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A hierarchical techno-economic sensitivity approach for evaluation of agroindustrial production chains

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Abstract : Sustainability of agroindustrial production chains presents high volatilities owing to the nature of feedstocks which are mainly commodities with uncertainties in costs and social problems generated in rural areas. In this work, a hierarchical technoeconomic sensitivity approach for evaluation of agroindustrial production chains is introduced; in a first stage, a technoeconomic evaluation is performed for finding economic indicators of the production chain, if results are suitable, a break-even analysis is performed for statement of technoeconomic reference stage, and finally, a technoeconomic sensitivity analysis previously developed by authors is performed taking into account critical parameters as on-stream efficiency at the break-even point, cost of raw materials, normalized variable operating costs among others, and analyzing its effect on economic indicators calculated in step 1. A case study for methodology application is presented for palm oil production chain. Results shows in first stage that for a processing capacity of 240,000 tons per year of palm bunch with a plant life of 15 years, the plant is an attractive project due to the annual sales (43.24 MM US$/y) are almost 50 % higher that the annualized operating cost (19.37 MM US$/y), making that ROI and NPV be 49.30 % and 369.85 MM$/y, respectively. In second step, technoeconomic reference stage was found in 50,000 t/y for production capacity and 1,667hours. In third step, analyzing on-stream efficiency, it was observed that plant has a broad range of possibilities to assign prices to its product between 680 and 980 US$/t, and it will tolerate a significant increase in the raw material price up to 100 US$/t. Finally, the plant can support high changes in NVOC, however, if they come up to 167 US$/t, there will be no return on investment, the plant will lose all its feasibility and the payback period will be higher than 19 years.
Keywords : Agroindustrial production chains, Hierarchical Process Evaluation, Techno-economic sensitivity, Plant Profitability.

Introduction

Crude palm oil (CPO) is the vegetable oil with the highest production in the world[1,2] as a result that this activity is a backbone for both local-global environment and social economy[3,4].In 2013, CPO production was 28.5 million tons in Indonesia and 18.5 million tons in Malaysia, amounts that represents approximately 88 % of the worldwide production[5].In 2014, this production was about 59.2 million of tons, followed by soybeans and rapeseed oil with 45.1 and 27.2 million of tonnes respectively[6]. Countries as Colombia (plant localization for case study) that contributes only 2 % to the production of palm oil worldwide[7], 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 Colombia there are plans to increase production to six times by 2020, which would require 3 million hectares for plantations. This large production demand 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, without leaving aside the economic viability[8].However, Economic sustainability of palm oil production chain presents high volatilities owing to changes in palm oil prices and social problems as strikes, violence and illegal crops which affects operating costs of the plant. In this work, a hierarchical technoeconomic sensitivity approach for evaluation of agroindustrial production chains is introduced as shown in Figure 1; in a first stage, a technoeconomic evaluation is performed for finding economic indicators of the production chain, if results are suitable, a break-even analysis is performed for statement of technoeconomic reference stage, and finally, a technoeconomic sensitivity analysis previously developed by authors is performed taking into account critical parameters as on-stream efficiency at the break-even point, cost of raw materials, normalized variable operating costs among others, and analyzing its effect on economic indicators calculated in step 1. As case study, a production chain that has as its main product crude palm oil obtained from the mesocarp of *Elaeis guineensis* palm fruit[9] through physical processes as sterilization, threshing, digestion, drying, among others[10] is evaluated.

