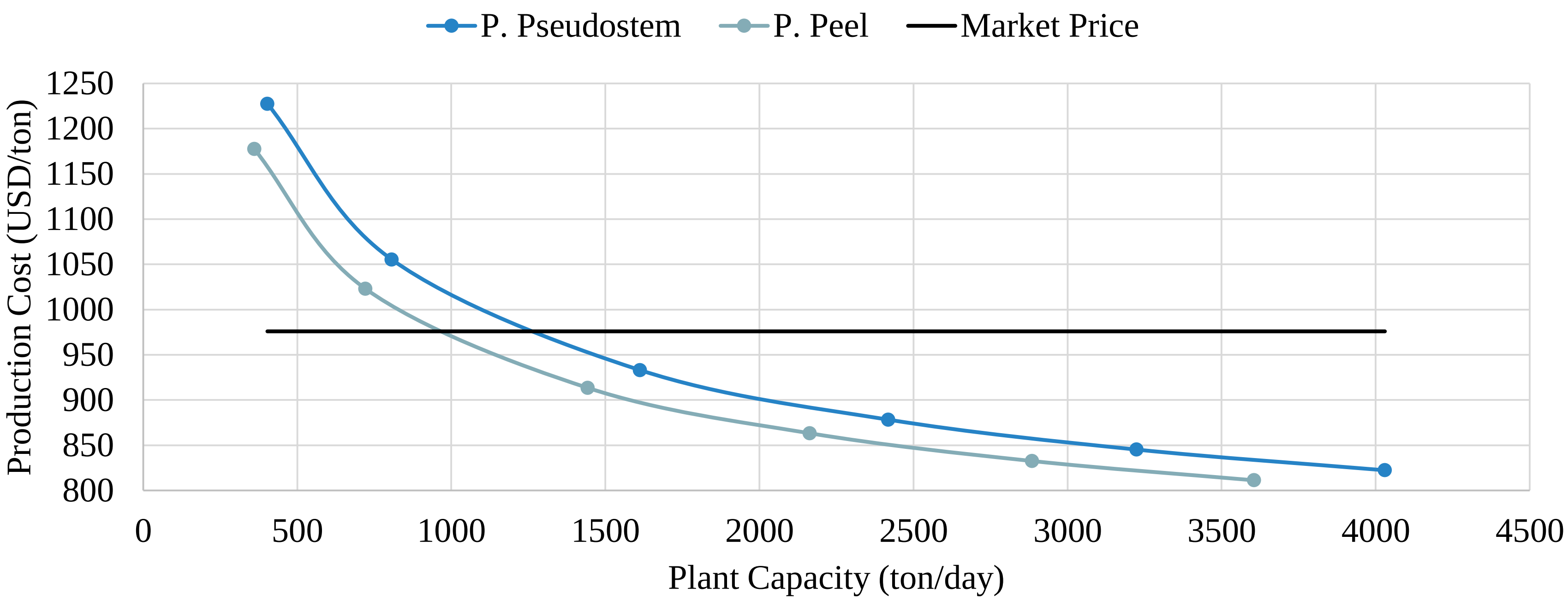


Figure 12. Effect of each plant processing capacity in the production cost of the bioethanol.

Economic Assessment

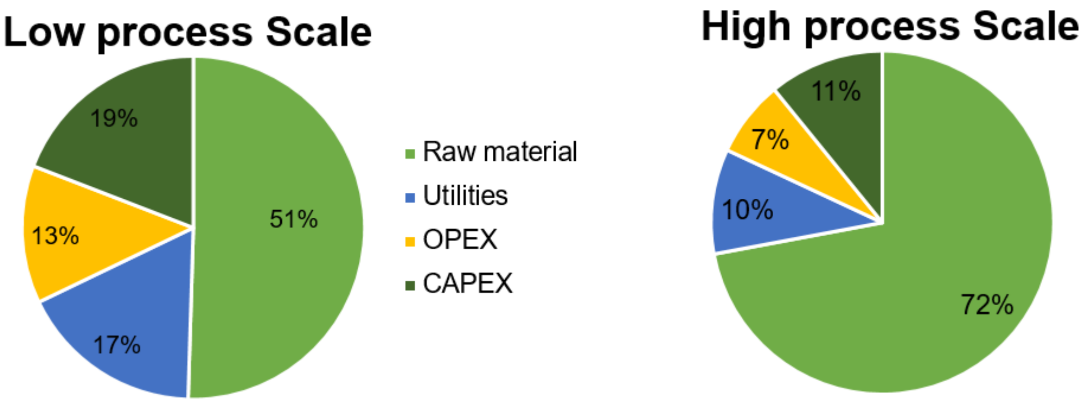


Figure 13. Effect of the process scale in the contribution of the main economic parameters of the pseudostem biorefinery

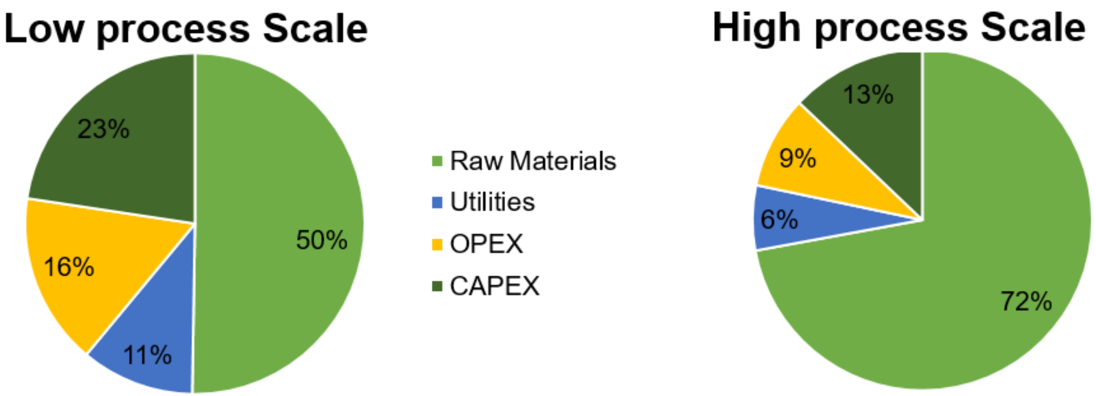


Figure 14. Effect of the process scale in the contribution of the main economic parameters of the plantain peel biorefinery

Economic Assessment

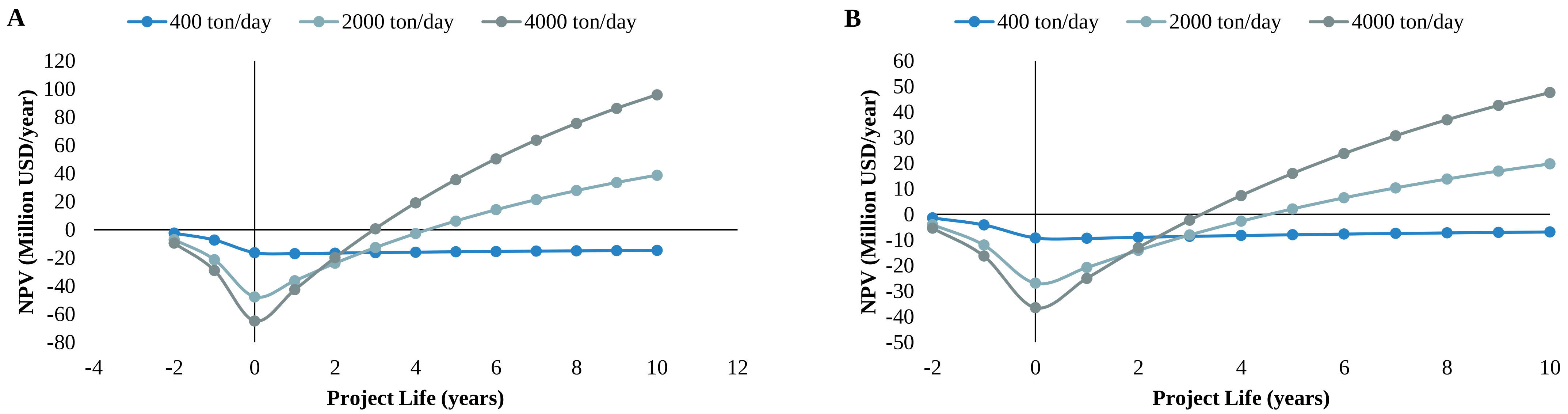


Figure 15. Effect of the plant capacity in the economic profitability of the biorefinery. A. Plantain Pseudostem. B. Plantain Peel

Market Price Sensibility Analysis: Pseudostem

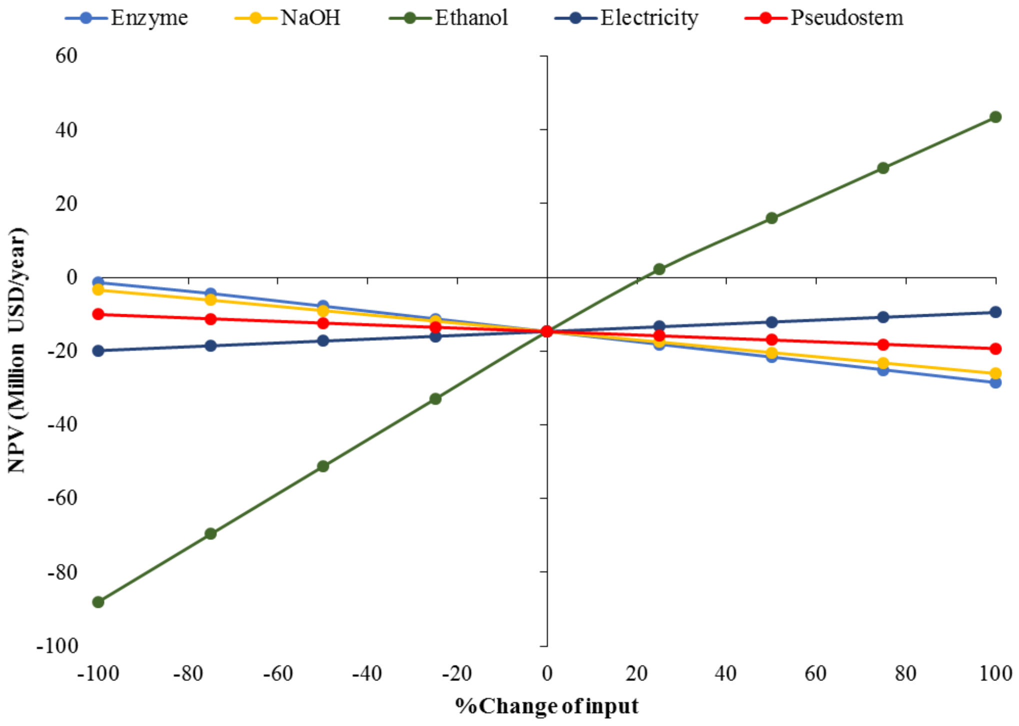


Figure 16. Market Price Variations of low-scale biorefinery (200 ton/day)

