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A Techno-Economic Sensitivity Approach for Development of a Palm-based Biorefineries in Colombia

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Colombia is the fourth global producer of palm oil and, according to the national agenda of R+D, solving the needs of palm oil production chain is a high priority for Colombian government; for this reason, application of biorefinery concept can represent the solution. In this work, an approach based on economic evaluation, techno-economic sensitivity analysis and economic indicators was used for the development of a biorefinery based on the lineal palm oil production chain in order quantify the economic improvements of biorefinery concept implementation. Results showed that for a processing capacity of 240,000 tons per year of palm bunch with a plant life of 15 years, economic indicators are improved using the biorefinery concept due to selling price of all products, however, both palm oil plant and biorefinery present a strong sensitivity to raw material costs with a break-even price of 125 and 155 US$/t, respectively. In addition, operating costs have a critical value in 146 and 170 US$/t of palm fruit for palm oil plant and biorefinery, after this cost a low increase of NVOC can increase PBP in decades.

1. Introduction

Crude palm oil (CPO) is the vegetable oil with the highest production in the world. In 2014, CPO production was about 59.2 million tons, followed by soybeans and rapeseed oil with 45.1 and 27.2 million tons, respectively (Garcia et al., 2016). Although Colombia contributes only 2 % to the production of palm oil worldwide (Fedepalma, 2016), leads the production of palm oil in Latin America. In 2015, the total area planted with palm in the country reached 465,985 hectares, increasing by 3.6 % compared to 2014 with a production of CPO of 1,272,521 tons, a growth close to 15 %. In addition, in Colombia there are plans to increase production to six times by 2020, which would require 3 million hectares for plantations. This large production demand, mainly driven by the high global market prices which provide good profit margin compared to other types of land use, is leading palm growing countries to seek and implement optimal and efficient processes that can ensure a better use of raw materials and high oil yield (Martinez et al., 2016). In this sense, implementation of biorefinery concept as the topological development to produce several products that give economic competitiveness at low value of a main product with high value co-products is relevant (Pinzón et al., 2014; González-Delgado et al., 2015). This paper proposes the implementation of this concept as a feasible alternative for a plant that has as its main product palm oil and as byproducts palm kernel oil and palm cake, stages as sterilization, threshing, digestion, drying, among others, are part of the palm oil production process, and stages as pressing can be used also for production of plam kernel oil which presents a higher value than CPO (Uribe, 2011). the techno-economic sensitivity approach is based on 1) economic evaluation, 2) techno-economic sensitivity analysis calculating on-stream efficiency and break-even point and 3) economic indicators such as Net Present Value (NPV), Return of Investment (ROI) and Payback Period (PP), were used for the development of a palm-based biorefinery under Colombian economic conditions.

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2. Materials and methods

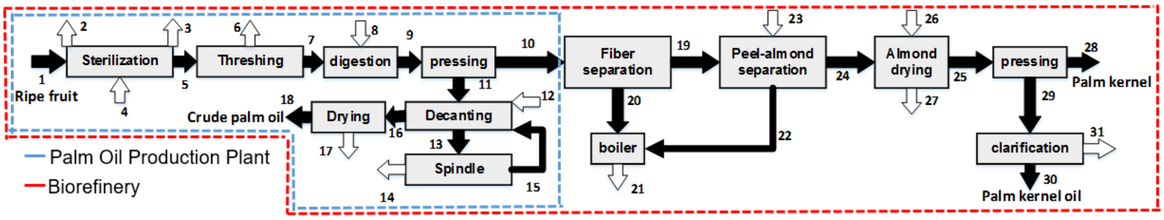

Figure 1: Block diagram for palm oil linear production chain and palm-based Biorefinery

