

Techno-Economic Analysis for Small Scale Production of Rubber Seed Oil and Biodiesel in Palangkaraya, Indonesia

M. Y. Abduh, R. Manurung, and H. J. Heeres

Abstract—Estimation of production cost and sensitivity analysis for small scale production of rubber seed oil and biodiesel was studied. The production unit is projected to be built in the ex-Mega Rice Project area south of Palangkaraya, Indonesia which has a serious land degradation and deforestation problem. The valorization of rubber seed to produce bioproducts is seen as a contribution to revitalize the area. The production cost for rubber seed oil and rubber seed biodiesel in a small-scale (55 ton/y) was estimated to be €0.42/L and 1.00/L, respectively. This value is comparable with the price of diesel in remote areas in the ex-Mega Rice Project area close to Palangkaraya (up to €1.25/L). The effects of capital investment, production capacity, price of co-product credit, employees' salary and price of raw materials towards the production cost of rubber seed oil and biodiesel were investigated in the sensitivity analysis. The cost of capital investment has a relatively minor impact on the production cost of the rubber seed oil and biodiesel. The production capacity has a very strong influence in the production cost of rubber seed oil. The effect of other input variables is significant and all are showing about equal sensitivity.

Index Terms—Biodiesel, production cost, rubber seed oil, sensitivity analysis.

I. INTRODUCTION

The global market for biobased products is estimated to grow to €200 billion by 2020 [1]. The pace of this development may be enhanced by using a biorefinery concept which aims to optimise the use of resources and minimise waste production in order to maximise benefit and profitability for sustainable development [1]. In a biorefinery, a wide range of processes are coupled for the production of biobased products from various biomass feedstocks [2]. An attractive biorefinery scheme for rubber seeds from rubber trees (*Hevea brasiliensis*) is shown in Fig. 1. Rubber seeds are of particular interest as these are currently not valorised and regarded as waste. The rubber seed yield is reported to be in the range of 100-1200 kg/(ha.y) [3], [4]. From a biorefinery perspective, the identification of high added value outlets for the rubber seeds is highly relevant as it increases the profit for the rubber plantation to latex value chain [5].

The rubber seeds consist of a kernel (61 wt%) surrounded by a hard shell (39 wt%). The kernel contains 40-50 wt% of

oil [6], [7] embedded in a protein rich matrix which can be isolated from the seeds by using for instance an expeller. By assuming the given composition and a rubber seed yield in the range of 100-1200 kg/(ha.y), the productivity of rubber seed oil (RSO) yield is estimated to be in the range 5-300 kg/(ha.y). The oil is a valuable source for the production of biodiesel (and by-product glycerol) and biopolymers [8], [9]. The protein rich press cake may find applications as a valuable source of protein [10], for instance to be used as cattle feed. In addition, the press cake may also be used for the production of biomaterials such as binderless boards [11], biogas and as the input for thermochemical processes like pyrolysis [12], [13].

The production of biodiesel from RSO can be carried out on different scale. For large-industrial scales (100 kton/y up to 250 kton/y), the processing technology have higher efficiencies at the expense of expensive capitalisation and on site construction. The rubber seeds can be obtained in abundance from rubber tree plantations. However, the transport of raw material from its source and also the products to the end user is normally long distance and requires a high transportation cost.

Biodiesel can also be produced in small scale system (< 15 kton/y) which requires less complicated and less expensive processing technologies and can be applied in rural areas. This may lower the capital cost and reduce the transportation cost of both the feedstock and product as well as improving the overall efficiency of the market delivery [14]. This study reported a preliminary techno-economic evaluation for small scale production of plant oil and biodiesel from rubber seeds in Palangkaraya, Indonesia. The production cost for RSO and biodiesel was estimated and sensitivity analysis was performed to evaluate the potential application of RSO as a feedstock for producing biodiesel.