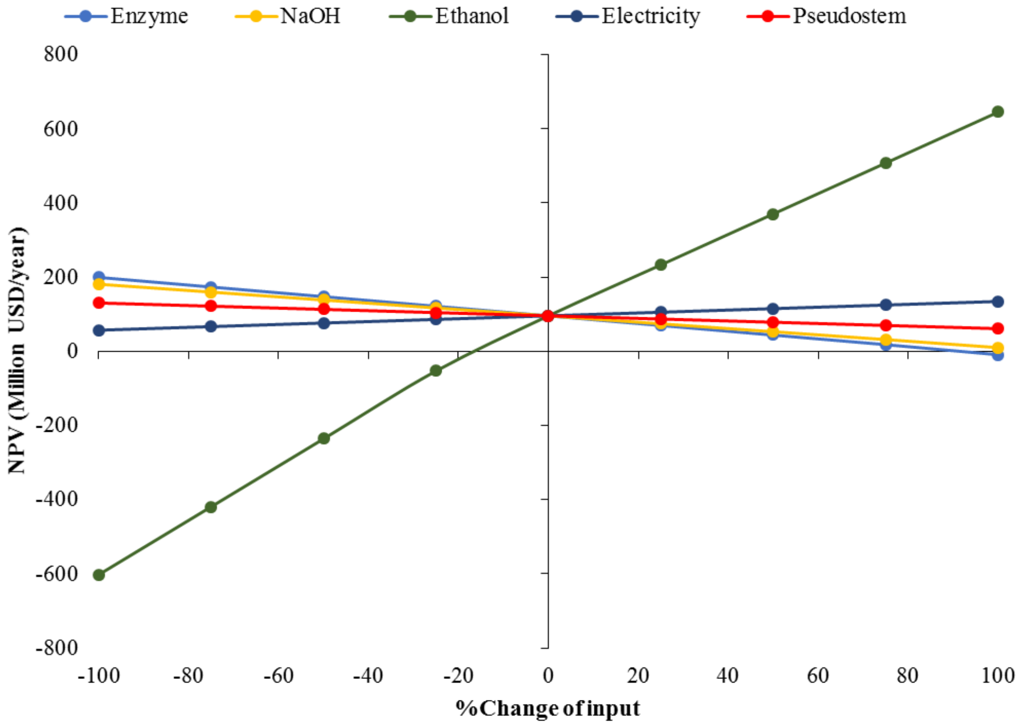


Figure 17. Market Price Variations of high-scale biorefinery (2,000 ton/day)

Market Price Sensibility Analysis: Peel

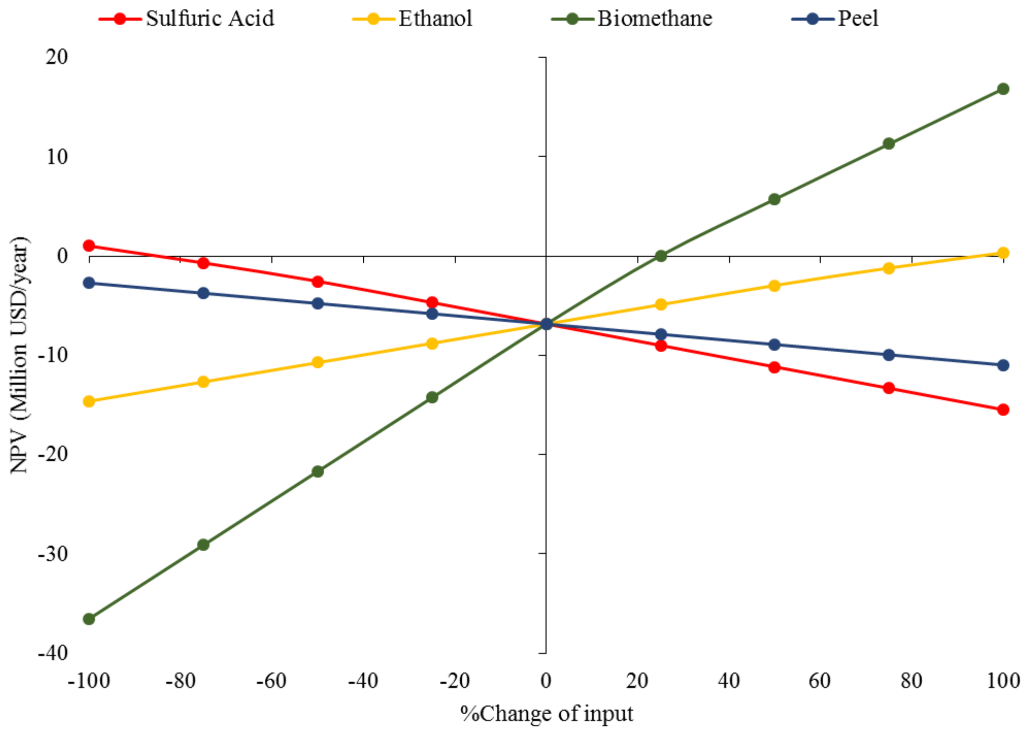


Figure 18. Market Price Variations of low-scale biorefinery (200 ton/day)

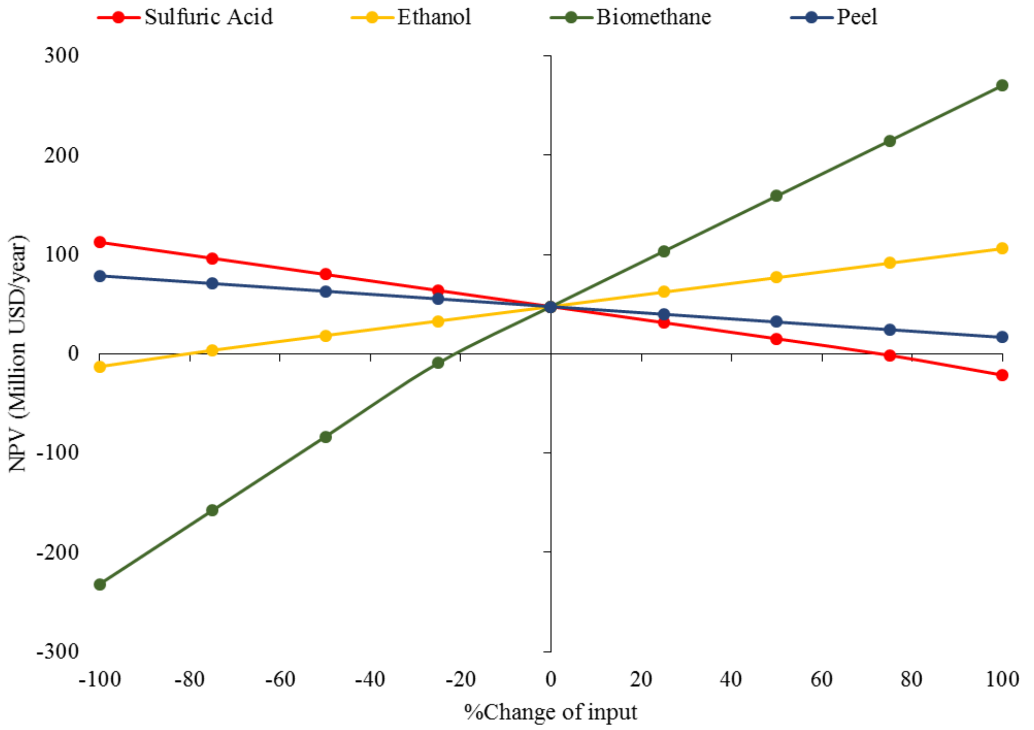


Figure 19. Market Price Variations of high-scale biorefinery (2,000 ton/day)

Environmental Assessment

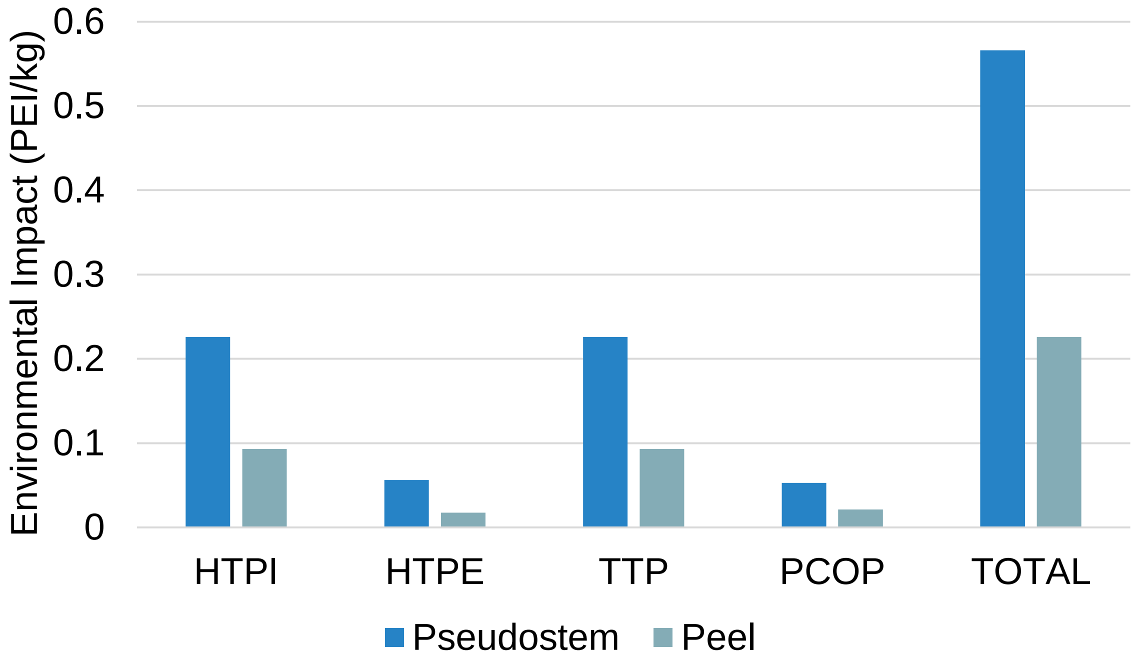


Figure 20. Potential Environmental Impact of the Integrated Biorefinery

High Contribution to PEI

Human Toxicity by Ingestion (HTPI) and Terrestrial Toxicity Potential (TPP)