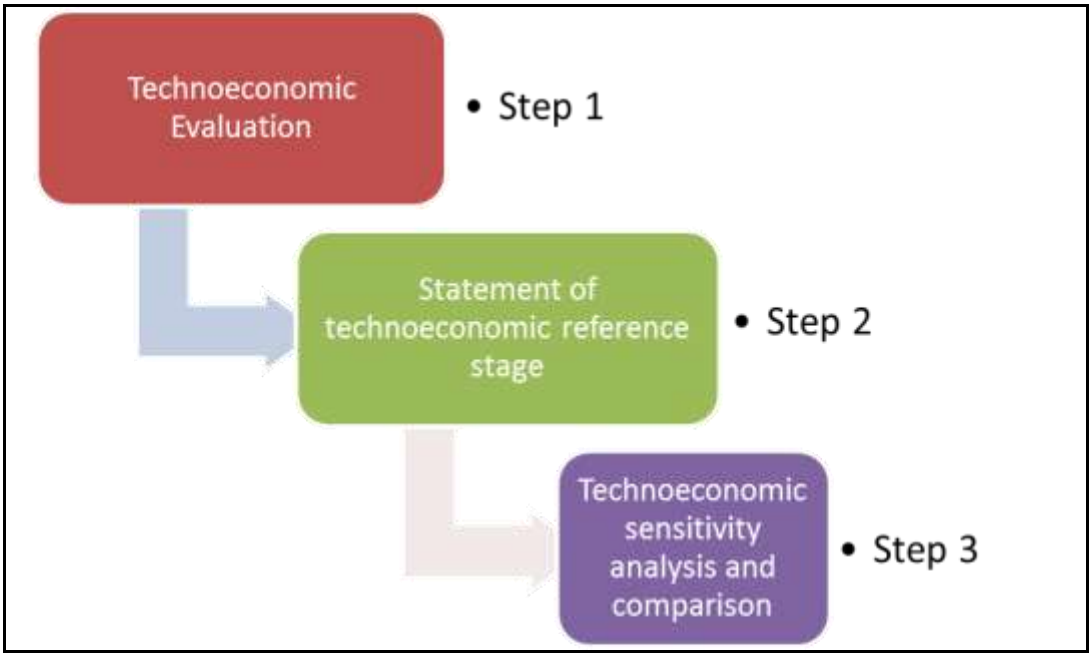

Figure 1. Hierarchical approach for evaluation of agroindustrial production chains proposed

Methodology of Technoeconomic evaluation

Technoeconomic evaluation was carried out using US Dollar of 2016, a period of operation of 15 years and 6 process units in the plant. Costs of equipment were calculated using information of vendors (www.palmoilmachine.com), costs of raw materials were consulted from INDUPALMA (www.indupalma.com) and costs of utilities as gas, steam, water and electricity were calculated under real Colombian conditions. Total Capital Investment and Operational Cost (OC)were calculated using Equations (1) and (2). Equations (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), Net Present Value (NPV) and On-Stream efficiency[11], where $m_j C_j^{RM}$ is the product of the raw material flow and the selling price, U are the utilities costs, AOC are Annualized Operating Costs, $m_i C_i^V$ is the product of product flowrate and selling price, itris the tax rate, ACF is the net profit for the year n, TAC are the Total Annualized Costs, $m_{BEP}$is the production capacity at the Break-Even Point and m_{max} is the maximum production capacity[12].

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

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

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

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

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

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

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

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

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

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

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

$$\eta_{On-stream}^{BEP} = \frac{m_{BEP}}{m_{\max}} \quad (12)$$

Table 1 shows the parameters and assumptions taken into account for economic evaluation.

Table 1. Techno-economic assumptions for the crude palm oil plant

Processing capacity (t/y)	240,000.00
Main product flow (t/y)	54,056.00
Raw material cost ($/t)	50.00
Crude palm oilcost ($/t)	800.00
Salvage value	10 % of depreciable FCI
Construction time of the plant (years)	2
Taxrate	39 %
Discountrate	9 %
Subsidies	0
Type of process	Provenprocess
Process control	Digital
Project type	Plant on non-built land
Soiltype	Soft clay
Percentage of contingency	30 %

Tankdesigncode	ASME
Specificationdiametervessels	Internaldiameter
Number of workers per shift	13
Salary per operator ($/h)	30.00

Results and Discussion

Step 1. Economic evaluation

In Table 2 is found that Equipment represents the highest costs (43 %) compared to other factors that affect DFCI due to includes 6 process units to carry out the sterilization, threshing, digestion, pressing, clarification and drying operations. The last operations were needed due to oil obtained is not always pure, containing significant amount of water, metals and dust that make it less suitable for its different applications[13.] To avoid this, solvent extraction technology might be used due to yields higher percentage of recovered oil, however, the capital cost and the rates of energy and water consumption are higher[14].