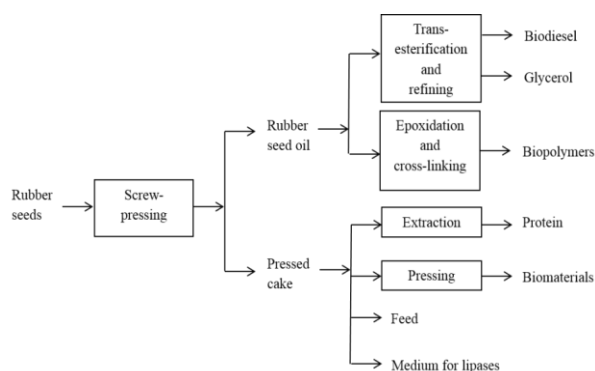


Fig. 1. Biorefinery scheme for rubber seed valorization.

II. PROCESS DESCRIPTION AND MASS BALANCES

The techno-economic evaluation reported in this paper is

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divided in two parts. The first part reports an evaluation for a small scale production unit of plant oil from rubber seeds using a screw expeller. The second part concerns the production of biodiesel on small scale from RSO using a continuous centrifugal contactor separator (CCCS) technology. CCCS is basically a device that integrates reaction and separation of liquid-liquid systems in a single device. Detailed description of the CCCS is described elsewhere [15]-[17]. Experimental and modelling studies on continuous synthesis and refining of biodiesel in a dedicated bench scale unit using CCCS technology has been reported by Abduh *et al.* [17]. From the study, it has been demonstrated that CCCS device is compact, robust and flexible in operation which allows continuous operation even at small scale.

The production unit is projected to be built in the ex-Mega Rice Project area south of Palangkaraya, the capital city of Central Kalimantan, Indonesia. During 1995-2006, this area of more than one million hectare of peat and lowland swamp was developed for large scale rice cultivation. However, due to improper peatland preparation, the land proved unsuitable for rice cultivation and this has led to serious land degradation and deforestation.

Currently about 110.000 ha is planted with rice. The average yields are low (1.5-2.5 tons/ha) due to poor land and water management. Small tree-farm based systems are mainly focused on rubber (33.500 ha) and coconut (24.500 ha) production. The valorisation of rubber seeds to produce biobased products is seen as a contribution to revitalize the area. Hence, a field study was carried out to collect rubber seeds in Palangkaraya. The RSO was then isolated from the seeds on site using a screw expeller and the oil was converted into biodiesel using a laboratory scale batch reactor. In the following, a preliminary techno-economic evaluation will be reported for the i) production of RSO from rubber seeds and ii) the conversion of RSO into biodiesel

A. Small Scale Production of RSO from Rubber Seeds

1) Process description

The production scale was set at an input of 60 kg wet rubber seed per hour, which is close to the maximum capacity of the available screw-press in the target area. With an estimated yield of 25 wt% of rubber seed oil on wet seeds, the estimated RSO production is 15 kg/h. When assuming 12 h per day of operation for 306 days a year, the annual RSO production of the unit is 55 ton. An overview of the RSO production unit is presented in Fig. 2. Rubber seeds are collected by the villagers in the target area during the harvesting season. The seeds typically have a moisture content of around 10 wt%. Directly after harvesting, the seeds are dried in an oven operated at 60 °C to reduce the moisture content to 7 wt% to improve storage stability. The seeds are then stored in sealed plastic bags which are placed in a closed plastic container. The (whole) seeds are pressed using a screw-press. Initial tests showed that oil yields are improved when using whole seeds instead of dehulled seeds and as such a dehuller was not included in the process design. The resulting crude RSO is stored in an oil drum for several days to allow solids to settle. The clear RSO free of solids is collected and stored in closed plastic containers.

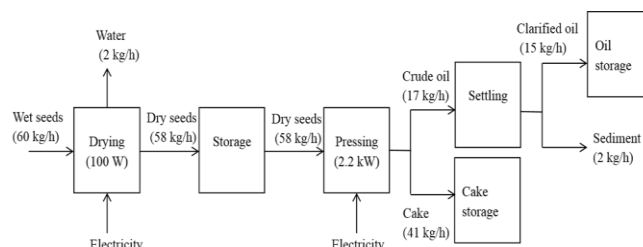


Fig. 2. Process flow diagram and mass balance for the production of RSO.