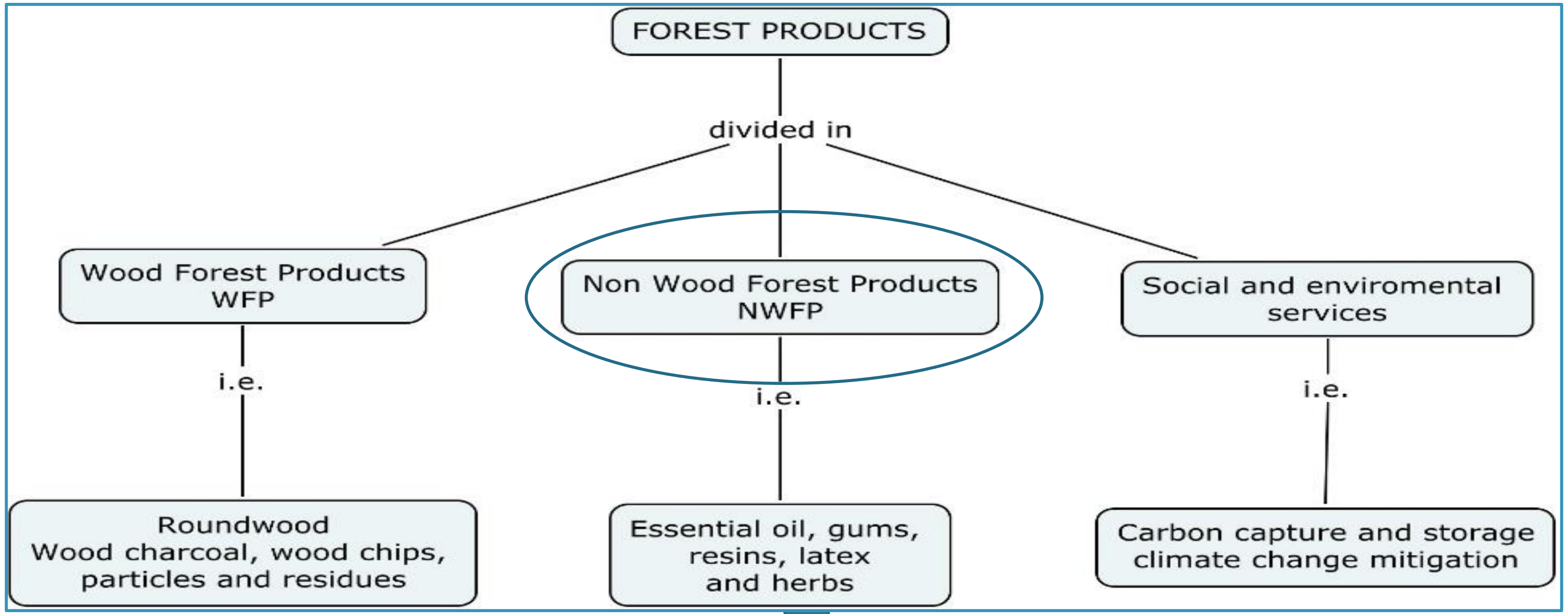
LD_{50} (Lethal Dose)

Xylose = 23,000 mg/kg

Glucose = 25,800 mg/kg

Case 2.Forest products

- 60 million indigenous inhabitants depend on forests
- 350 million people derive much of their livelihood and income from forests



Natural Products

Some are used in food, cosmetics and pharmaceutical applications.

Fig 6. Forest products classification

FAO, *Situación de los bosques del mundo 1999*. Roma, 1999.

International market of Natural Products

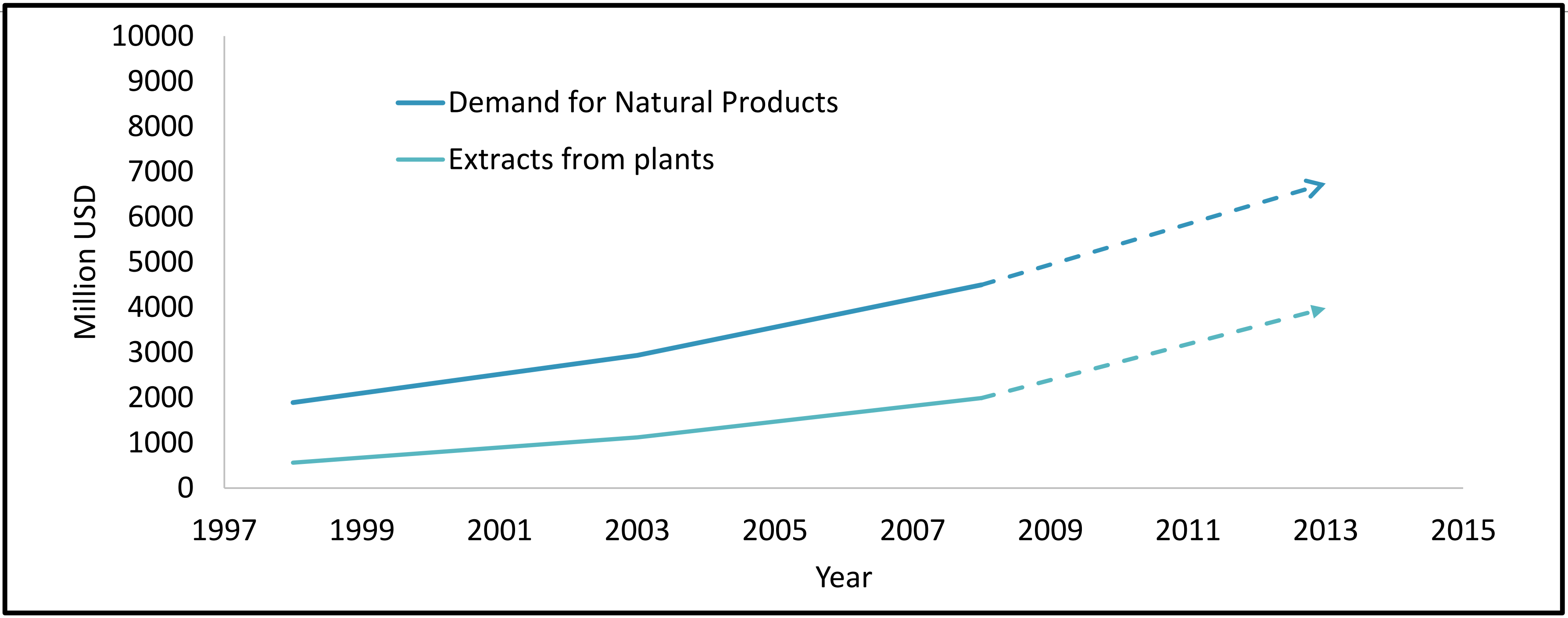


Fig 7. Annual international market of Natural Products

A. Zevallos Perez, “Informe ejecutivo de ferias,” Perú, 2013.

Experimental section

Experimental yields

SFE

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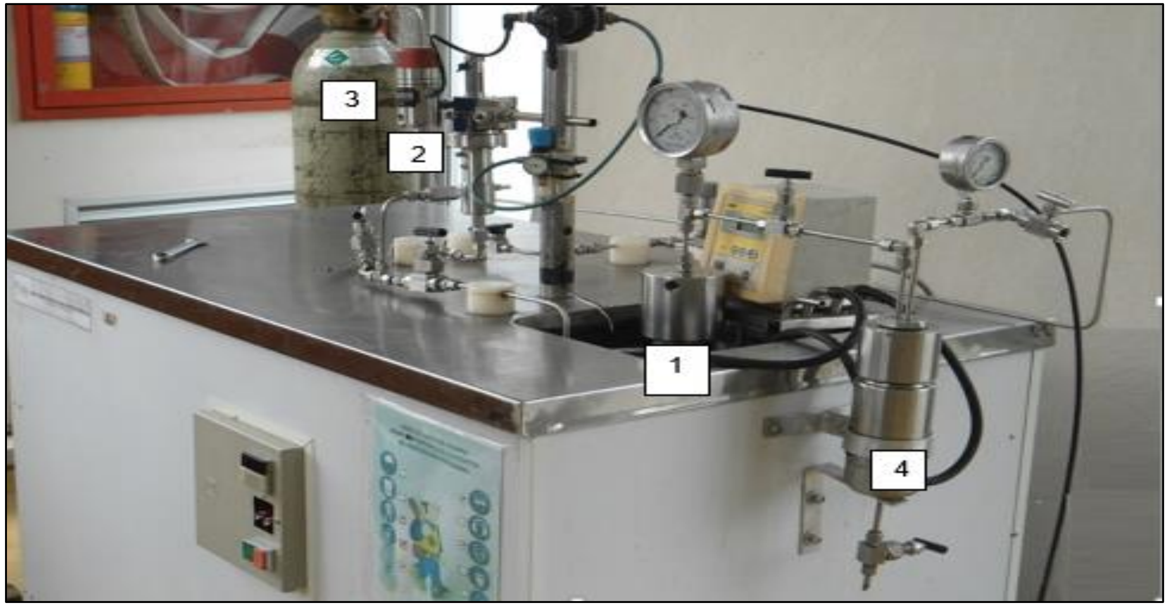

Figure 11. Supercritical extractor

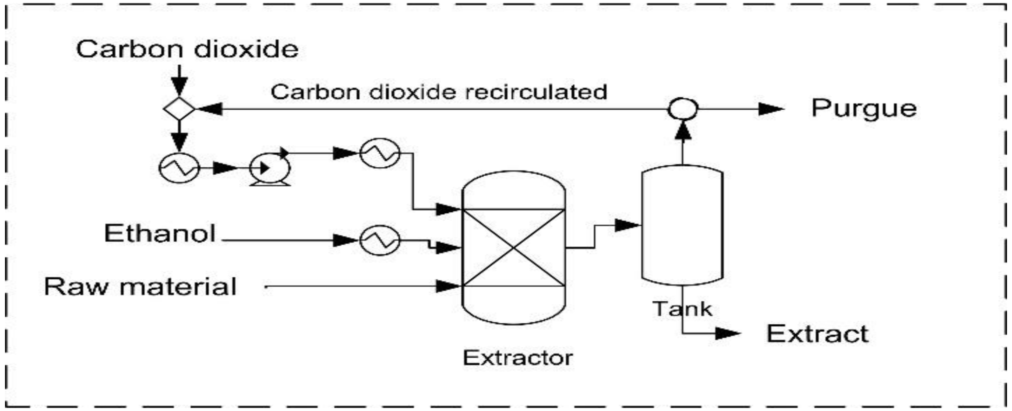

Figure 12. Simplified super critical extractor

1. Stainless steel cylinder.
2. Pump system.
3. Fluid CO_2.
4. Collector tank.

Experimental section

Experimental yields

Mechanical "butter"

extraction

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Temperature: 40°C and 70°C
Pressure: and 700 psi

Figure 13. Mechanical press

Experimental section

Experimental yields

Essential oil extraction

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Figure 14. Essential oil extractor

1. A stainless steel cylinder.
2. Boiler.
3. A condenser.
4. Collector tank.

Process design according to the raw material potential

Products selection:

Chemical characterization and published data.

Technology selection:

Logistical context of the region.

Scenarios definition:

Two process configuration (scenarios).

Scenario 1: base case.

Scenario 2: Extension of Sc 1 with wastes reduction. – Biorefinery concept.

Scenario 1 - rural areas.

Scenario 2 - Leticia.
Process extraction associated with the solvent use had to be limited due to the constraints attached with illicit traffic.