The block diagram representing the case studies (palm oil producing plant and biorefinery) is shown in Figure 1; the economic evaluation was carried out using US Dollars of 2016 and a plant life of 15 years as reference. Costs of equipment were calculated using information of vendors (www.palmoilmachine.com), costs of raw materials and products were consulted from INDUPALMA (www.indupalma.com), and costs of utilities as gas, steam, water and electricity were calculated under real Colombian conditions. According to Eqs. (1) and (2), Total Capital Investment and Operational Cost (OC), were calculated. Eqs.(3) to (12) show the economic indicators calculated, such as Gross Profit (depreciation not included) (GP), Gross Profit (linear depreciation included) (DGP), Profit After Taxes (PAT), Economic Potentials (EP_1, EP_2, EP_3), Cumulative Cash Flow (CCF), PayBack Period (PBP), Return on Investment (ROI), Incremental Return on Investment (IROI) and Net Present Value (NPV), where $m_jC_j^{RM}$ is the product of the raw material flow and the selling price, U are the utilities costs, AOC are annualized operating costs, $m_iC_i^v$ is the product of product flowrate and selling price, itr is the tax rate, ACF is the net profit for the year n, TAC are the total annualized costs, m_{BEP} is the production capacity on BEP and m_{max} is the maximum production capacity. The Incremental Return on Investment (IROI) was calculated in order to know if the application of biorefinery concept improves the plant performance, AATP is the annual incremental net benefit of the complementary project and is equal to the annual net profit of combined project less the net annual benefit of the base case; and the denominator is the incremental TCI of the complementary project and is equivalent to the TCI of the biorefinery minus the TCI of the base case (Perez Zúñiga et al., 2016; El-Halwagi, 2012). Table 1 shows the parameters and assumptions taken into account for economic evaluation.

$$TCI = FCI + WCI + SUC \quad (1)$$

$$OC = DPC + FCH + POH + GE \quad (2)$$

$$DGP = \sum_i m_i C_i^v - TAC \quad (3)$$

$$PAT = DGP(1 - itr) \quad (4)$$

$$EP_1 = \sum_i m_i C_i^v - \sum_j m_j C_j^{RM} \quad (5)$$

$$EP_2 = \sum_i m_i C_i^v - \sum_j m_j C_j^{RM} - U \quad (6)$$

$$EP_3 = \sum_i m_i C_i^v - AOC \quad (7)$$

$$CCF = \frac{\sum_i m_i C_i^v - AOC}{TCI} \quad (8)$$

$$PBP = \frac{FCI}{PAT} \quad (9)$$

$$\%ROI = \frac{PAT}{TCI} x100\% \quad (10)$$

$$NPV = \sum_n ACF_n (1+i)^{-n} \quad (11)$$

$$IROI \ on \ project \ B = \frac{AATP \ of \ B - AATP \ of \ A}{TCI \ of \ B - TCI \ of \ A} \quad (12)$$

3. Results

3.1 Economic evaluation

In Table 2 is shown the total capital investment for palm-based biorefinery to obtain palm oil, palm kernel oil and palm cake. Equipment represents the highest costs compared to other factors that affect DFCI due to the inclusion of the equipment necessary to carry out the sterilization, threshing, digestion, pressing, decantation and drying operations. In addition, to obtain palm kernel oil and palm cake was necessary to add more units to the process for fiber separation, peel separation and almond drying.

Table 1: Techno-economic assumptions for palm-based biorefinery (2016 US Dollars)

Processing capacity (t/y)	240,000.00
Main product flow (t/y)	54,056.00
Raw material cost ($/t)	122.30
Palm oil cost ($/t)	800.67
Palm kernel oil cost ($/t)	1,516.00
Palm kernel cake cost ($/t)	154.70
Final product cost total ($/t)	2,471.37
Salvage value	10 % of depreciable FCI
Construction time of the plant (years)	2
Tax rate	45 %
Discount rate	8 %
Subsidies	0
Type of process	New and unproven
Process control	Digital
Project type	Plant on non-built land
Soil type	Soft clay
Percentage of contingency	20 %
Tank design code	ASME
Specification diameter vessels	Internal diameter
Number of workers per shift	15
Salary per operator ($/h)	25

