Palm Oil (Elaeis Guiniensis) Plantations: A Potential Feedstock for Biodiesel Production, in Nigeria

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C.N. Anyanwu[*], V.K. Sharma[**], G. Braccio[**], F. Nanna[**] and C.O. Akubuo[***]

[*]National Centre for Energy Research and Development
University of Nigeria Nsukka
410001 Enugu State
NIGERIA
[**]ENEA Research Centre Trisaia
Solar Collector Testing Laboratory and Biomass Section
S.S. Jonica 106, 75026 Rotondella (MT)
ITALY
[***]Department of Agricultural Engineering
University of Nigeria Nsukka
410001 Enugu State
NIGERIA

ABSTRACT

Detailed feasibility study, focused predominantly on availability of Crude Palm Oil (CPO), Palm Kernel Oil (PKO) and Refined Palm Oil Sludge along with their use for biodiesel production, in Nigeria, is discussed. Production cost analysis and its comparison with Rapeseed and Soybean oil feedstocks has also been reported. Results obtained from the sensitivity analysis conduced have clearly demonstrated that the pay-back time of a biodiesel plant being highly dependent on the feedstock price, it is quite feasible to operate such a plant as a profitable business using Pam oil as starting raw material.

1. INTRODUCTION

The use of biodiesel has grown rapidly from virtually zero in 1995 to a total of about 1.5 MMT per annum worldwide in 2003. However, its production and marketing has been limited to Europe and USA where commercial plants have been processing Rapeseed and Soybean oils respectively for the past decade. In spite of the fact that Palm Oil is cheaper than the aforementioned feedstocks in an industry where the cost of raw materials is of critical importance in the total production cost structure, the fact remains that no serious attempt has been made so far to study extensively the feasibility of a commercial scale plant using this feedstock.

It is now a well-established fact that most vegetable oils including Palm Oil can be converted into a fuel grade product known as monoalkyl ester using the process of transesterification. This ester fuel, which can also be obtained from animal fats, is often referred to as Biodiesel. The process of transesterification is essentially a reaction between the alkyl esters of fatty acids (palmitates, stearates, oleates etc) and glycerol with a short chain alcohol, usually, methanol or ethanol. This reaction proceeds in the presence of acid or alkaline catalysts and the end products are Fatty Acid Methyl or Ethyl Ester (FAME or FAEE), i.e. biodiesel and glycerol. EU countries (2.25 MMT in 2004) and the United States of America (0.3MMT) are the major producers of biodiesel [1, 3].

Apart from the fact that biodiesel requires no major modifications to a normal compression ignition (diesel) engine, it has the rare advantage of reducing the incidence of harmful greenhouse gas emissions into the atmosphere as well as being a renewable resource since the trees continue to produce the oil through photosynthesis. Thus, the growth phase of the palm trees enhances CO_2 sequestration. Biodiesel has the highest BTU content of any alternative fuel (in the range between No. #1 and No. #2 diesel) and the highest energy balance of any fuel since 3.2 units of energy are gained for each unit of fossil energy used to produce biodiesel [2]. Reports indicate that the fuel properties as well as engine torque produced by palm oil diesel are similar to those of petroleum diesel [4]. It also produces less Particulate matter, Hydrocarbons, Aromatics, Carbon Monoxide and Soot emissions when burnt in the engines [5].

Another important consideration for a sustainable industry is the amount and availability of raw materials. The quantity of palm oil currently produced in Nigeria annually (about one million metric tons) appears insufficient to support commercial production of palm oil diesel, since a sizeable percentage of this produce is demanded by the beverage and cosmetics industries. However, with future acreage expansions and envisaged replacement of wild varieties, it is quite possible to double the production level, which is enough to sustain a commercial biodiesel industry.

The present study considers the factors affecting commercial biodiesel production from Nigerian oil palm plantations and includes an economic feasibility study carried out by comparing the use of crude palm oil (CPO), palm kernel oil (PKO) and waste palm oil (restaurant grease and sludge) as starting raw materials for this process. It also includes results of laboratory analysis carried out to characterize some waste palm oil sludge and refined waste oil samples as well as cost and income scenario for a large plant comparing these raw materials to Soy and Canola oils.