Table 2. Total capital investment for the crude palm oil plant

Capital investment costs	Total (US$)
Delivered purchased equipment cost	4,117,912.70
Purchased equipment (installation)	823,582.54
Instrumentation (installed)	329,433.02
Piping (installed)	823,582.54
Electrical (installed)	535,328.65
Buildings (including services)	1,647,165.08
Servicesfacilities (installed)	1,235,373.81
Total DFCI	**9,512,378.34**
Land	411,791.27
Yard improvements	1,647,165.08
Engineering and supervision	1,317,732.06
Equipment (R+D)	411,791.27
Construction expenses	1,400,090.32
Legal expenses	41,179.13
Contractors' fee	665,866.48
Contingency	1,235,373.81
Total IFCI	**7,130,989.42**
Fixed capital investment (FCI)	**16,643,367.76**
Working capital investment (WCI)	**9,986,020.66**
Start up Costs (SUC)	**1,664,336.78**
Total Capital Investment (TCI)	**28,293,725.19**

In addition, in Table 3, direct production costs (DPC), fixed charges (FCH) and general expenses(GE) are presented. Raw material used was palm fruits and utilities costs used for the plant were electricity and water, which are higher in Colombia in comparison to other palm producers.

Table 3.Operating cost for the crude palm oil plant

Operating costs	Total (US$/year)
Rawmaterials	12,000,000.00
Utilities (U)	86,400.00
Maintenance and repairs (MR)	832,168.39
Operatingsupplies	124,825.26
Operating labor (OL)	140,400.00
Direct supervision and clerical labor	21,060.00
Laboratorycharges	14,040.00

Patents and royalties	166,433.68
Directproductioncost (DPC)	**13,385,327.32**
Depreciation (D)	1,082,105.10
Local taxes	499,301.03
Insurance	166,433.68
Interest/rent	282,937.25
Fixedcharges (FCH)	**2,030,777.06**
Plantoverhead (POH)	**84,240.00**
General expenses (GE)	**3,875,086.10**
OperatingCost (OC)	**19,375,430.48**

Economic indicators

Table 4 presents the economic indicators calculated. It can be observed that an income of 369.85 MM US$/y demonstrates that selling an only product is viable due to it turns into a profit (annual cost/revenue is positive). In addition, the PBP for the plant is 1.19 years due to operating costs (19.34 MM US$/y) are almost 50 % less than the annual income (43.24 MM US$/y), so the plant will be able to support an increase in NVOC. The return on investment (% ROI) is 49.30 %. Finally, CCF is less than 1.0, which is attractive in a project.

Table 4. Results of economic indicators for the crude palm oil production plant

Economic indicators	**Base case**
Gross Profit (depreciation not included) (GP)	23,950,127.28
Gross Profit (depreciation included) (DGP)	22,868,022.18
ProfitAftertaxes (PAT)	13,949,493.53
Products (Revenues)	43,244,800.00
Economic Potential 1 ($/y)	31,244,800.00
Economic Potential 2 ($/y)	31,158,400.00
Economic Potential 3 ($/y)	23,869,369.52
Cumulative Cash Flow (CCF) (1/yr)	0.84
PaybackPeriod (PBP) (years)	1.19
%ROI	49.30 %
Net Present Value NPV (MM US$)	369.85
AnnualCost/Revenue	45.07