Table 2: Total capital investment for palm-based biorefinery

Costs of capital investment	**Total (US$)**
Delivered purchased equipment cost	4,110,391.25
Purchased equipment (installation)	822,078.25
Instrumentation (installed)	328,831.30
Piping (installed)	822,078,25
Electrical (installed)	534,350.86
Buildings (including services)	1,644,156.50
Services facilities (installed)	1,233,117.38
Total DFCI	**9,495,003.79**
Land	411,039.13
Yard improvements	1,644,156.50
Engineering and supervision	1,315,325.20
Equipment (R+D)	0.00
Construction expenses	1,397,533.03
Legal expenses	41,103.91
Contractors' fee	664,650.27
Contingency	1,233,117.38
Total IFCI	**6,706,925.41**
Fixed capital investment (FCI)	**16,201,929.20**
Working capital (WC)	9,721,157.52
Start up (SU)	1,620,192.92
Total Capital Investment (TCI)	**27,543,279.63**

In addition, in Table 3, direct production costs, fixed charges and general costs are presented. Raw material used was palm bunches and utilities costs used for the plant were gas, electricity and water, which are higher in Colombia in comparison to other palm producers.

3.2 Techno-economic sensitivity analysis

The techno-economic sensitivity analysis performed was based on the break-even point and the on-stream efficiency applied to 2 topologies. For base case, palm oil was considered as the only product of the plant and for case 2 or biorefinery case, it was considered all the production (palm oil, palm kernel oil and palm cake). Figure 2(a) shows that for base case, the equilibrium point of the production capacity does not vary significantly so that, from this perspective it is not necessary to apply the biorefinery concept. In addition, when the annual sales are analyzed, it can be observed that profits correspond to 45.03 MM$/y, while for case 2

(Figure 2b) these increase when the raw material is fully utilized, exceed the 55 MM$/y. Therefore, it is appropriate to apply the concept of biorefinery and increase production capacity.

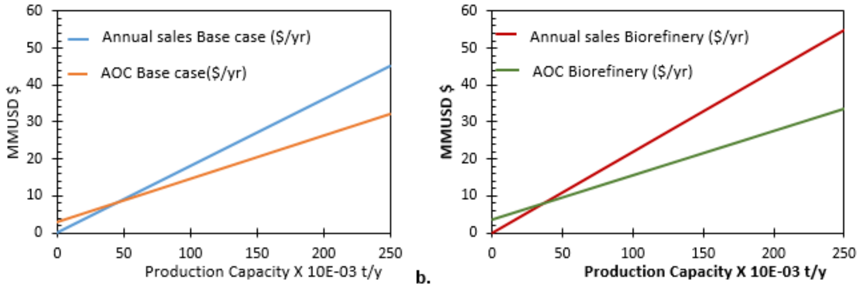

Figure 2: Break-even analysis of a) palm oil production chain and b) palm-based biorefinery

Table 3: Annual total production cost at 100 % capacity

Operating costs	Total (US$/year)
Raw materials	21,960,000.00
Utilities (U)	870,417.48
Maintenance and repairs (MR)	810,096.46
Operating supplies	121,514.47
Operating labour (OL)	195,000.00
Direct supervision and clerical labour	29,250.00
Laboratory charges	19,500.00
Direct production cost (DPC)	**24,005,778.41**
Depreciation (D)	986,930.63
Local taxes	324,038.58
Insurance	162,019.29
Interest/rent	275,432.80
Fixed charges (FCH)	**1,748,421.30**
Plant overhead (POH)	**117,000.00**
General expenses (GE)	**6,467,799.93**
Total product cost (TPC)	**32,338,999.64**

Figure 3 presents the sensitivity analysis of the On-Stream efficiency of the process at the equilibrium point respect to sales price of the products. From this figure, three moments can be identified, the first one is where the On-Stream efficiency presents a high sensitivity to the selling price, reason why it decreases drastically under relatively small changes; the second moment is known as the transition period, where the change in On-Stream efficiency is not as pronounced allowing a greater operability to changes in the selling price and finally in the third moment, it is observed that although the price increases to a great extent there will be no significant change in the decrease in On-Stream efficiency. According to Table 1, for case 1 and 2, the selling price of palm oil (800.67 US$/t) and all products obtained in the biorefinery (2,471.37 $/t), places them in the transition period, which allows increasing price of the product if it is necessary by effects of uncertainties, or unforeseen changes in supply/demand.