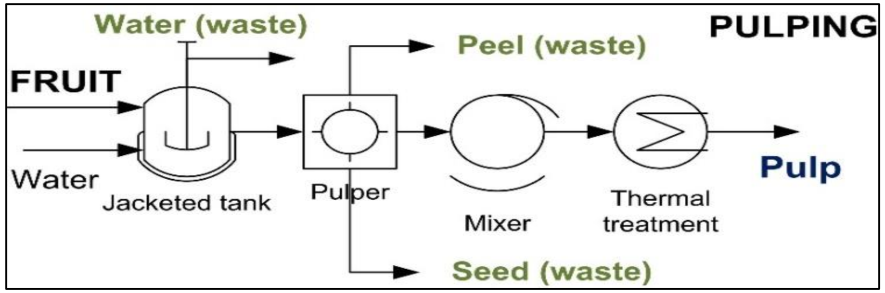


Figure 15. Simplified process-flow Scenario 1

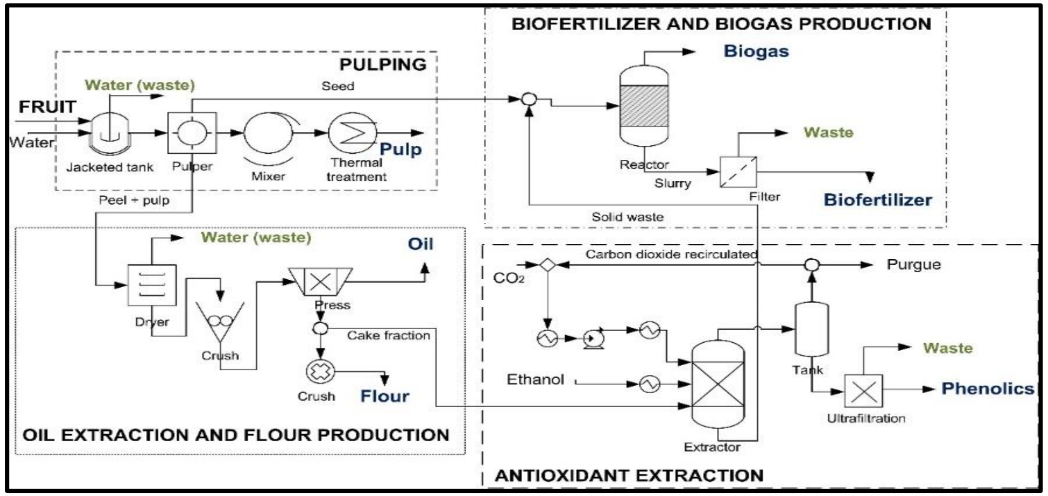


Figure 16. Simplified process-flow Scenario 2

Process simulation

Technologic assessment:

Mass and energy balances.

Economic assessment:

Period:10 years.

Amazonas context.

8 Categories: raw material, operating labor, maintenance, utilities, operating charges, plant overhead, general and administrative and capital depreciation cost.

Economic metrics: Net present value, profitability index, payout period.

Individual production cost: Allocation factor.

Sensitivity analysis: 50% above and below of prices.

Production capacity: 1 tonne (base case), 3, 5, 7 and 10 tonne/day.

Environmental assessment:

Potential Environmental Impact (PEI):

HTPI: Human Toxicity Potential by Ingestion, **HTPE:** Human Toxicity Potential by Exposure, **TTP:** Terrestrial Toxicity Potential, **ATP:** Aquatic Toxicity Potential, **GWP:** Global Warming Potential, **ODP:** Ozone Depletion Potential, **PCOP:** Smog Formation Potential, **AP:** Acidification Potential.

Raw materials selected

Makambo	Aguaje	Cedro
Theobroma bicolor	*Mauritia flexuosa*	*Cedrela odorata*
		
Sterculiaceae family. Theobroma cacao (Cocoa) and Theobroma grandiflorum (Copoazú). It grows in different regions of Central and South America. Pulp has been used for direct consumption as food. Seeds are used as a kind of cocoa. Peel is generally disposed as waste.	Arecaceae family. Amazonian tree, that grows in Brazil, Colombia, Ecuador, Bolivia, Venezuela and Peru. The tree grows in an ecosystem called “cananguchales” or “aguajales”.	Meliaceae family. It is one of the most important timber trees in Latin America. The excellent quality of the wood makes it one of the most expensive in the market.

Table 3. Raw materials

Makambo case

Theobroma bicolor

http://foro.portalplantas.com/plantas-en-general/4613-plantas-y-flores-curiosas-11.html

http://aplicaciones2.colombiaaprende.edu.co/concursos/expediciones_botanicas/fotos/918_6316_1.jpg

Chemical characterization

Features	Pulp (%)	Seed (%)	Peel (%)
Fruit proportion	**25,7 ± 3,7**	36,0 ± 3,1	38,3 ± 4,3
Moisture	84,90 ± 0,37	55,52 ± 0,64	52,88 ± 0,58
Extractives	5,71 ± 0,03	0,24 ± 0,02	4,01 ± 0,01
Lipids	-	15,65 ± 0,02	-
Palmitic acid (%)		7,56	
Stearic acid (%)		34,16	
Oleic acid (%)		**44,51**	
Linoleic acid (%)		6,11	
Arachidic acid (%)		4,23	
Behenic acid (%)		3,43	
Hemicellulose	-	8,66 ± 1,84	10,58 ± 1,81
Cellulose	-	14,89 ± 0,02	11,98 ± 1,81
Lignin	-	2,29 ± 0,52	16,67 ± 0,02
Fiber	3,29 ± 0,03	-	-
Ash	6,10 ± 0,02	2,70 ± 0,11	3,88 ± 0,80
Phenolic compounds (mgGAE/100 g dw)	857,64 ± 0,02	1520,94 ± 0,01	**2153,03 ± 0,01**
Phenolic comp. (mg Catechin/ 100 g dw)	n.d.	n.d.	222,70 ± 0,30
Antioxidant activity (meq Trolox/g dw)	0,073 ± 0,000	0,699 ± 0,002	**0,797 ± 0,008**

Table 4. Chemical composition of Makambo fruit

Theobroma bicolor

Products:

Pasteurized pulp.

Seed butter.

Residual cake (it is paste, that should be used as an ingredient in a food industry) as a substitute for cacao.

Phenolic compounds.

Biogas.

Biofertilizer.

Experimental yields

SFE

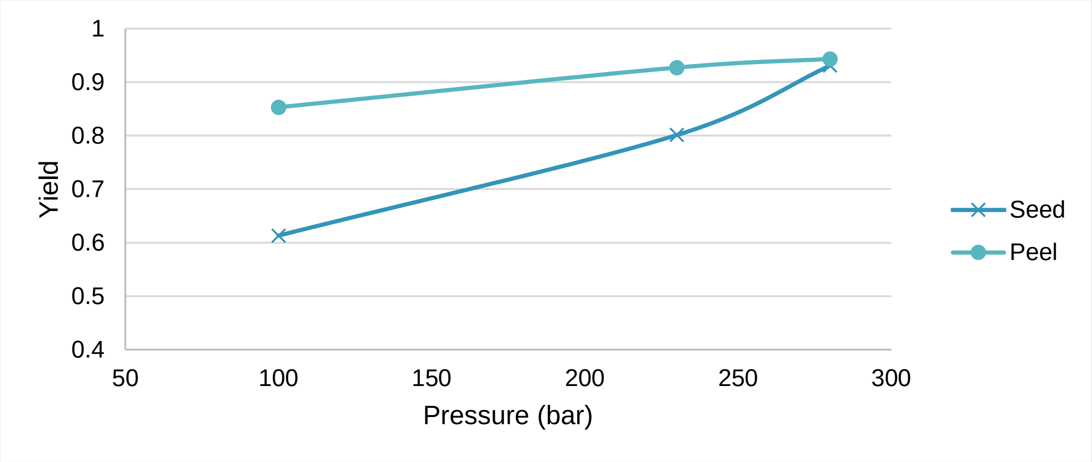


Fig 19. Yield of phenolic compounds extraction by EFS from Makambo seeds and peel

BUTTER EXTRACTION

Temperature (°C)	Yield (g Butter extracted/g Lipids in RM)
40	0,55 ± 0,02
70	0,82 ± 0,03