2. FUEL PROPERTIES OF VEGETABLE OILS

The potential to run engines on biofuel go all the way back to Rudolph Diesel's successful trials using peanut oil over a century ago**.** Yet it is only now, with the transport sector likely to be the fastest growing contributor to greenhouse gas emissions this century, and diesel prices climbing steadily as oil appears scarcer and less secure, that the advantages of biodiesel are being appreciated by governments around the world.

The idea of using vegetable oils in diesel engines is supported by research results, which indicate that they possess good lubricating properties in addition to their excellent combustibility. The major setback to this concept emanates from the high viscosity of vegetable oils, which is due mainly to their large molecular mass in comparison to that of diesel fuel [4, 6]. Studies indicate that the onset of atomization, which is the initial stage of combustion in a compression ignition engine, is significantly affected by the fuel's viscosity [7]. Apart from this, the use of vegetable oils in place of diesel in conventional engines has led to problems such as carbon deposits, oil ring sticking and gelling of lubricating oils [8, 9]. This has necessitated the transformation of vegetable oils into biofuels, which are more suitable for combustion in diesel engines.

There are several proven ways of converting vegetable oils into fuel grade products. Physical techniques include dilution and micro-emulsification, whereas catalytic cracking, pyrolysis and transesterification are prominent among the chemical methods [8,10]. Of these methods, transesterification has found widespread application owing to its relative simplicity and cost advantage [10]. Methyl and Ethyl Esters of different vegetable oils including crude palm and palm kernel oils have been found to possess similar fuel properties to those of petrodiesel but with significantly reduced pollutant emissions levels [11,12]. Fuel and rheological properties of some vegetable oils are compared to that of diesel in table 1.

Table 1. Fuel and Rheological Properties of Some Vegetable Oils and Diesel Fuel [5], [13]-[17]

Vegetable Oil	Kinematic Viscosity at 38° C (mm^2/s)	Cetane Number	Heating Value (MJ/Kg)	Cloud Point (° C)	Pour Point (° C)	Flash Point (° C)	Specific Gravity
Corn	34.9	37.6	39.5	-1.1	-40.0	277	0.9095
Cottonseed	33.5	41.8	39.5	1.7	-15.0	234	0.9148
Crambe	53.6	44.6	40.5	10.0	-12.2	274	0.9048
Linseed	27.2	34.6	39.3	1.7	-15.0	241	0.9236
Peanut	39.6	41.8	39.8	12.8	-6.7	271	0.9026
Rapeseed	37.0	37.6	39.7	-3.9	-31.7	246	0.9115
Safflower	31.3	41.3	39.5	18.3	-6.7	260	0.9144
Sesame	35.5	40.2	39.3	-3.9	-9.4	260	0.9133
Soybean	32.6	37.9	39.6	-3.9	-12.2	254	0.9138
Sunflower	33.9	37.1	39.6	7.2	-15.0	274	0.9161
Palm	39.6	42.0	39.3	31.0	-	267	0.9180
Babassu	30.3	38.0	-	20.0	-	150	0.9460
Diesel	3.1	50.0	43.8	-	-	76	0.8550

3. AVAILABILITY OF PALM OIL RAW MATERIALS

The Oil Palm (Elaeis Guiniensis) is native to West and Central Africa, where the food use of its produce dates back to many centuries. It can also be cultivated in areas within 10^0 from the equator. The plant is the oil producer with the highest yield, since one tree (improved variety) can produce as much as 20 tons of fruit per year equivalent to about 11 tons of palm oil. The wild variety of the tree can grow up to 30 metres high, but new improved species are much shorter and, thus, easier to harvest. Each fruit consists of a hard kernel (seed) inside a shell (endocarp), surrounded by a fleshy mesocarp [18]. The mesocarp contains about 49 % palm oil and the kernel, about 50% of palm kernel oil (PKO). Both palm oil and palm kernel oil are appropriate raw materials for biodiesel production.

Worldwide, Palm oil is the second most important vegetable oil after Rapeseed oil. It accounts for about 28 % of the total vegetable oil demand, which translates to about 30 million metric tons annually [19, 20]. Malaysia (45%) and Indonesia (28%) are responsible for the bulk of this output, whereas Nigeria is the third largest producer with about 8% of total world output, which is barely sufficient for her internal market. The country has been importing palm oil recently in order to offset increasing local demands.