Step 2. Statement of technoeconomic reference stage

Figure 2 shows that production capacity at the break-even point is 50,000 t/y. By comparing this value with the installed production capacity (240,000 t/y), it can be concluded that the process is more resistant to external changes that may affect the production and sales rate, which is beneficial because of the fruits availability is influenced mainly by climatic changes, tending to decrease in arid times. This process can reduce its production capacity by up to one quarter without ceasing to offset its operating costs and, an increase in its production capacity beyond its current installed capacity will not impact operating costs in the same proportion, probably due to economies of scale.In addition, when the annual sales are analyzed, it can be observed that profits correspond to 43.24 MM US$/y which is a higher value that Annualized Operating Costs (19.4 MM US$/y) leading to operational problems such as preventive/corrective maintenance activities that result in periods of restructuring during which the process is partially/totally halted, or market conditions that require a reduction in the time of production rates to maintain the selling price or to stay within the level of demand, do not significantly affect the process.

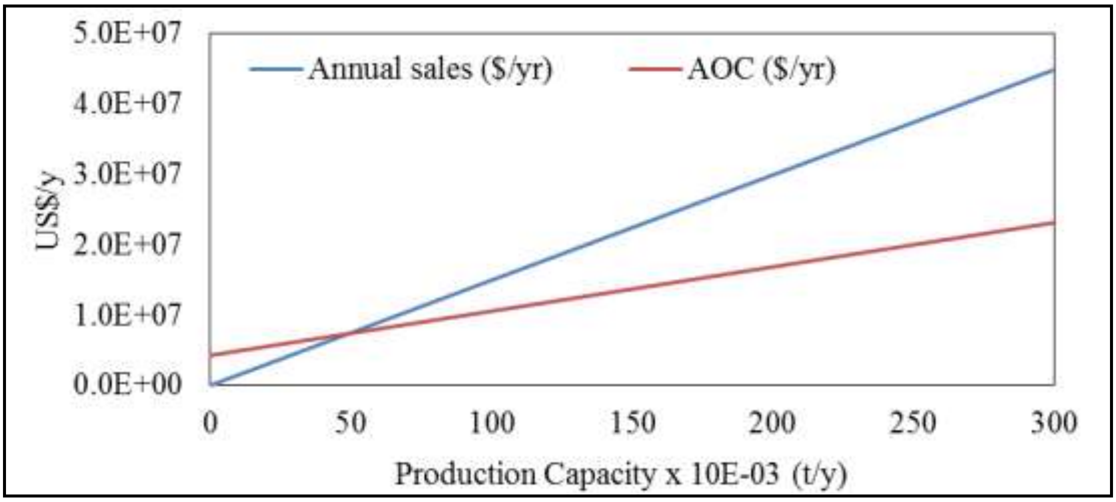

Figure 2. Break-even analysis of the crude palm oil plant

Step 3. Technoeconomic sensitivity analysis

Figure 3 presents the sensitivity analysis of the On-Stream efficiency of the process at the equilibrium point respect to sales price of the product. 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 (380 to 580 US$/t), reason why it decreases drastically under relatively small changes; the second moment is known as the transition period, where the change in On-Stream efficiency is not as pronounced allowing a greater operability to changes in the selling price(680 to 980US$/t) and finally in the third moment, it is observed that although the price increases to a great extent (1,080 to 1,580 US$/t) there will be no significant change in the decrease in On-Stream efficiency (7,4 to 4,5 %). According to Table 1, the selling price of crude palm oil (800.00 US$/t) places them in the transition period, which allows increasing price of the product if it is necessary by effects of crisis, unforeseen or supply/demand. It should be noted that if the sale price of crude palm oil declines to 400 US$/t, the process will have an on-stream efficiency close to 95% to reach its equilibrium point, and as production excess the capacity at the break-even to achieve an acceptable level of profitability, this sales price per tonne is, in fact, unacceptable.