Table 5. Yield of Makambo butter extraction

Scenarios

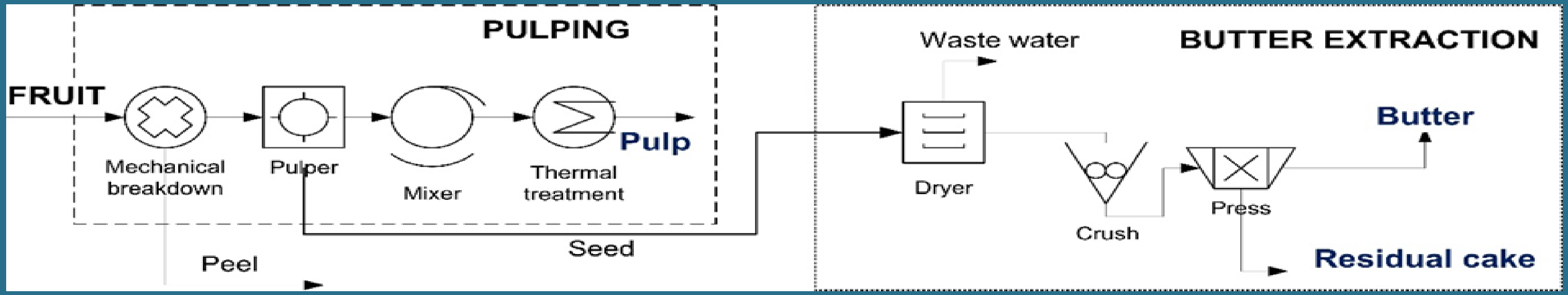


Fig. 20 Simplified process-flow Sc 1

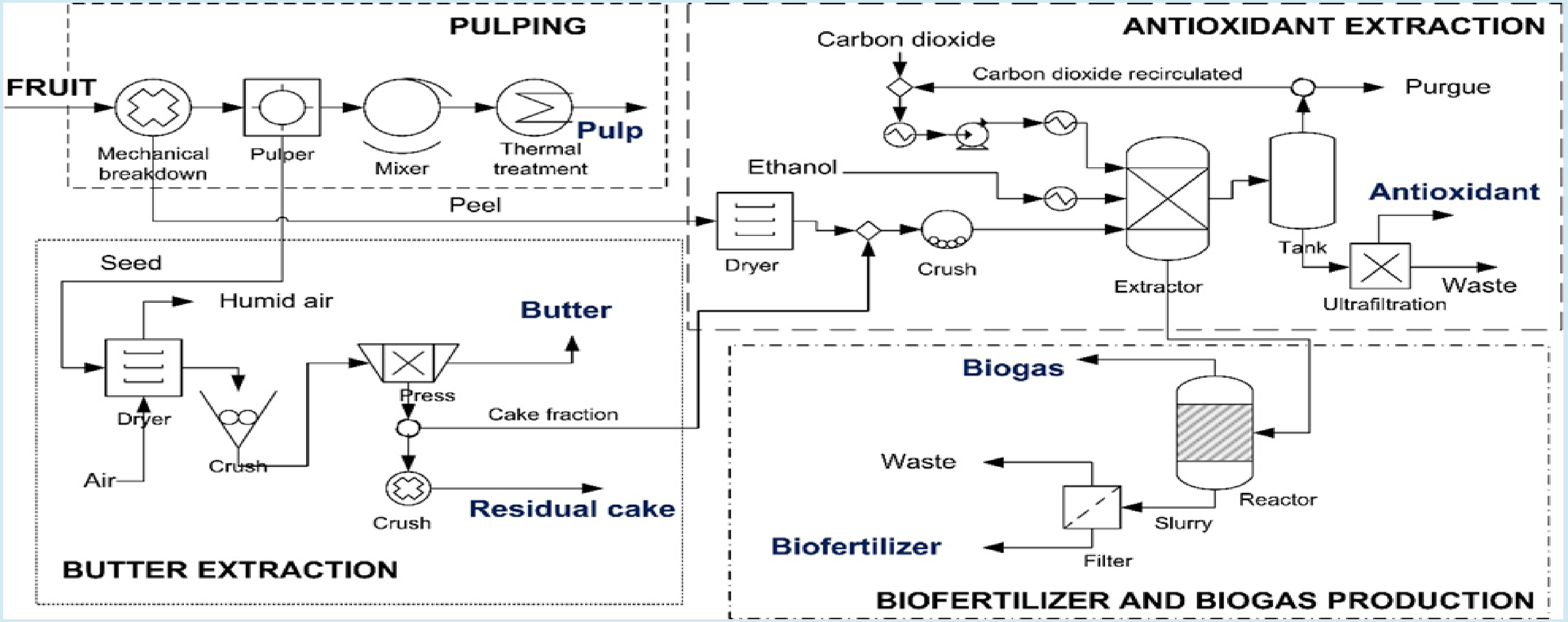


Fig. 21 Simplified process-flow Sc 2

Mass balance

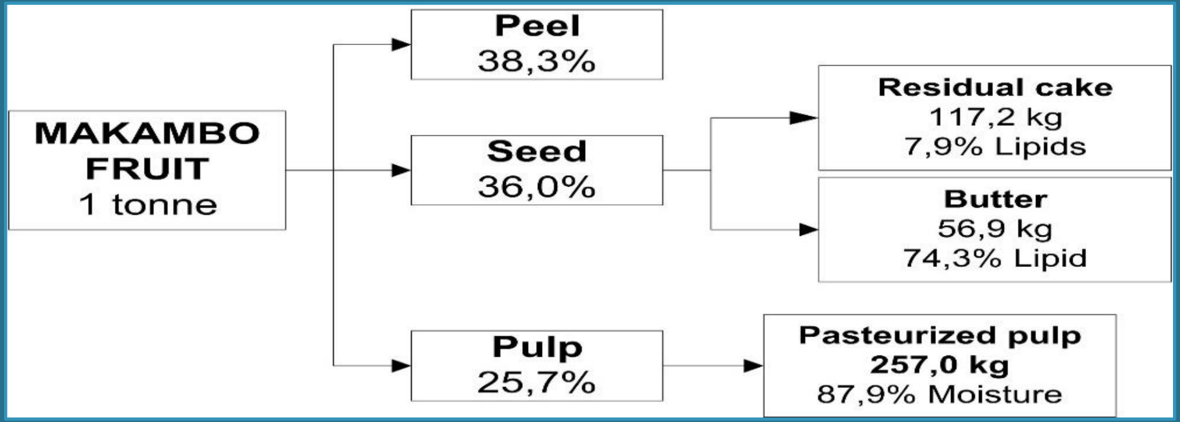
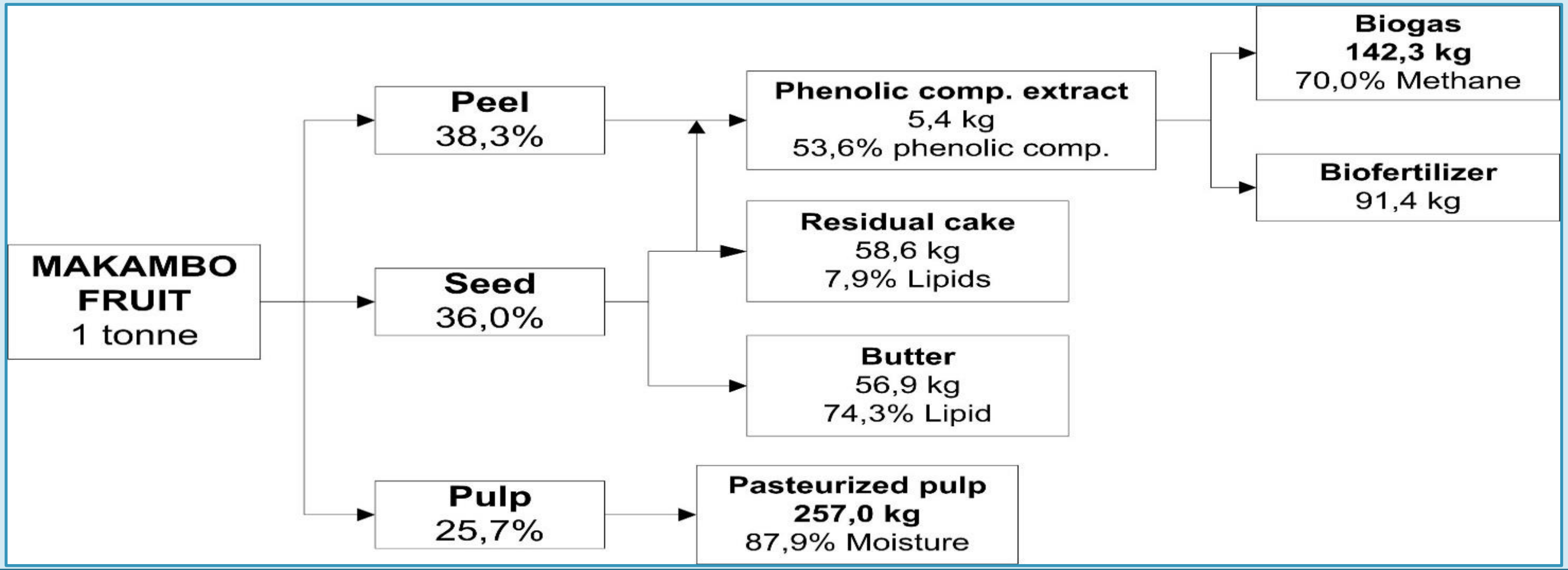