2) Mass balances

The mass balance of the process is given in Fig. 2. It assumes an input of 60 kg/h of wet rubber seeds (10 wt% water). After drying, 58 kg/h of dried seeds (7 wt% water) are pressed using a screw-press. Assuming a crude RSO yield of 28 wt% on wet seeds, it is estimated that 17 kg/h crude oil and 41 kg/h of press cake can be obtained [18]. After settling of the crude oil, an estimated 2 kg/h of sediment is formed whereas 15 kg/h of clarified RSO is stored for further use.

B. Small Scale Biodiesel Production Using CCCS Technology

1) Process description

The production of RSO in the expeller unit is approximately 15 kg/h, see previous section for details. When assuming a 98 mol% biodiesel yield from RSO in combination with a molecular weight of 0.890 kg/mol and 0.298 kg/mol for RSO and RSO methyl esters [8], respectively, the estimated production scale of the biodiesel unit is approximately 15 kg/h, which is equivalent to 55 ton/y biodiesel (12 h operation per day for 306 days per year). An overview of the biodiesel process is presented in Fig. 3. It involves storage vessels for feeds and products, a reactor/separator (CCCS), a crude biodiesel wash section, a biodiesel drying unit, a glycerol and methanol recovery unit.

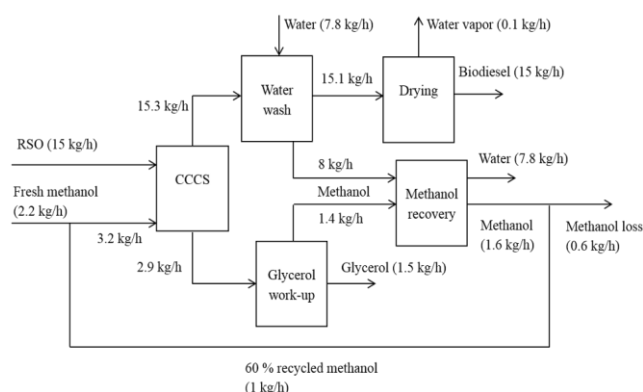


Fig. 3. Process flow diagram and mass balance for the production of RSO biodiesel.

A CCCS type CINC V05 with an estimated production capacity of 55 ton/y biodiesel is used as the reactor/separator. In the device, the RSO reacts with methanol in the presence of a catalyst (KOH). It is assumed that potassium hydroxide has similar performance as sodium methoxide. It is assumed that the free fatty acid content in the RSO feed is below 1 wt% to exclude an initial acid catalysed esterification reaction. The methanol from the crude biodiesel and the crude glycerol are recovered using an alcohol recovery unit.

2) Mass balances

The mass balance of the process is provided in Fig. 3 and is based on a 15 kg/h RSO input. A 6:1 molar ratio of methanol to oil is used which is equivalent to an input of 3 kg methanol/h to the reactor. The required water for the biodiesel wash unit is set at 7.8 kg/h, which was found the best ratio as reported in our previous study [17]. After drying, 15.0 kg/h biodiesel is produced. The water stream from the wash section, also containing dissolved methanol is fed to an alcohol recovery unit. An additional amount of methanol is recovered in the glycerol work-up. It is assumed that 60% of the excess methanol [19] can be recovered (1 kg/h) and may be recycled to reduce the amount of fresh methanol used in the process (2.2 kg/h). Besides biodiesel, 1.5 kg/h of glycerol is also obtained in a glycerol-work up unit.

III. COST ESTIMATION AND SENSITIVITY ANALYSIS

The total capital and production cost estimates for production of RSO and biodiesel are based on a cost estimation procedure by Garret [20] and Peters and Timmerhaus [21]. Overhead, research, financing as well as distribution and marketing cost are excluded from the calculation of the total production cost. Land acquisition is excluded from the capital costs, as the small scale unit is expected to require a limited amount of space.

A. Small Scale Production of RSO from Rubber Seeds

1) Cost estimation

The total equipment cost based on the process description and mass balance as shown in Fig. 2 are estimated at €10.800 (Table I). This cost includes storage facilities for oil cake residue as well as process equipment such screw press (60 kg/h), drying oven and weighing balance. The costs are based on online prices [22] and data available in the literature [23].