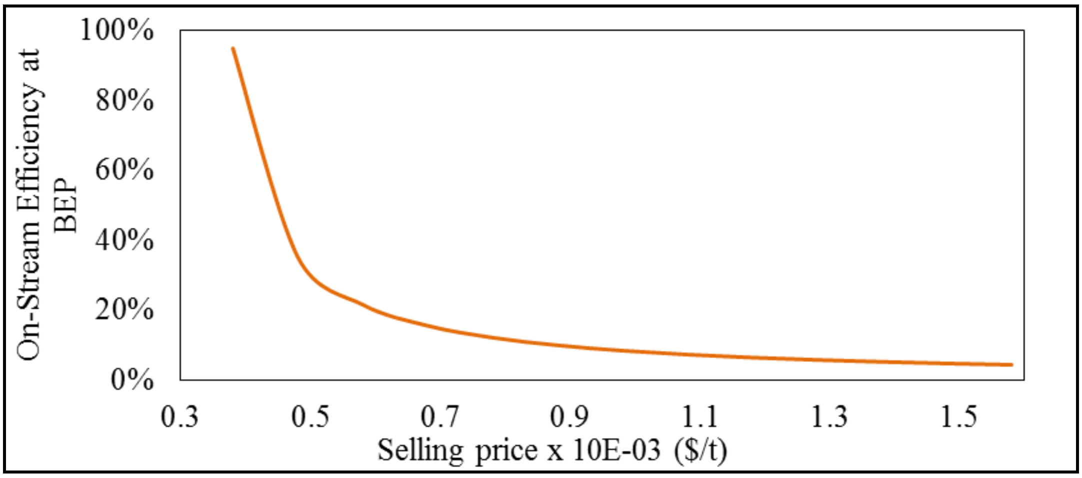

Figure 3. Effect of selling price of crude palm oil on On-stream efficiency at the break-even point

The effect of raw material costs on process profitability is shown in Figure 4. The plant presents a critical point around 100 and 120 US$/tons of raw material where it does not generate profits and below this value will be generated losses. According to the palm fruits price found in table 1 (50.00US$/t), it can be said that despite its high sensitivity, the plant will be able to tolerate to double the cost of raw material without generating losses. On the other hand, a decrease in palm fruits costs economically benefits the process, a 50 % reduction in the palm fruits cost increases the profitability after-tax by 48 % and a 100 % decrease in the cost of raw material increases it by 96 %. When analyzing the gross profit, it is evident that an increase in palm fruits price will make the profitability decrease in the same proportion. In addition, the depreciable gross profit is more affected by changes in raw material costs that profit after taxes due to the tax rate includes a component proportional to the income obtained from the process.