In Nigeria, oil palm is cultivated on about 364 thousand hectares mainly in the Southern parts of the country. The average yield per hectare is about 4.0 tones of palm fruit, or 2.2 tons of crude palm oil per hectare (about 800 thousand tons of CPO per annum), which can be doubled through research [20,21]. Government policy is currently geared towards replacing one million wild trees with the high yielding Tenera species capable of producing up to 5 tons of oil per hectare with an optimal life cycle of 9 - 19 years as well as doubling the acreage. This level of production can support a thriving biodiesel industry capable of delivering 1 million tones of fuel per annum, even if only 30 % of the total output is considered available for this purpose in view of stiff competition from the cosmetics and beverage industries. More palm kernel oil would also become available for the cosmetics industry.

In the past few years, research has shown that the cost of biodiesel feedstock is a crucial factor in the final production cost [22]. A ton of crude palm oil sells for about $380 (€ 290) in the international market, which is lower than other major vegetable oils; such as Rapeseed oil ($650 or €496), Soybean oil

($470 or €360) and Sunflower oil $690 (€527), respectively. Obviously, palm kernel oil is much more expensive ($670/ton) since its production requires more energy mainly for cracking the nuts. The local price of palm oil in Nigeria is generally lower than the international price.

4. CHEMISTRY OF PALM OIL TRANSESTERIFICATION

Most vegetable oils are composed of fatty acid triglycerides, i.e. esters formed by the reaction of propane 1,2,3 – triol (glycerol) with long chain fatty acids. In the case of crude palm oil unsaturated fatty acids account for about 44 to 57%, whereas saturated fatty acids are within the range of 45 to 55 %, thus making its fatty acid ratio close to unity [19, 23]. The predominant esters in palm oil are those of Palmitic (41 to 47%), Oleic (38 to 43%), Linoleic (6 to 12%) and Myristic (1 to 6%) acids. Other esters present in trace quantities include those of Palmitoleic, Linolenic and Arachidic acids.

A comparison of the fatty acid composition of various vegetable oils is given in table 2. It is quite clear from the table that Palm oil and palm kernel oil contain much higher percentage of saturated fatty acids as well as lower percentage of unsaturated fatty acids, in comparison with most other edible oils. This scenario favours their use as industrial raw materials. Further, the low conversion rate of about 60 to 70 % obtained when cracking palm oil products with catalysts was attributed to their high saturated fatty acid content [8,12,24]. The transesterification of Palm oil consists, essentially, of the reaction of the constituent esters with a short chain alcohol, usually ethanol or methanol in the presence of a mineral acid or alkaline catalyst.

Table 2. Fatty Acid Composition (%) of Various Vegetable Oils [16,23]

Fatty acid	Red Palm	Palm Kernel	Coconut	Soybean	Groundnut	Cotton Seed	Corn	Sunflower
Capronic 6:0	-	0.2	0.5	-	-	-	-	-
Caprylic 8:0	-	3.3	8.0	-	-	-	-	-
Capric 10:0	-	3.5	6.4	-	-	-	-	-
Lauric 12:0	0.2	47.8	48.5	-	-	Trace	-	-
Myristic 14:0	1.1	16.3	17.6	0.1	0.1	0.8	-	-
Palmitic 16:0	44.0	8.5	8.4	11.0	11.6	23.7	12.2	6.5
Stearic 18:0	4.5	2.4	2.5	4.0	3.1	2.6	2.2	4.5
Oleic 18:1	39.2	15.4	6.5	23.4	48.5	18.4	27.5	21.1
Linoleic 18:2	10.1	2.4	1.5	53.2	31.4	53.0	57.0	66.2
Linolenic 18:3	0.4	-	-	7.8	-	0.1	0.9	-
Arachidic 20:0	0.1	0.1	-	-	1.5	0.3	0.1	0.3
Saturates	49.9	82.1	91.9	15.1	16.3	27.4	14.5	11.3
Monounsaturates	39.2	15.4	6.5	23.4	48.5	18.4	27.5	21.1
Polyunsaturates	10.5	2.4	1.5	61.0	31.4	53.1	57.9	66.2

Note: The numbers x:y given with each fatty acid refer to the number of carbon atoms (x) and the number of double bonds (y) respectively in their structure.