TABLE I: ESTIMATED TOTAL EQUIPMENT COST FOR A 55 TON/Y RSO PROCESSING UNIT IN PALANGKARAYA, INDONESIA

Item	Cost (€)
Storage facilities	
Seed Storage	2.000
Oil Storage	1.600
Cake Storage	2.000
Subtotal storage facilities	5.600
Process equipment	
Screw press, 60 kg/h	5.000
Seed drying oven	100
Weighing balance, 100 kg	100
Subtotal process equipment	5.200
Total equipment cost	10.800

The total capital investment (TCI) for the small-scale RSO production facility was estimated to be €35.620. This value is the sum of the fixed capital investment (FCI) and working capital investment (WCI), which were evaluated independently (Table II). An overview of the total production cost for a 55 ton/y RSO processing unit in Palangkaraya is given in Table III.

The cost of the rubber seed input was estimated at Rp1.500/kg. Assuming a currency exchange of 16.000 Rp/€, this equals to €0.094/kg. The annual electricity required for the process was estimated to be around 8800 kWh. Assuming an electricity cost of €0.05/kWh [24], the annual cost for electricity is €441. The wages for the employees are based on the standard salary for employment in Indonesia (€3/h). Assuming 4 employees working a 6 h shift per day and that the unit is 12 h/d in operation, the total employee costs is €22.030.

TABLE II: ESTIMATED TOTAL CAPITAL COST FOR A 55 TON/Y RSO PROCESSING UNIT IN PALANGKARAYA, INDONESIA

Item	Cost (€)
Direct Cost (DC)	
Equipment cost (E)	10.800
Instrumentation and Control (0.4E)	4.320
Electrical Distribution System (0.1E)	1.100
Establishment of Equipment (0.45E)	4.860
Total DC	21.100
Indirect Cost (IC)	
Technical and Supervision (0.15DC)	3.160
Unexpected Expenses (0.15FCI)	4.270
Total IC	7.430
Fixed Capital Investment (FCI)	
FCI = DC + IC	28.490
Working Capital Investment (WCI)	
WCI = 0.2TCI	7.120
Total Capital Investment (TCI)	
TCI = FCI + WCI	35.620

TABLE III: ESTIMATED TOTAL PRODUCTION COST FOR A 55 TON/Y RSO PROCESSING UNIT IN PALANGKARAYA, INDONESIA

Item	Cost (€)
Raw materials/year	20.710
Employees' salary/year	22.030
Electricity cost/year	441
Maintenance (0.01 FCI)	285
Operating supplies (0.1 salary)	2.200
Supervision (0.1 salary)	2.200
Administration cost (0.02 TPC)	540
Depreciation (0.1 FCI)	2.850
Subtotal production cost	51.240
Co-product credit-press cake	25.594
Total production cost (TPC)	25.676

By assigning a market value of €0.17/kg for the press cake [22], the total annual production cost is reduced to €25.676. Taking into account the total oil production of 55 ton/y, the oil production cost is approximately €0.47/kg, which is €0.42/L when assuming an RSO density of 0.91 kg/L [6]. For comparison, the diesel price at fuel stations in the city centre of Palangkaraya is approximately €0.47/L. However, the price of diesel outside the city is considerably higher and may be up to €1.25/L. As such, the RSO may be a competitive

product for stationary electricity generation using a diesel engine.

2) Sensitivity analysis

A sensitivity analysis was performed to investigate the effect of input variables on the RSO production cost which includes price of press cake, cost of rubber seeds, employees' salary, production capacity and total capital investment. The sensitivity bounds for the input variables were set at 50 and 150% of the base case. The results of the sensitivity analysis are summarised in Fig. 4. Clearly, the capital investment cost has a relatively minor impact on the production costs of the RSO. Thus, optimisation of the design and reduction of the equipment costs should not be considered as a major research and development topic. The major variable is the amount of RSO produced in the unit. When the unit produces only 7.5 kg/h instead of the projected 15 kg/h, the production costs of the RSO increases to €0.93/L. The effect of the other three input variables (price of press cake, salary costs and costs of the rubber seed) is significant and about equal.