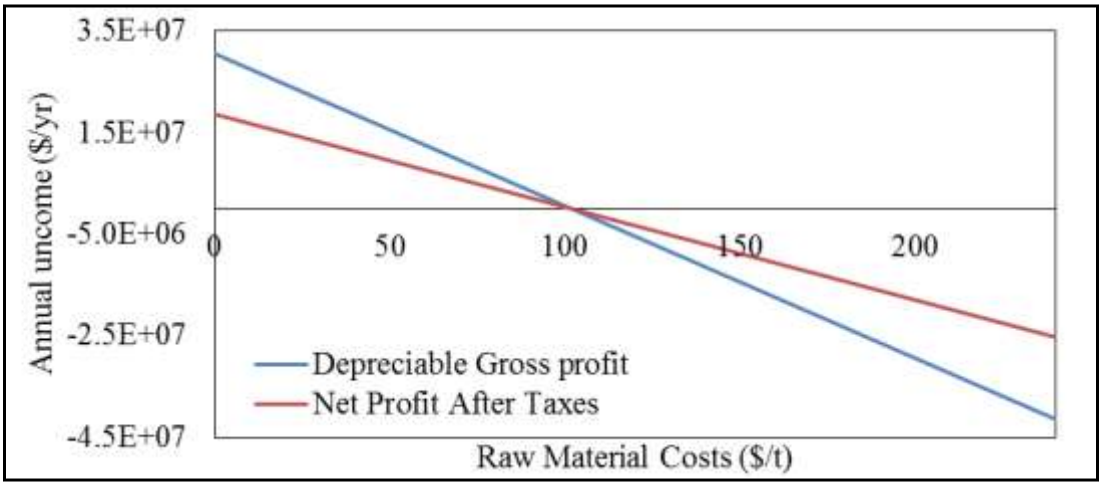

Figure 4. Sensitivity analysis of raw material cost on process profitability

The variation of ROI and PBP respect to changes in NVOC is shown in Figures 5 and 6. According to Figure 5, if variable operating costs (include industrial services, maintenance, employee salaries) come up over 167.6 US$/t, there will be no return on investment and the plant will lose all its feasibility. In this study case, this value is far enough away from the actual NVOC (72.27 US$/t),which provides a high elongation of this indicator, making the process more reliable to changes in variable costs. At the local level, there are some social problems such as electricity supply, employee strikes and high labor costs that can impact this indicator. Finally, the plant will have a ROI of 71 % in the hypothetic scenario where NVOC are 0 $/t, being greater than that of other processes of palm biomass utilization[15], which reinforces the high economic potential of this process, however the critical value of NVOC is much lower than that of the reported process, due to the difference in raw material costs between the two processes.

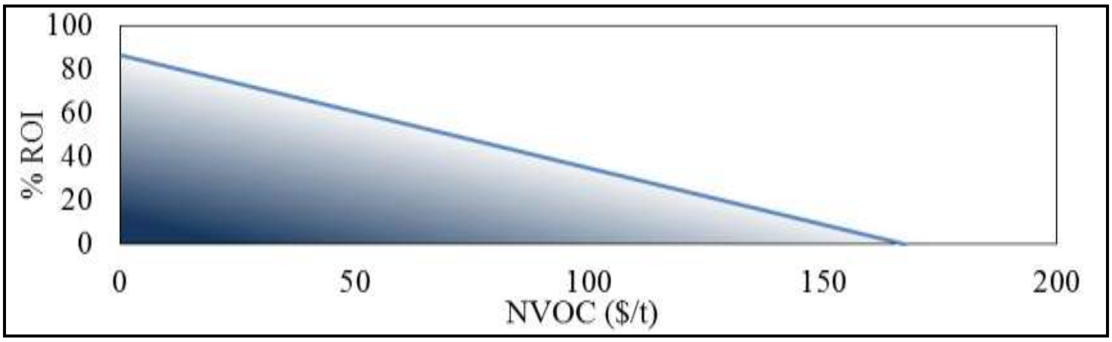

Figure 5. Effect of operating costs on the process ROI for the crude palm oil plant

On the other hand, Figure 6shows that the plant has a high sensitivity of PBP to NVOC. However, this behavior is inevitable when working with raw materials volatile in their price. In addition, an zone of relative stability can be identified for values of NVOC in the range of 60 to 80 US$/t and from there, a transition zone until there is a lack of control in the process economy where there is less tolerance to the increase in NVOC, detecting a critical point in 150 US$/t of raw material. In the zone of runaway it is appropriate left to speak of differences in fractions of year, to speak of an affectation in decades due to a variation in the operative costs.

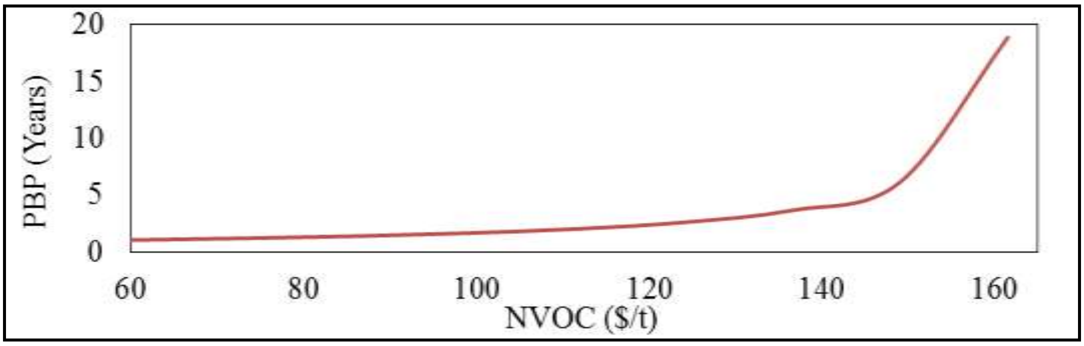

Figure 6. Effect of operating costs on the process Payback period for the crude palm oil plant