Eq. (1) is a chemical representation of the formation of vegetable oils. In the case of palm oil, the radical R is of the order of 16 to 18 Carbon atoms and is either unsaturated, e.g. Palmitate or of varying levels of saturation e.g. Oleic (1), Linolenic (3) etc.

$$3RCOOH + C_3H_5(OH)_3 \rightarrow C_3H_5(COOR)_3 + 3H_2O \quad (1)$$

During transesterification, palm oil is made to react with an alcohol, usually methanol or ethanol in the presence of a catalyst, such as NaOH, KOH, $NaOCH_3$ or H_2SO_4 at slightly elevated temperatures of 55 to 70 ^{0}C. The products of this reaction are a fatty acid methyl (or ethyl) ester (FAME or FAEE) and glycerol according to eq. (2). The average molecular masses of the methyl (ethyl) esters of CPO and PKO as calculated from their composition are shown in tables 3 and 4.

$$C_3H_5(COOR)_3 + 3CH_3OH \rightarrow 3RCOOCH_3 + C_3H_5(OH)_3 \qquad (2)$$

The stoichiometry of eq. (2) in corroboration with data from tables 3 and 4 suggest that 1 Kmol (about 847.2 Kg) of oil would yield 3 Kmols (892.2 Kg) of Ethyl ester at optimal conversion using an alcohol to triglyceride (oil) molar ratio of 3:1. However, experimental results indicate that the reaction requires different levels of excess alcohol. The triglyceride conversion, measured as a function of methyl ester yield, is generally within the range of 70 to 90 % [23, 25]. In addition to alcohol/oil molar ratio, two other factors, namely the nature and amount of catalyst as well as the reactor temperature are of immense importance to the reaction kinetics [26].

Table 3. Estimation of the Molecular Mass of the ME (EE) of Crude Palm Oil (CPO)

Fatty Acid	**Weight Percent**	**Formula**	**Molecular Mass**
Lauric 12:0	0.2	$C_{11}H_{23}COOCH_3$ (C_2H_5)	214.0 (228.0)
Myristic 14:0	1.1	$C_{13}H_{26}COOCH_3$ (C_2H_5)	242.0 (236.0)
Palmitic 16:0	44.0	$C_{15}H_{31}COOCH_3$ (C_2H_5)	270.0 (284.0)
Stearic 18:0	4.5	$C_{17}H_{35}COOCH_3$ (C_2H_5)	298.0 (312.0)
Oleic 18:1	39.2	$C_{17}H_{33}COOCH_3$ (C_2H_5)	296.0 (310.0)
Linoleic 18:2	10.1	$C_{17}H_{31}COOCH_3$ (C_2H_5)	294.0 (308.0)
Linolenic 18:3	0.4	$C_{17}H_{29}COOCH_3$ (C_2H_5)	292.0 (306.0)
Arachidic 20:0	0.1	$C_{19}H_{39}COOCH_3$ (C_2H_5)	326.0 (340.0)
Weighted Molecular Mass	99.6		283.7 (297.4)

Table 4. Estimation of the Molecular Mass of the ME (EE) of Palm Kernel Oil (PKO)

Fatty Acid	**Weight Percent**	**Formula**	**Molecular Mass**
Capronic 6:0	0.2	$C_5H_{11}COOCH_3$ (C_2H_5)	130.0 (144.0)
Caprylic 8:0	3.3	$C_7H_{15}COOCH_3$ (C_2H_5)	158.0 (172.0)
Capric 10:0	3.5	$C_9H_{19}COOCH_3$ (C_2H_5)	186.0 (200.0)
Lauric 12:0	47.8	$C_{11}H_{23}COOCH_3$ (C_2H_5)	214.0 (228.0)
Myristic 14:0	16.3	$C_{13}H_{27}COOCH_3$ (C_2H_5)	242.0 (256.0)
Palmitic 16:0	8.5	$C_{15}H_{31}COOCH_3$ (C_2H_5)	270.0 (284.0)
Stearic 18:0	2.4	$C_{17}H_{35}COOCH_3$ (C_2H_5)	290.0 (304.0)
Oleic 18:1	15.4	$C_{17}H_{33}COOCH_3$ (C_2H_5)	296.0 (310.0)
Linoleic 18:2	2.4	$C_{17}H_{31}COOCH_3$ (C_2H_5)	294.0 (308.0)
Arachidic 20:0	0.1	$C_{19}H_{39}COOCH_3$ (C_2H_5)	326.0 (340.0)
Weighted Molecular Mass	99.9		236.8 (250.8)

5. PROCESS FLOW SCHEME

Generally, 100 parts of vegetable oil are reacted with 10 parts of alcohol (methanol or ethanol) in the presence of a catalyst to produce 10 parts of glycerol and 100 parts of FAME (FAEE), i.e. biodiesel.