Fig. 22 Material balance for Sc. 1

Fig. 23 Material balance for Sc. 2



Scale production assessment

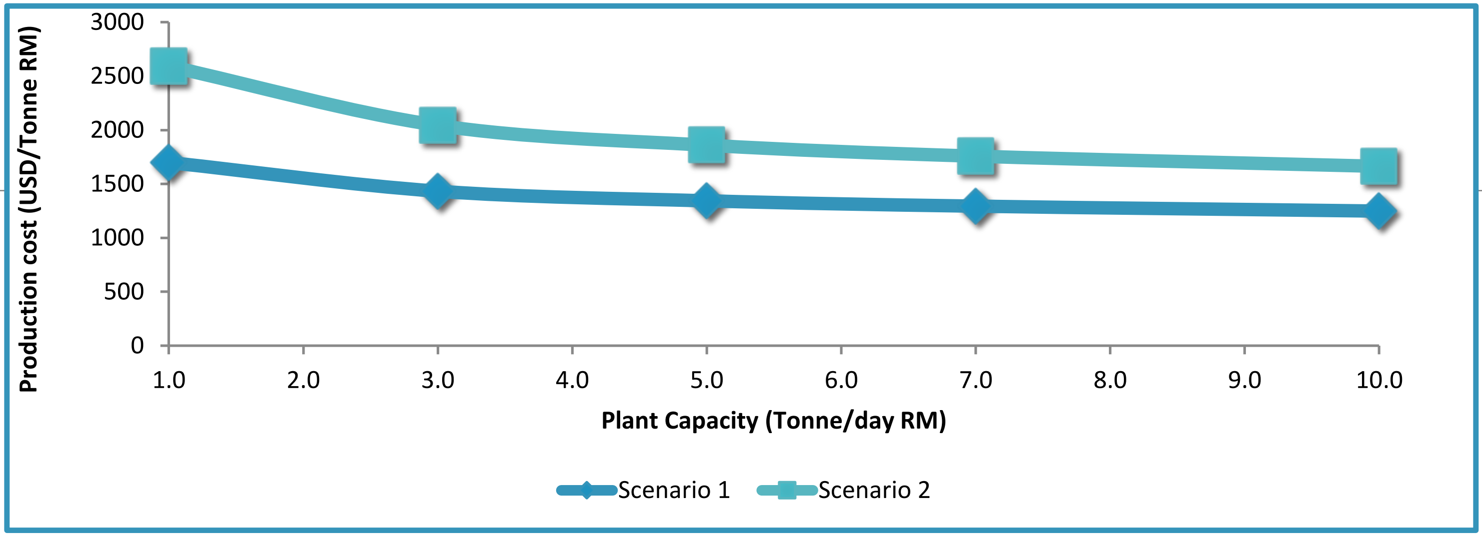


Figure 26. Annualized cost for different production scale

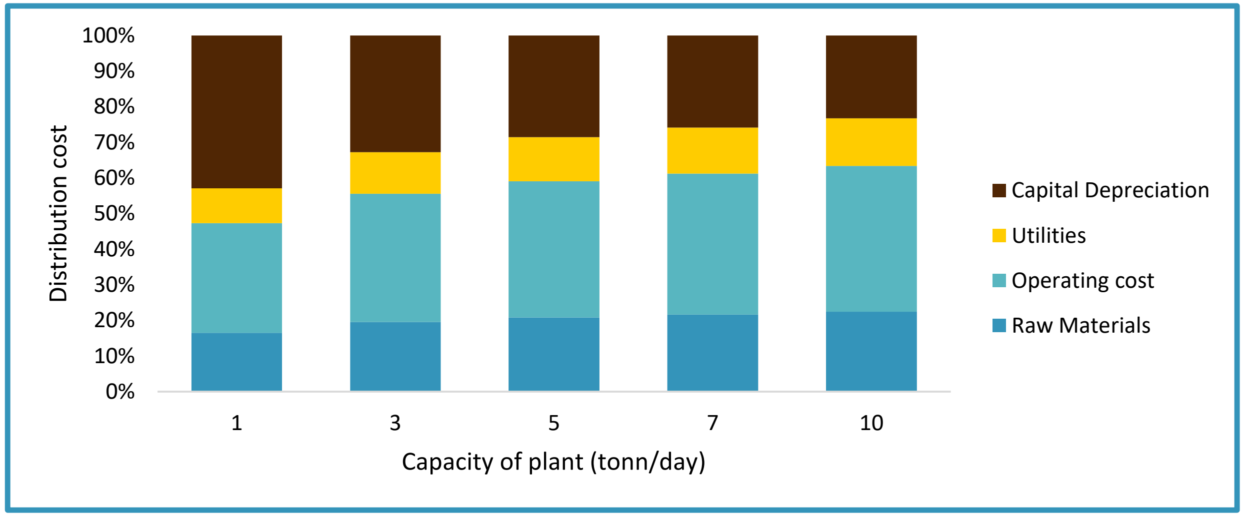


Figure 27. Annual cost distribution for different production scale for Sc 1

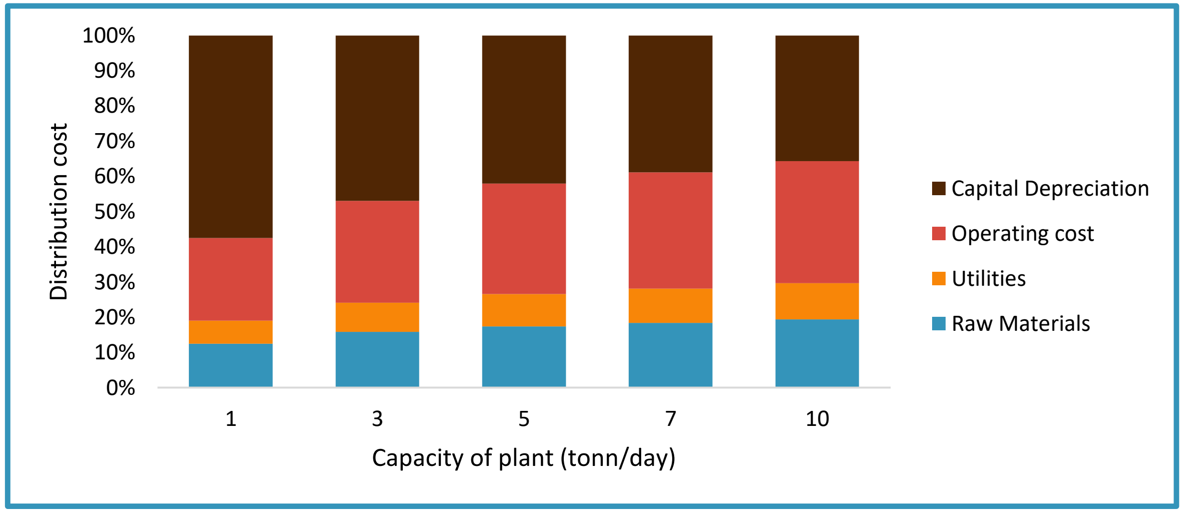


Figure 28. Annual cost distribution for different production scale for Sc 2

Environmental assessment

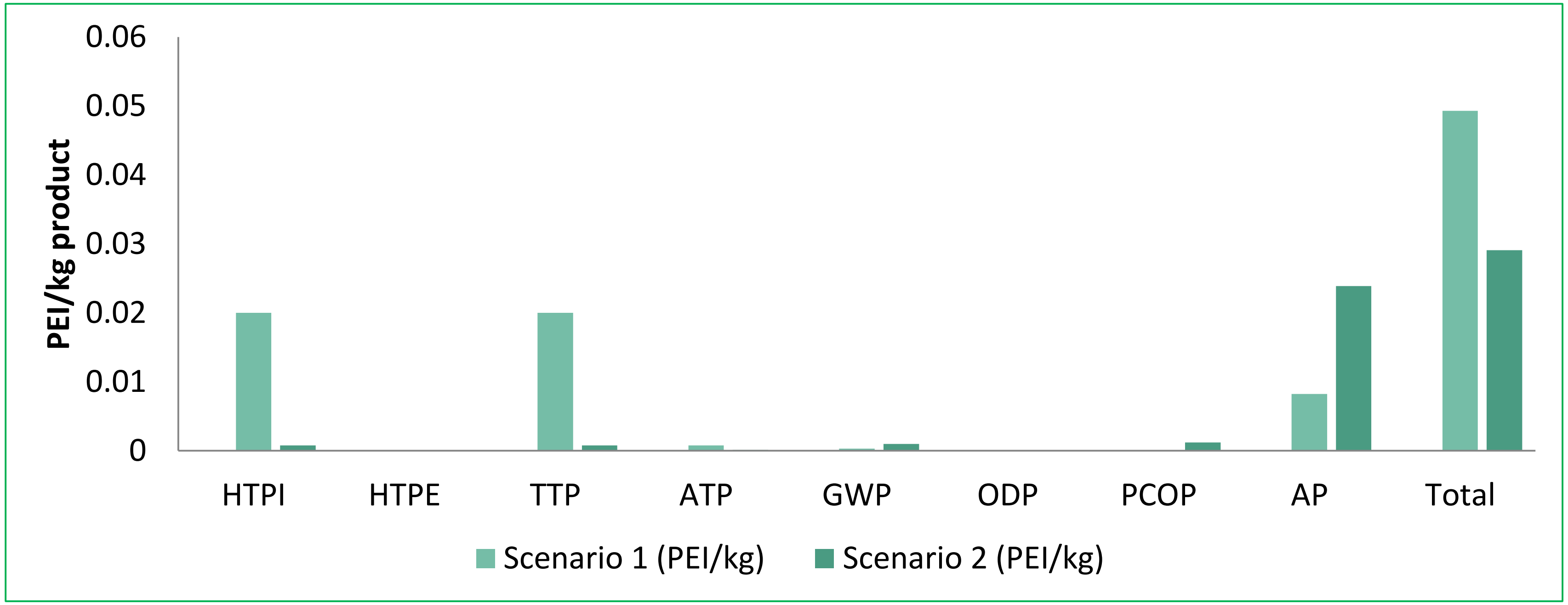


Fig. 29 Potential Environmental Impact generated per Scenario

Aguaje case

Mauritia flexuosa

http://www.amazonia-andina.org/media-gallery/detail/364/509

http://www.bionaturaleza.com/2012/02/el-aguaje-el-fruto-amazonico-mas.html

Chemical characterization

Features	Pulp (%)	Seed (%)	Peel (%)
Fruit proportion	**25,7± 2,06**	**51,8 ± 0,46**	22,5 ± 1,60
Moisture	55,84 ± 0,81	50,32 ± 0,37	56,39 ± 0,25
Extractives	4,82 ± 0,34	1,14 ± 0,78	4,36 ± 0,15
Lipids	18,52 ± 0,38	-	-
Hemicellulose	-	22,86 ± 0,82	18,11 ± 0,95
Cellulose	-	17,38 ± 0,42	11,68 ± 0,32
Lignin	-	5,29 ± 0,51	6,62 ± 0,93
Fiber	17,15 ± 0,71	-	-
Ash	3,71 ± 0,99	3,03 ± 0,18	2,83 ± 0,03
Phenolic compounds (mgGAE/100 g dw) mg Cathechin/ 100 g dw	451,72 ± 0,00 n.d.	176,63 ±0,00 n.d.	**3400,59 ± 0,01** 204,86 ± 3,39
Antioxidant activity (m eq Trolox/ g dw)	0,051 ± 0,000	0,048 ± 0,000	1,443± 0,003

Table 8. Chemical composition of Aguaje fruit

Products:

- Pasteurized pulp
- Pulp Oil
- Flour for animal meal
- Phenolic compounds
- Biogas
- Biofertilizer

Experimental yields

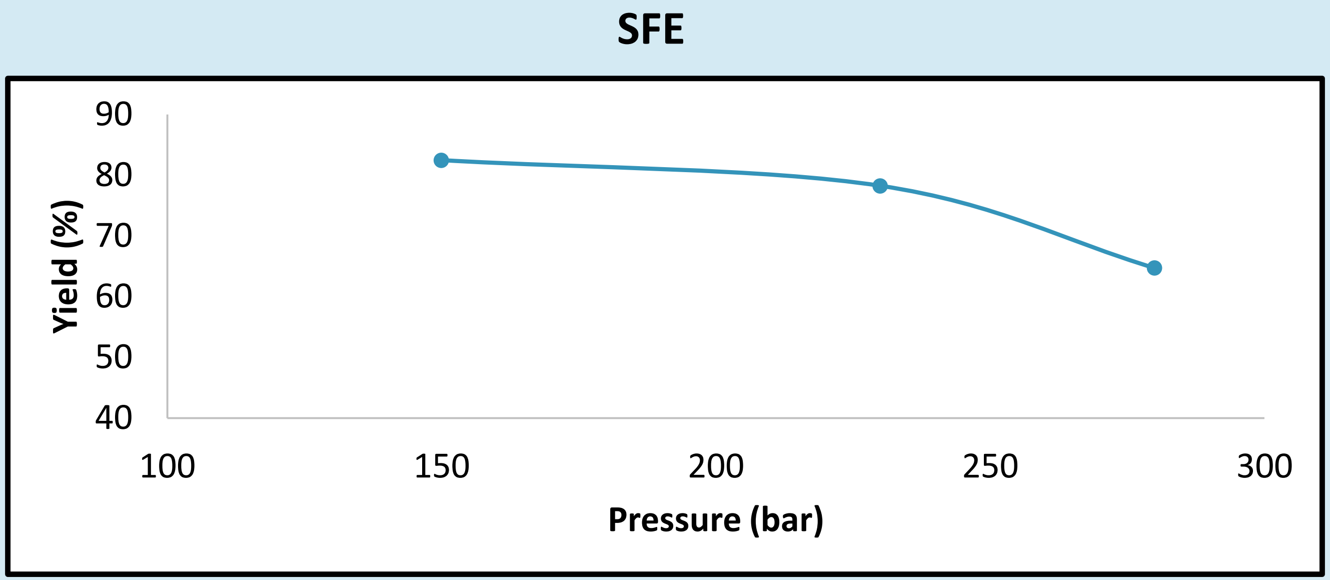


Fig 30. Yield of phenolic compounds extraction by SFFE from residual cake

Scenarios

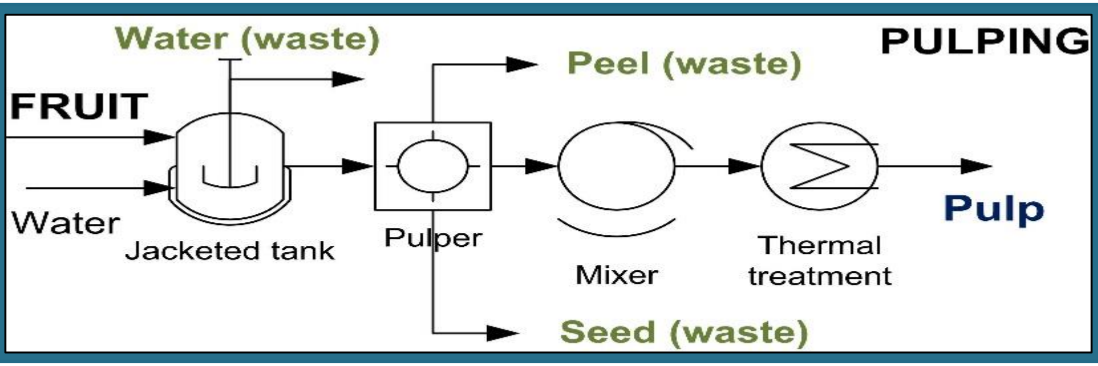
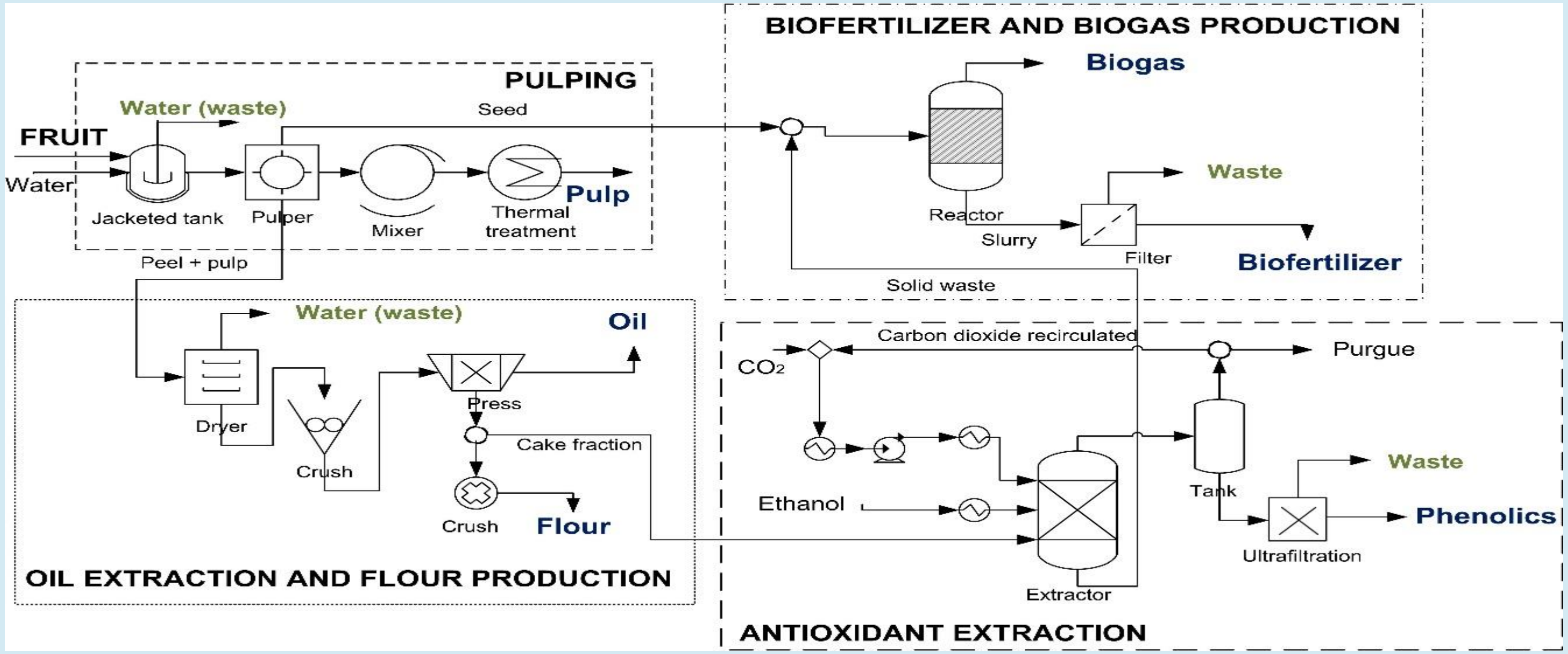