Figure 7 shows the behavior of NPV during the 15 years of plant life where it is observed thatthe project yields approximately 370 MM US$/y of Net Present Value, which means that after paying all the process costs and absorbing a 9 % annual erosion in the value of the money, the project income will give a net value of 370 million in dollars of the present. In addition, the investment will produce profits from the 6 years of the plant life, which is beneficial due to if at any moment of the project life arises any eventuality that leads to suspend it or cause it to be affected economically, the initial investment made will have been recovered.

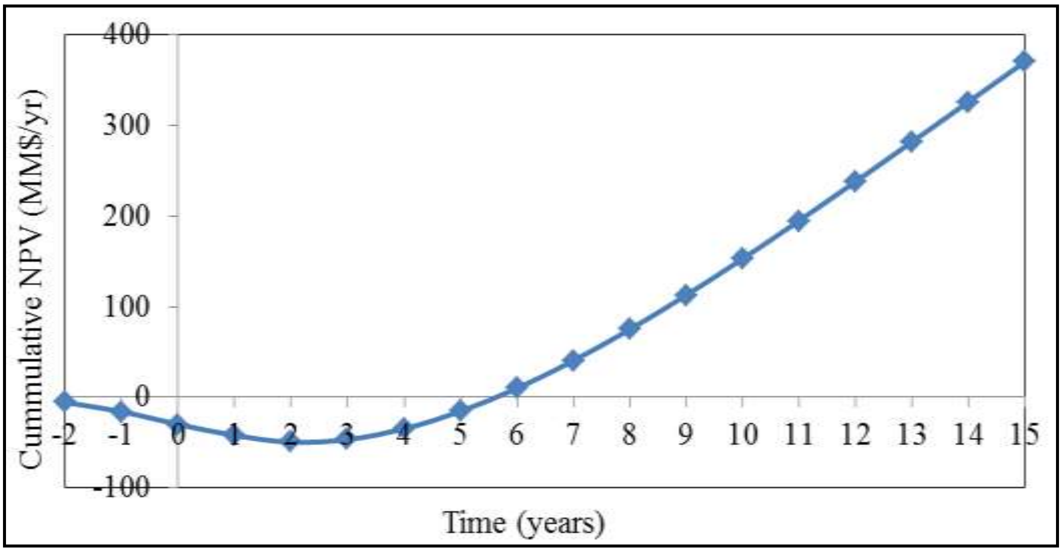

Figure 7. Sensitivity analysis for the Net Present Value for the crude palm oil production plant

Conclusions

A hierarchical technoeconomic sensitivity approach for evaluation of agroindustrial production chains was introduced and developed using a crude palm oil production chainas case study. For a flow rate of 240,000tons of palm fruits per year, based on assumptions established, the plant is an attractive project. It was found that annual sales (43.24 MM US$/y) are almost 50 % higher that the annualized operating cost (19.37 MM US$/y), making that ROI and NPV be 49.30 %and 369.85 MM$/y, respectively, at the end of the 15 years. However, when analyzing on-stream efficiency, it was observed that plant has a broad range of possibilities to assign prices to its product (680 to 980 US$/t) and it will tolerate a significant increase in the raw material price (up to 100 US$/t).Finally, the plant can support high changes in NVOC, however, if they come up to 167 US$/t, there will be no return on investment, the plant will lose all its feasibility and the payback period will be higher than19 years.

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