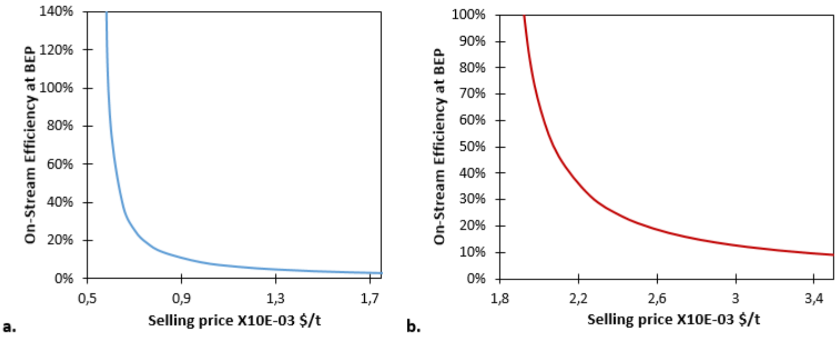

Figure 3: Effect of selling price of a) palm oil production chain and b) palm-based biorefinery on On-Stream efficiency at the break-even point

3.3 Economic indicators

Table 4 presents the economic indicators for base case and biorefinery. It can be observed that palm oil production generates an income of 161.39 MM US$/y while for biorefinery is 342.00 MM US$/y, which demonstrates the high added value generated by application of biorefinery concept. In addition, the PBP for the biorefinery is 1.43 years, so even still supports an increase in NVOC. The incremental return on investment (% IROI) is 28,84%. Finally, CCF is lower than 1.0 for both cases, which is attractive in a project.

Table 4: Results of economic indicators for the oil production plant and palm-based biorefinery

Economic indicators	**Base case**	**Biorefinery**
Gross Profit (depreciation not included) (GP)	12,276,932.98	19,571,201.88
Gross Profit (depreciation included) (DGP)	11,506,524.13	18,584,271.25
Profit After taxes (PAT)	6,328,588.27	11,336,405.46
Products (Revenues)	43,244,800.00	51,837,198.40
Economic Potential 1 [$/y]	21,284,800.00	29,877,198.40
Economic Potential 2 [$/y]	20,713,600.00	29,006,780.92
Economic Potential 3 [$/y]	12,211,924.40	19,498,198.76
Cumulative Cash Flow (CCF) (1/yr)	0.57	0.71
Payback Period (PBP) (years)	1.98	1.43
%ROI	29.74%	41.16%
Net Present Value NPV (MM US$)	161.39	342.00
Annual Cost/Revenue	18.23	38.64

The effect of raw material costs on process profitability is shown in Figure 4. For base case, the plant presents a critical point around 125 $/t of raw material where it does not generate profits, whereas the biorefinery is more tolerable, reaching a palm bunch cost up to 155 $/t. According to the palm bunch price found in table 1 (122.30 $/t), it can be said that for base case the plant will not tolerate a significant increase in the price so that the profits will be very low, while for biorefinery, the profitability is around 11 MM$/y. Finally, for both cases, when analyzing the gross profit, it is evident that an increase in palm bunch price will make the profitability decrease at the same rate.

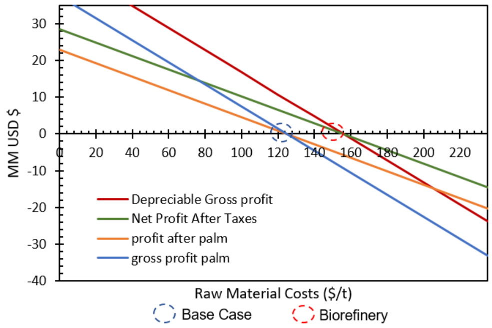

Figure 4: Effect of raw material cost on profitability for palm oil production chain and palm-based biorefinery