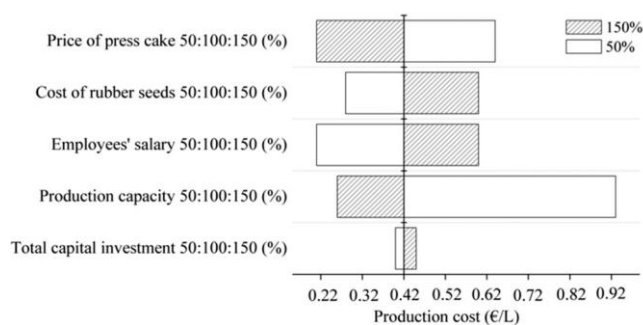


Fig. 4. Sensitivity analysis for RSO processing unit in Palangkaraya, Indonesia.

B. Small Scale Biodiesel Production Using CCCS Technology

1) Cost estimation

The total capital and production cost estimates are, like for RSO in the previous section, based on cost estimation procedure by Garrett [20] and Peters and Timmerhaus [21]. Overhead, research, financing as well as distribution and marketing are excluded from the calculation of the total production cost. Land acquisition is excluded from the capital costs, as the small scale unit is expected to require a limited amount of space.

The total equipment cost based on the process description and mass balance as shown in Fig. 3 are estimated at €40,000 (Table IV). The costs are based on online prices [22] and data available in the literature [20], [21]. The price of the CCCS was obtained from the supplier (CINC Industries). The equipment cost includes an RSO storage tank with a 30-day supply capacity.

The TCI for the small-scale RSO biodiesel production facility was estimated to be €123,000 (Table V). This value is the sum of the fixed capital investment (FCI) and working capital investment (WCI), which were evaluated independently. Almost one third of the capital investment is for purchase of equipment while the other two thirds are construction cost, indirect cost and working capital.

The cost of raw materials for the 55 ton/y biodiesel unit is

provided in Table VI. The cost of RSO feedstock is the estimated price as provided in the previous section (€470/ton). The annual electricity consumption was not calculated in detail but taken as 10000 kWh, which is the reported electricity requirement for a small scale biodiesel production unit [23]. Assuming an electricity cost of €0.05/kWh, the annual electricity cost is €500.

TABLE IV: ESTIMATED TOTAL EQUIPMENT COST FOR A 55 TON/Y RSO BIODIESEL PROCESSING UNIT IN PALANGKARAYA, INDONESIA

Item	Cost (€)
Storage facilities	
Oil storage tank	1.600
Biodiesel storage tank	1.200
Crude glycerol storage tank	800
Methanol storage tank	800
KOH storage tank	400
Biodiesel wash tank	900
Additional storage tank	3.200
Subtotal storage facilities	8.900
Process equipment	
Methanol/catalyst mixer	250
CCCS pre-heater	250
CCCS	20.000
Washing unit	300
Drying unit	300
Methanol recovery unit	10.000
Subtotal process equipment	31.100
Total equipment cost	40.000

TABLE V: ESTIMATED TOTAL CAPITAL COST FOR A 55 TON/Y RSO BIODIESEL PROCESSING UNIT IN PALANGKARAYA, INDONESIA

Item	Cost (€)
Direct Cost (DC)	
Equipment cost (E)	40.000
Instrumentation and Control (0.4E)	16.000
Electrical Distribution System (0.1E)	4.000
Establishment of Equipment (0.45E)	18.000
Total DC	78.000
Indirect Cost (IC)	
Technical and Supervision (0.15DC)	11.700
Unexpected Expenses (0.15FCI)	12.800
Total IC	24.500
Fixed Capital Investment (FCI)	
FCI = DC + IC	102.500
Working Capital Investment (WCI)	
WCI = 0.2TCI	20.500
Total Capital Investment (TCI)	
TCI = FCI + WCI	123.000

The sub-total production cost for the biodiesel unit is estimated at €64,162 per year (Table VII). By assigning a market value of €0.33/kg for the glycerol [24], the total annual production cost is reduced to €62,344. Combined with the annual production capacity (55 ton/y), the biodiesel production cost is approximately €1.13/kg, which is €1.00/L when using a biodiesel density of 0.88 kg/L [6].