The transesterification of crude palm oil is normally catalyzed by caustic soda (NaOH) or potassium hydroxide (KOH) or, in some cases, sodium methanoate ($NaOCH_3$), which is first dissolved in the alcohol in slight excess. The alcohol/catalyst mixture is then charged into a reaction vessel and the oil is added. Then, the system is totally closed to the atmosphere while keeping the temperature just above the boiling point of the alcohol to speed up the reaction and also to avoid the need for mechanical mixing, since the boiling alcohol helps to agitate the mixture. Reaction time varies between 1 and 9 hours, at the end of which the biodiesel is separated from glycerol.

In some cases the reaction is stopped through the addition of a weak acid, such as Acetic acid, to neutralize the unreacted base. Both fractions contain a substantial amount of the excess alcohol. The glycerol phase is much denser than the biodiesel (relative density of 1.25 compared to 0.90 for biodiesel) making it possible for them to be separated by gravity but also, in some cases, through the use of a centrifuge. In some practically realized plants the alcohol is first removed through distillation before the remaining mixture is phase-separated in tall settling tanks. The typical process scheme of a biodiesel plant is shown in figure 1.

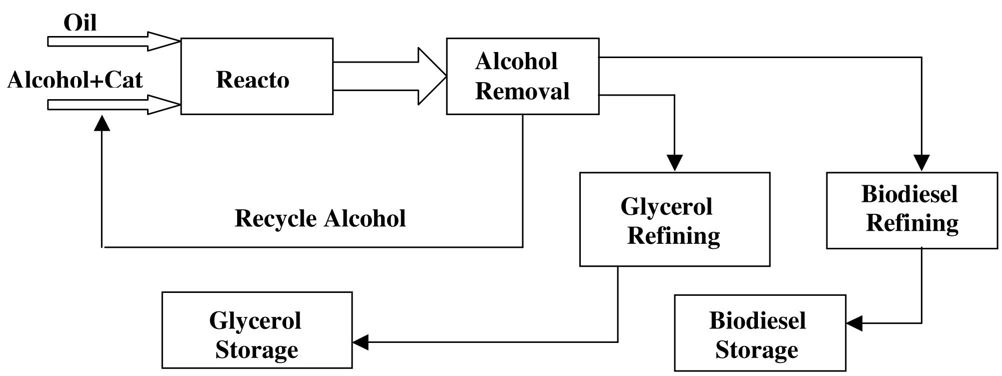

Fig.1. Process scheme of a biodiesel plant.

5.1 Alcohol Removal

In other process schemes each of these two phases (Biodiesel and Glycerol) is subjected to flash evaporation or distillation to separate the excess alcohol, which can be reused. The glycerol phase contains unused catalyst and soaps and has to be acid neutralized before it can be stored. The purity requirements towards this product are quite stringent: pharmaceutical grade glycerol must be 99.8 % pure. This is difficult to achieve in terms of the energy costs. Hence, the by-product is often sold as crude (80 to 88% pure) glycerol after water and alcohol have been removed.

5.2 Biodiesel Phase

The methyl or ethyl ester (biodiesel) is then washed with warm water to remove any remaining catalyst and soap, desiccated and finally sent to storage. It is an amber-yellow liquid, with a viscosity similar to petrodiesel. The specific gravity of palm oil biodiesel is within the range of 0.88 to 0.92 depending on the alcohol/oil ratio, reaction time and type of catalyst used [27]. This figure is slightly higher than that of biodiesel produced from other sources as could be observed from table 5. The final stage of biodiesel production is obviously quality control of the product to ensure conformity with the emerging standards.

Table 5. Comparison of the Specific Gravities of Biodiesel from Different Sources

Biodiesel Type	Specific Gravity
Palm Oil Methyl Ester	0.91
Rapeseed Methyl Ester	0.88
Rapeseed Ethyl Ester	0.88
Soy Ethyl Ester	0.87

6. PROCESS COST ANALYSIS

This section includes three types of cost analyses, namely: 1) analysis of production cost based only on feedstock prices, 2) cost and income scenario for a large plant and 3) sensitivity analysis. Under the cost analysis based on feedstock prices, we shall dwell on three types of palm produce, i. e. Crude palm oil, Palm Kernel Oil and Palm Oil Sludge.