Fig. 31 Simplified process-flow Sc. 1

Fig. 32 Simplified process-flow Sc. 2



Mass balance

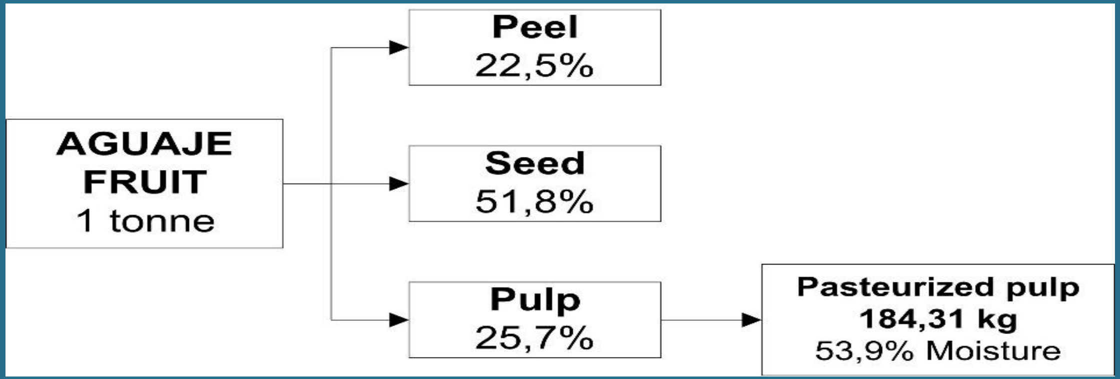
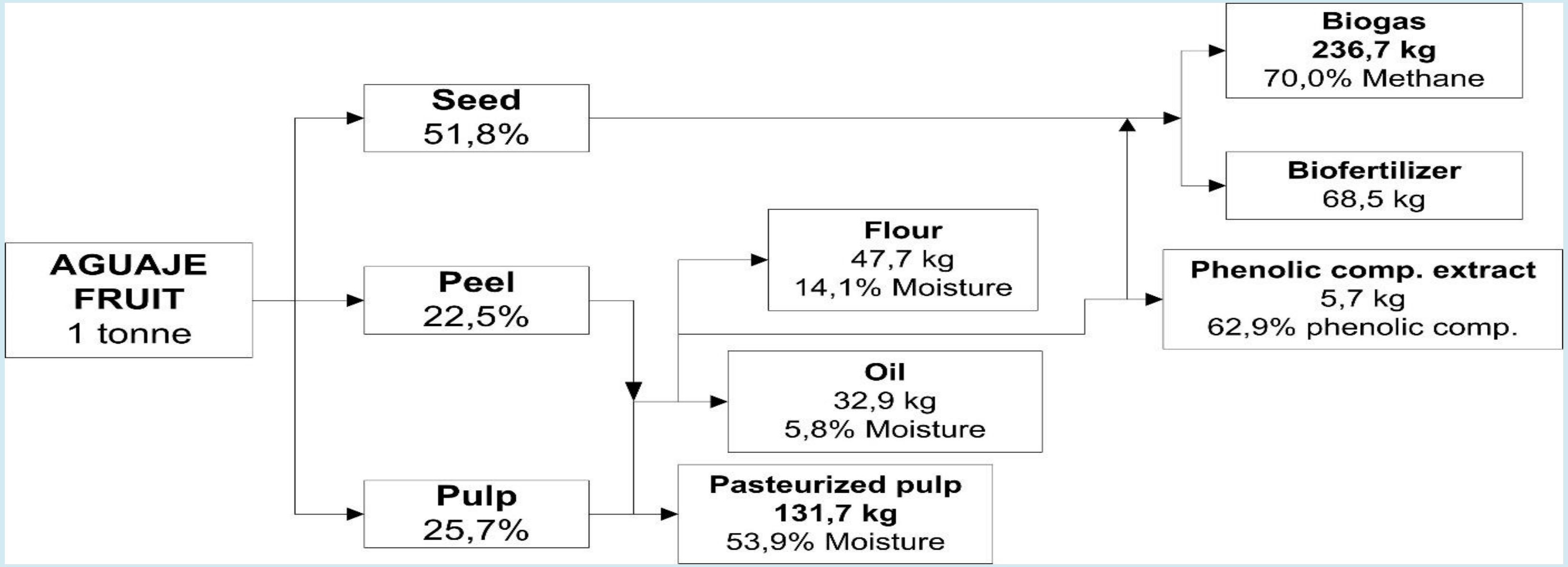


Fig. 33 Material balance for Scenario 1

Fig. 34 Material balance for Scenario 2



Economic assessment

	Scenario 1	Scenario 2
Product	USD/kg	USD/kg
Pasteurized pulp	8,55	5,10
Pulp oil	-	15,29
Flour	-	2,55
Phenolic compounds	-	407,84
Biogas	-	0,06
Biofertilizer	-	0,25

Table 9. Production cost per product

Economic metric	Scenario 1	Scenario 2
NPV	-763.449,00	607.936,00
Payout period (years)	NA	9,72
Profitability index	0,79	1,01

Table 10. Economic metric per scenario

Sensitivity analysis

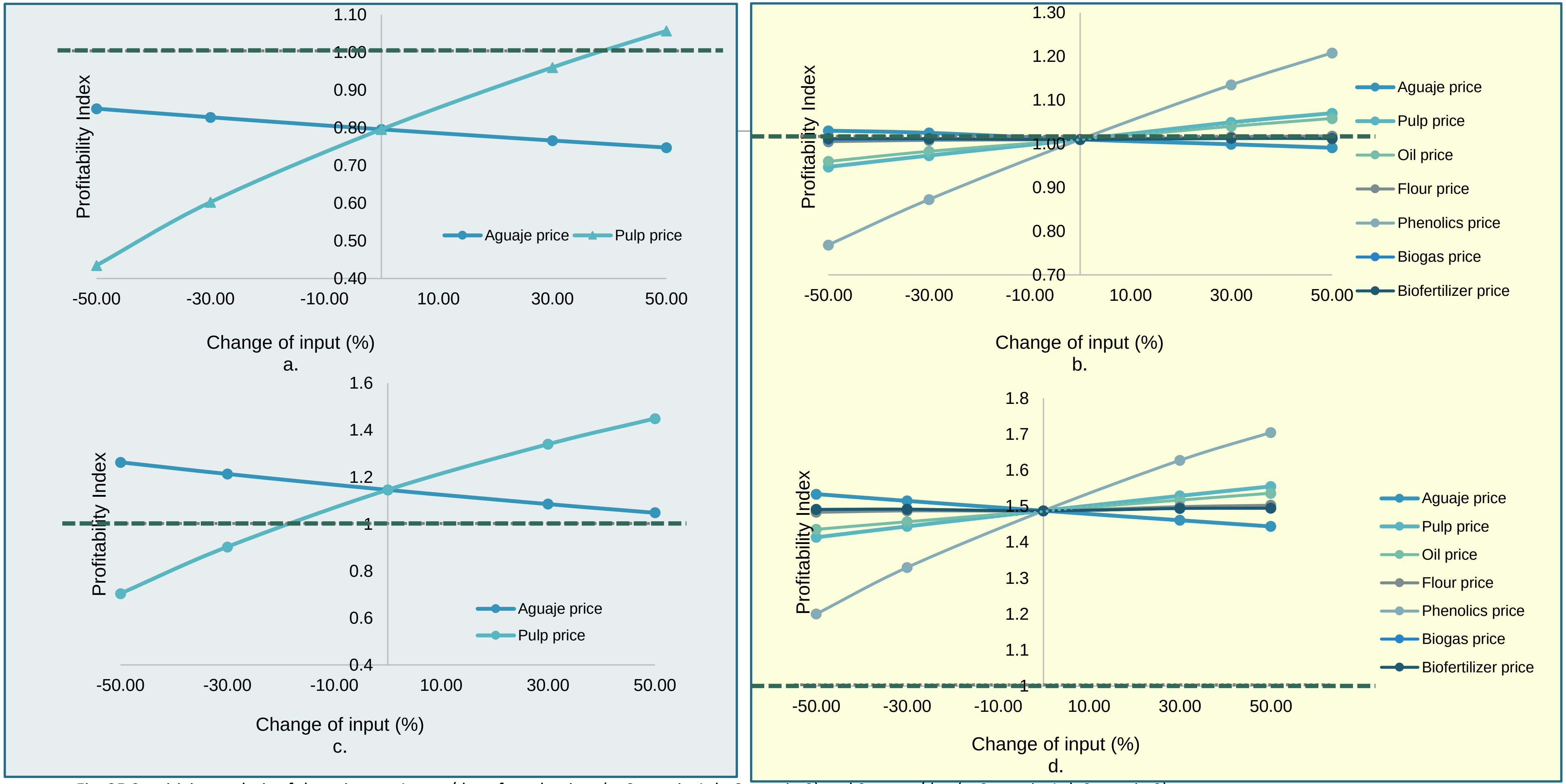


Fig. 35 Sensitivity analysis of the prices to 1 tonn/day of production. (a. Scenario 1. b. Scenario 2) and 2 tonne/day (c. Scenario 1 d. Scenario 2)