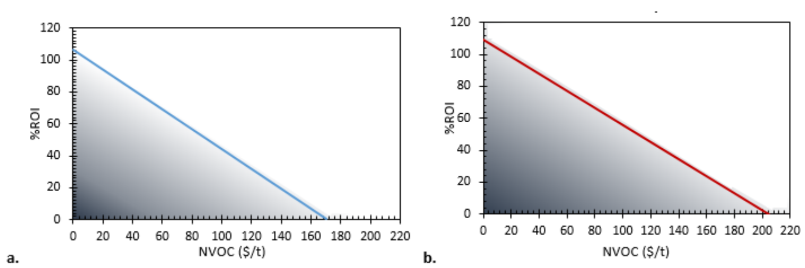

Figure 5: Effect of operating costs on the process ROI for a) palm oil production chain and b) biorefinery

The variation of ROI respect to changes in NVOC is shown in Figure 5. For base case, if variable operating costs (include industrial services, maintenance, employee salaries) come up over 175 $/t of palm fruit, there will be not return on investment and the plant will lose all its feasibility, while for case 2, the plant will support increases in NVOC up to approximately 200 $/t. In addition, for both cases the plant will have a ROI higher than 100% in the hypothetic scenario where NVOC are 0 $/t. According with Figure 6(a), the plant is sensitive to changes in variable operating costs for both cases, however, for case 1 it is observed that plant has less tolerance to the increase in NVOC when they exceed 146 $/t, while in biorefinery the increase is noticeable from 170 $/t. Figure 6(b) shows the behavior of NPV during the 15 years of plant life, for the palm oil production plant and the biorefinery, the investment will produce profits from 8 and 7 years, respectively, and at the end of 15 years, the economic benefits of biorefinery exceed the 300 MM$/y while the palm oil production plant will not reach the 150 MM$/y.

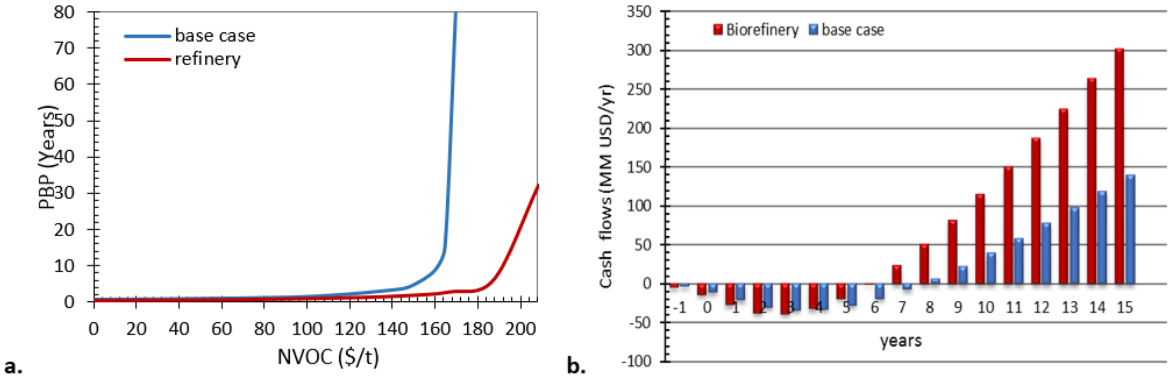

Figure 6: Sensitivity of a) PBP to operating costs and b) NPV for base case and palm-based biorefinery

4. Conclusions

Development of a palm-based biorefinery under Colombian conditions was performed using a techno-economic sensitivity approach. For a flow rate of 240,000 t/y of palm fruit under assumptions established, the biorefinery presents better economic performance compared to the palm oil production plant. Annual sales of biorefinery are 10 MM$/y more than base case. Analyzing On-Stream efficiency, it was observed that biorefinery has a broader range of possibilities to assign prices to its products because of raw material price can tolerate an increase up to 32.7 $/t. Finally, the biorefinery can support 200 $/t in NVOC, 25 $/t more than the base case, the profits acquired at the end of the lifetime of the biorefinery in present value is more than twice the cash flow of base case, and cash flow of biorefinery becomes positive two years before palm production chain.

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