6.1 Production Cost Based on Feedstock Price

The cost of production of biodiesel from oil palm produce can be estimated starting from the stoichiometry of the transesterification reaction. In this section we consider only the cost of feedstock for three different biodiesel starting raw materials derived from the oil palm, namely: crude palm oil, palm kernel oil and refined waste palm oil sludge. Later, these figures are scaled up using the established relationship between feedstock and total costs (referred to in tables 6 to 8 as Total Cost Factor), which was obtained from the experience of existing plants of 60,000 to 120,000 MT/yr output [22]. It is the ratio of the cost of feedstock to the average fraction of the total production cost it represents derived in the following way:

$$\mathit{Total}\ \text{Production Cost} \equiv \text{Feedstock} + \text{Runing Cost} + \text{Capital Cost} \tag{3}$$

On the average for existing plants

$$\mathit{Feedstock} \equiv 0.75x\,\mathit{Total\ Costs} \tag{4}$$

Hence

$$\mathit{Total}\ \text{Costs} \equiv \frac{1}{0.75}\text{Feedstock} \equiv 1.33\,\text{Feedstock}$$

Thus, using a Total Cost Factor of 1.33 we are able to convert the cost of feedstock to total cost of production. In order to arrive at a conservative estimate the income derived from selling the glycerol by-product is not considered.

6.2 Cost of Production of Biodiesel from Crude Palm Oil

A ton of starting raw material (CPO) requires 100 Kg of alcohol and about 3.5 Kg of NaOH catalyst. Furthermore, we assume that the alcohol used is ethanol, which is more readily produced from starchy raw materials as well as palm wine in Nigeria and is therefore cheaper than methanol. At optimal conversion levels, this arrangement would yield about 1 ton of Biodiesel and 100 Kg of glycerol. The estimated total cost of production using this option is shown in table 6 below. Local prices of all raw materials have been used throughout.

Bearing in mind that 1 tonne of palm oil biodiesel is equivalent to 1111.11litres ($\rho = 900 Kg/m^3$) this translates to 0.38 €/l.

Table 6. Estimation of the cost of production of Biodiesel from Crude Palm Oil

Item	**Cost per Ton (Euro equivalent)**	**Required Quantity per Ton of Biodiesel (Ton)**	**Total Cost Factor**	**Total Cost (Euro equivalent)**
Crude Palm Oil	290.00	1.000	1.33	385.70
Ethanol	250.00	0.100	1.33	33.25
Sodium Hydroxide	500.00	0.004	1.33	2.66
Total				**421.61**

6.3 Cost of Production of Biodiesel from Palm Kernel Oil

Palm kernel oil (PKO) contains more saturated fatty acids (about 82%), is less abundant and requires more energy input per litre produced. It is thus more expensive compared to crude palm oil. Since the cost of feedstock accounts for a lion's share of the total production cost of biodiesel this option is obviously more expensive. However, PKO does not compete with CPO as edible oil - the former being exclusively used as an industrial raw material. The estimated cost is analyzed in table 7. The production cost from palm kernel oil is, thus, 0.75 €/l.

Table 7. Estimation of the Cost of Production of Biodiesel from Palm Kernel Oil

Item	Cost per Ton (Euro equivalent)	Required Quantity per Ton of Biodiesel (Ton)	Total Cost Factor	Total Cost (Euro equivalent)
Palm Kernel Oil	600.00	1.000	1.33	798.00
Ethanol	250.00	0.100	1.33	33.25
Sodium Hydroxide	500.00	0.004	1.33	2.66
Total				**833.91**

6.4 Cost of Production of Biodiesel from Palm Oil Sludge

A very interesting option for the commercial production of biodiesel is the use of palm oil sludge, obtained as restaurant grease and various waste oil sources. Although this raw material can be obtained at little or no cost, it requires preliminary refining. Refining of waste oils is an emerging industry, which currently employs many young school leavers both in the urban and rural areas of Nigeria since the process is quite simple, requires little capital investments and is flexible in terms of level of automation. Refined palm oil is currently used for vegetable oil production, although it is also a suitable starting raw material for biodiesel production. Waste oil is usually refined by mixing with water in a suitable ratio and heating for 3 to 4 hours at boiling point to ensure bubble mixing, which enhances the migration of (inorganic) impurities from the waste oil into the water phase. The mixture is then allowed to settle for about 6 hours before the refined oil (top phase) is collected by decantation.