Scale production assessment

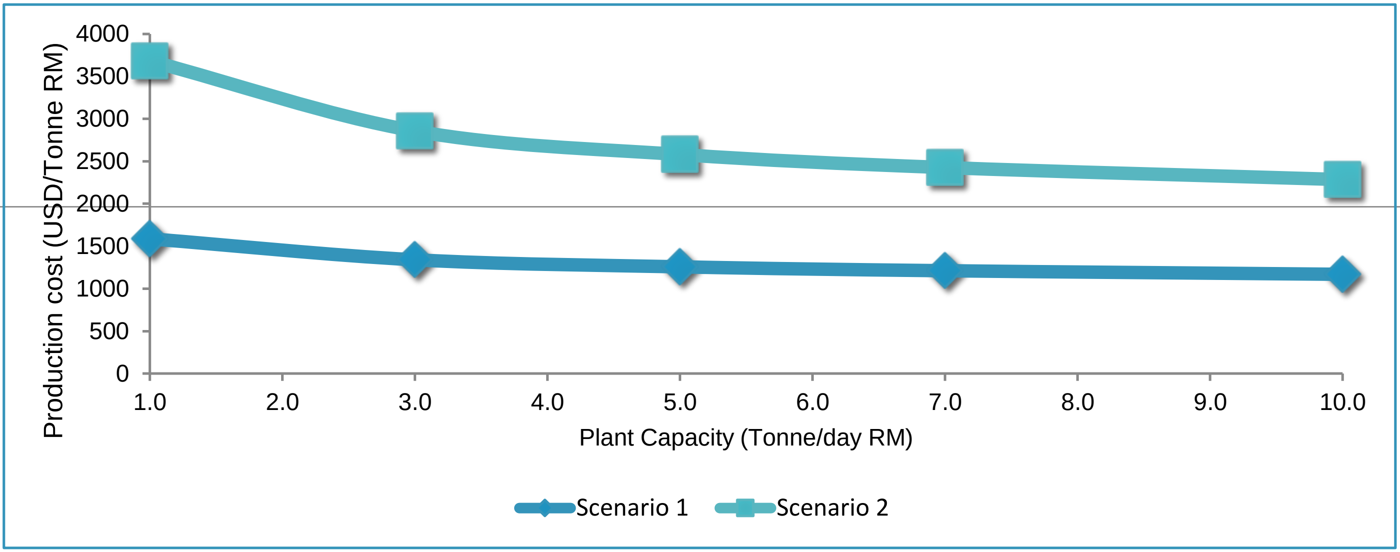


Figure 36. Annualized cost for different production scale

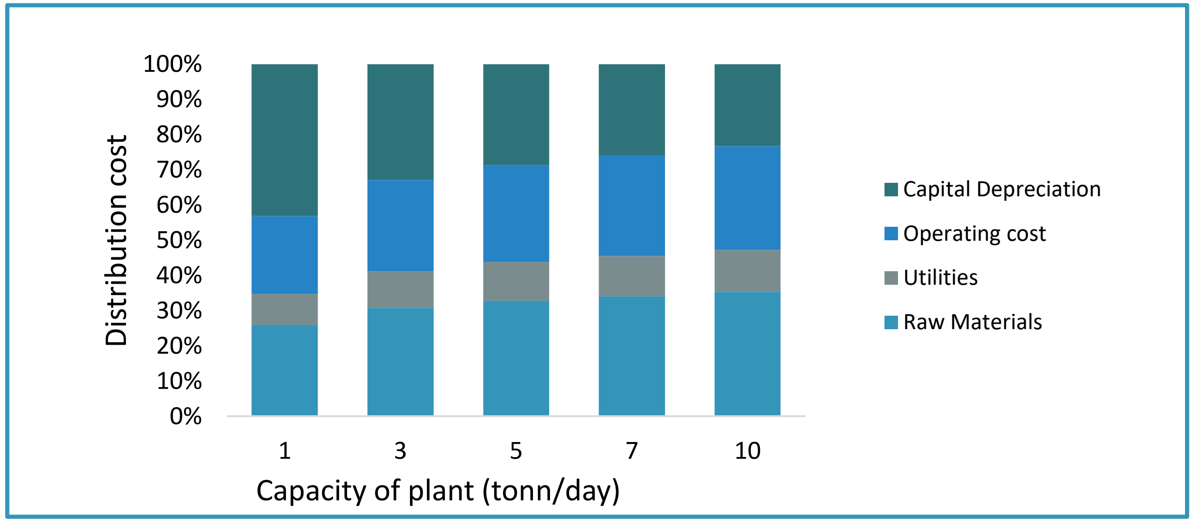


Figure 37. Annual cost distribution for different production scale for Sc 1

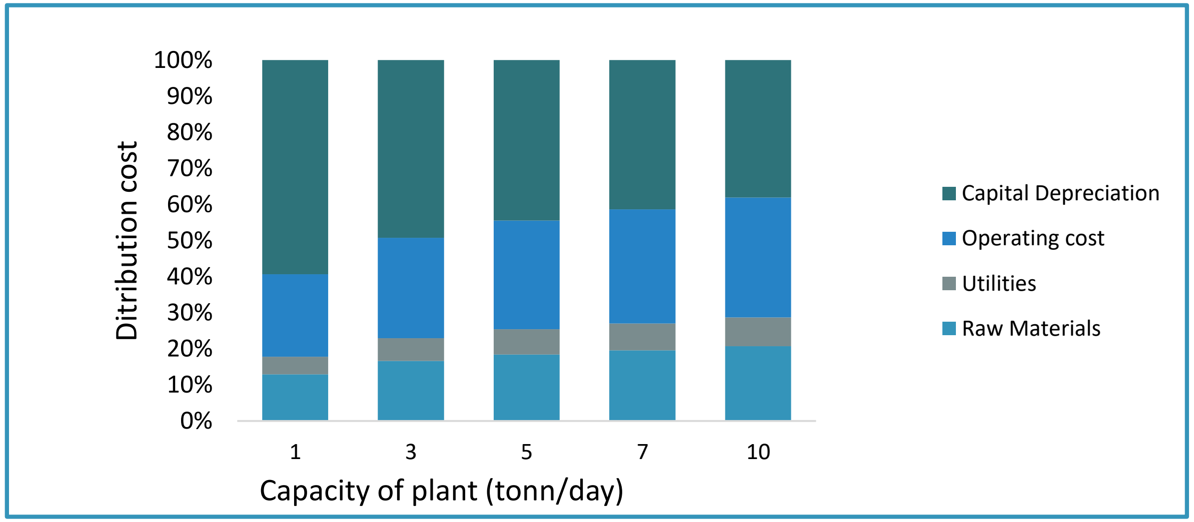


Figure 38. Annual cost distribution for different production scale for Sc 2

Environmental assessment

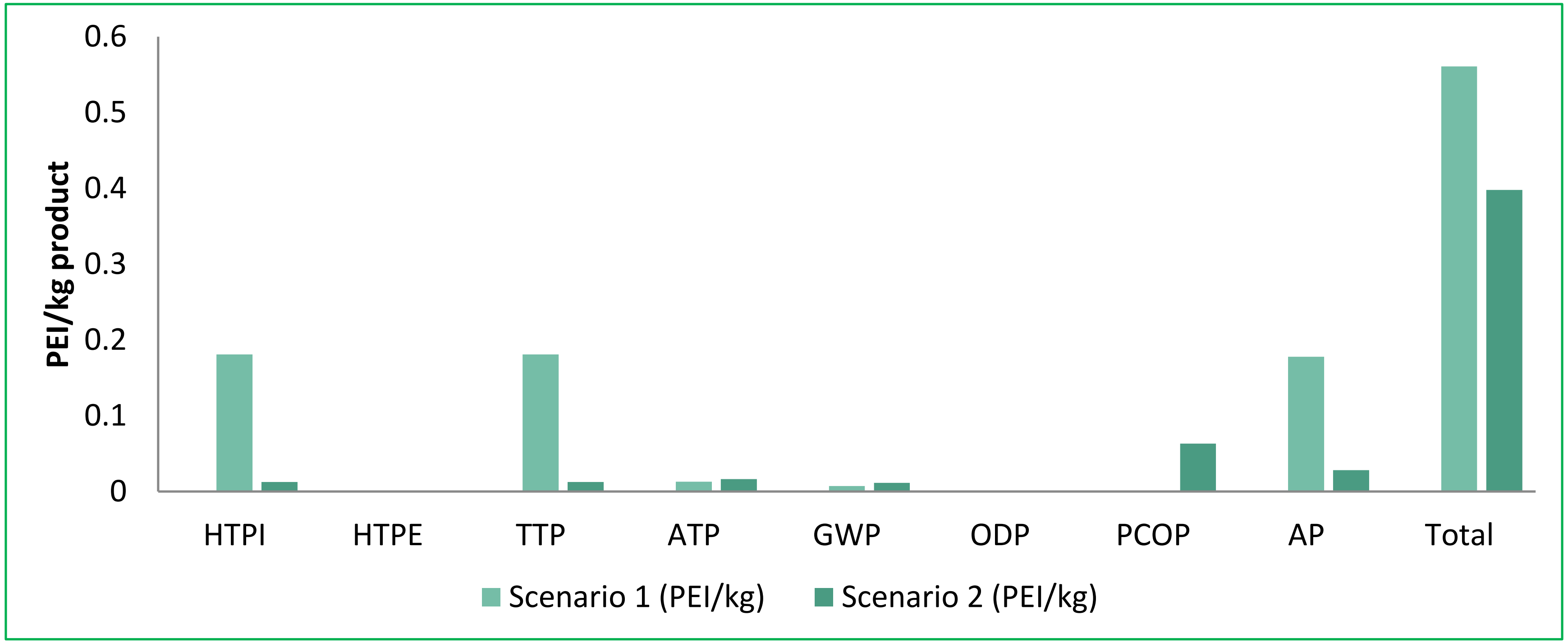


Fig. 39 Potential Environmental Impact generated per Scenario

Overall results

Capacity (tonne/day)	Makambo		Aguaje		Cedro	
	Sc 1	Sc 2	Sc 1	Sc 2	Sc 1	Sc 2
1	✓	✓	✗	✓	✗	✓
2	✓	✓	✓	✓	✗	✓
5	✓	✓	✓	✓	✓	✓
Risk	Seasonality New fruit into the market New products		Seasonality Absence the agronomic package Harvesting is a destructive practice		Natural demand Waste	
Advantages	Domestic fruit Versatility of products Exotic fruit Amazonian Agronomic package		Recognized products into the market Most important fruit in South Amazonian		High quality wood Agronomic package	

Table 14 Overall results, risk and advantages associated with the raw materials

Stand alone processes “working” at small scale that should adopt the biorefinery concept in Colombia

- 10-20 kWh gasification for electricity in not interconnected rural areas
- Metabolites extraction processes
- Small dairy plants , for example the milk whey problem
- Small coffee pretreatment plantes

Conclusions

- Small scale, lower scale and available scale are the real questions.
- Only High added value products can make very small scale biorefineries feasible.
- The biorefineries scales can demonstrate the advantages over any stand alone only after a deep technical and economic analysis.
- The logistics however finally will reduce the scale possibilities.

Thanks for your attention

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