TABLE VI: RAW MATERIAL COSTS FOR A 55 TON/Y RSO BIODIESEL PROCESSING UNIT

Raw materials	Annual use (ton)	Annual cost (€)
Rubber seed oil	55	23.134
Potassium hydroxide	0.6	44
Methanol	8.1	1.454
Process water	29	8
Hydrochloric acid	0.6	58
		24.698

TABLE VII: ESTIMATED TOTAL PRODUCTION COST FOR A 55 TON/Y RSO BIODIESEL PROCESSING UNIT IN PALANGKARAYA, INDONESIA

Item	Cost (€)
Raw materials/year	24.698
Employees' salary/year	22.030
Electricity cost/year	500
Maintenance (0.01 FCI)	1.025
Operating supplies (0.1 salary)	2.200
Supervision (0.1 salary)	2.200
Administration cost (0.02 TPC)	1.250
Depreciation (0.1 FCI)	10.250
Subtotal production cost	64.162
Co-product credit-glycerol	1.820
Total production cost (TPC)	62.344

2) Sensitivity analysis

A sensitivity analysis was performed to investigate the effect of input variables on the RSO biodiesel production costs which includes price of glycerol, cost of RSO, employees' salary, production capacity and total capital investment. The sensitivity bounds for the input variable were set at 50 and 150% of the base case. The results of sensitivity analysis are shown in Fig. 5. Production capacity has the largest effect on the production cost. A reduction in the plant capacity to 50% leads to an increase in the biodiesel price to €1.99/L. An increment in the plant capacity to 150% leads to a decrease in the biodiesel price to €0.66/L. Other important input variables are the salaries and the cost of the RSO oil. As with the RSO unit, the total capital investment has a rather limited effect on the biodiesel production costs. The selling price of the co-product glycerol has the least effect on the production cost and as such of less importance.

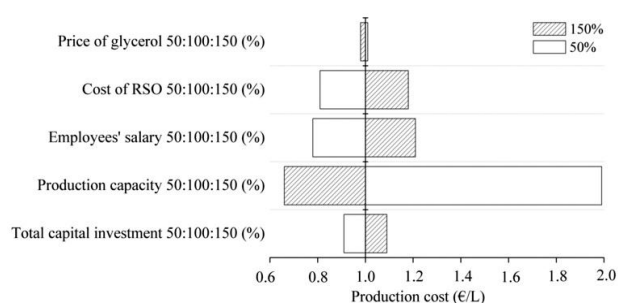


Fig. 5. Sensitivity analysis for RSO biodiesel processing unit in Palangkaraya, Indonesia.

IV. CONCLUSIONS AND OUTLOOK

The production cost for RSO in a small-scale rubber seed expeller unit (55 ton RSO/y) in Palangkaraya were estimated to be €0.42/L. The capital investment cost has a relatively minor impact on the production cost of the RSO. Thus,

optimisation of the design and reduction of the equipment costs should not be considered as a major research and development topic. The major variable is the amount of RSO produced in the unit. When the unit produces only 7.5 kg/h instead of the projected 15 kg RSO/h, the production cost of the RSO increase to €0.93/L. The effect of the other three input variables (market price of press cake, salary costs and costs of the rubber seed) is significant and all are showing an about equal sensitivity. For comparison, the diesel price at fuel stations in the city centre of Palangkaraya is approximately €0.47/L. However, the price of diesel outside the city is considerably higher and may be up to €1.25/L. As such, the RSO may be a competitive product for stationary electricity generation using a diesel engine both in Palangkaraya as well as the rural areas in the ex-Mega rice project.

In addition, the total production cost for biodiesel at small scale (55 ton/y) from RSO using CCCS technology was also evaluated and found to be €1.00/L. This value is comparable with the price of diesel in remote areas in the ex-mega rice project area close to Palangkaraya (up to €1.25/L). The CCCS technology is also particularly suitable for mobile biodiesel unit application due to its compactness, robustness and flexibility in operation.

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