To verify the inherent effect, as well as the economic justification for this method, samples of the commonly used palm oil sludge as well as the refined waste oil were subjected to chemical analysis at the ENE-BIO laboratory of the Italian National Agency for New Technologies, Energy and the Environment (ENEA), Trisaia, Italy. Elemental analysis was carried out on both samples using *CHN Perkin Elmer 2400* analyzer. The percentage of Oxygen was obtained as the difference i.e. (100-C-H-N). Also, the Lower and Higher Heating Values of both samples were determined by calorimetry according to ASTM 240D, which corresponds to ISO 1928 and DIN 51900 in other standard methods. Results of these tests are shown in table 8 below.

Table 8. Test Results for Sludge and Refined Waste Palm Oil (RWPO)

Sample	C %	H %	N %	O %	LHV KJ/Kg	HHV KJ/Kg
Oil Sludge	51.17	8.50	3.10	37.23	22142.58	22574.93
RWPO	73.98	12.2	0.39	13.43	34233.16	34886.10

It is clear from the results that the difference between the LHV and the HHV for sludge and RWPO samples is less than 2% of the LHV, showing that their moisture content is very small. Further, the heating value of the refined waste palm oil (RWPO) is quite close to that of refined palm oil (39.3MJ/Kg) as reported by Prateechaikul and Apichato, 2003 [28], who carried out a comparative study of refined palm oil as an alternative fuel for agricultural diesel engines; as well as petrodiesel (43.3MJ/Kg).

It is also evident that the heating value of the waste oil was raised by about 12 MJ/Kg during the refining process. Obviously, the fatty acid content of the refined waste oil is small, which permits the use of an acid catalyst, such as H_2SO_4. Again, the other factors remain unchanged and the estimated cost of production is as shown in table 9. The projected cost of production using this raw material is about 0.36 €/l.

Table 9 Estimation of the Cost of Production of Biodiesel from Refined Waste Palm Oil Sludge

Item	Cost per Ton (Euro equivalent)	Required Quantity per Ton of Biodiesel (Ton)	Total Cost Factor	Total Cost (Euro equivalent)
Waste Oil Sludge	240.00	1.000	1.33	319.20
Ethanol	250.00	0.100	1.33	3.33
Sulphuric Acid	300.00	0.004	1.33	1.60
Waste Oil Refining	60.00	-	1.33	79.80
Total				**403.93**

6.5 Process Cost and Income Scenario for a Large Plant

Another way of assessing the effect of feedstock price on the overall production cost of a biodiesel plant is by substituting the cost of another vegetable oil (rapeseed or soybean) with that of palm oil in the cost and return analysis of an existing or envisaged plant, since most of the already realized plants utilize either Rapeseed or Soybean oil. Thus, the production estimates of a 60000-ton per annum biodiesel plant comparing the use of Soybean and Palm oils is shown in table 10. It is quite evident from the table that, whereas the biodiesel plant is not very feasible with Soybean oil, it is slightly profitable with Rapeseed oil but quite profitable when the starting raw material is Palm oil. Furthermore, the Internal Rate of Return (IRR) Net Present Value (NPV in Million Euros) of the plant calculated for all three raw material types according to the formula

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o \qquad (5)$$

where,

Ct = Cash flow for the t-th year (Million €);
Co = Initial investment (Million €);
r = Cost of capital i.e. interest rate (usually 10 to 15 %).

Table 10. Cost and Return Scenario of a 60,000-Ton Biodiesel Plant

	Soya Bean Oil	Rapeseed Oil	Crude Palm Oil
Income	**Million €**	**Million €**	**Million €**
		@ € 686/ton	
60,000 tons of biodiesel @ € 620/ton	37.20	41.16	37.20
7500 tons 80% glycerol @ € 500/ton	3.75	3.75	3.75
Undetermined amount of FFA sold as livestock feed			
Total income	40.95	44.91	40.95
Initial Investment	30.00	28.20	30.00
Expenses			
60,900 tons of Vegetable oil	€ 520/ton	€ 550/ton	€ 290/ton
	31.67	33.50	17.66
6,000 tons of Methanol @ € 265/ton	1.59	1.59	1.59
Undetermined amounts of NaOH and HCl included as variable costs			
€ 30 million investment amortized over 10 years at 10% interest	4.70	4.70	4.70
Variable costs equal to fixed costs	4.70	4.70	4.70
Total Expenses	**42.66**	**44.49**	**28.65**

The graph (figure 2) indicates clearly that the payback period of the plant is only about two years when using CPO compared to Soybean oil, which does not pay back in a reasonable time (13.5 years). Rapeseed oil based production is also not very profitable, having a payback period of about 7.3 years. The sensitivity analysis comprises of a plot of the payback period as a function of feedstock prices (figure 3).

Based on the graphs, the following straight line equations are deduced to approximate the NPV (Million Euro) of the plant as a function of Time (X, years) when running on the three different oil feedstocks:

(i) For Soybean oil feedstock: NPV = 2.15x – 29.10 i.e. payback period of 13.5 years

(ii) For Rapeseed oil feedstock: NPV = 3.65x – 26.60 i.e. payback period of 7.3 years

(iii) For Palm oil feedstock: NPV = 12.20x – 24.90 i.e. payback period of 2 years.

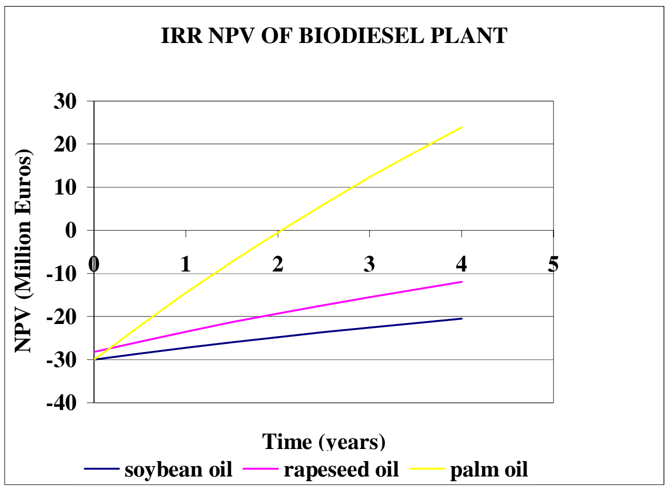

Fig. 2. NPV with IRR of a 60,000 MT/Yr biodiesel plant.

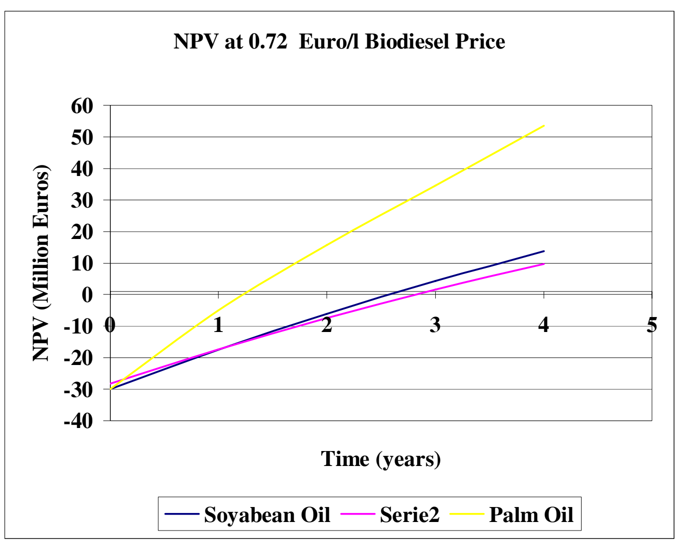

Fig. 3. NPV with 10 % increase in feedstock prices.

6.6 Sensitivity Analysis

In order of importance, the three major factors affecting the pay back period of a Biodiesel plant are: i) Price of feedstock; ii) Price of Biodiesel product and iii) price of Glycerol by-product. The effects of each of these factors are captured graphically in figures 3 to 5. Taking current trends into account the effect of these factors can be summarized as follows:

- It is clear that the payback periods increase respectively to 2.3 years for Palm Oil and 21.6 years for Rapeseed Oil. For Soybean Oil when the feedstock prices increase by only 10 % the plant is in a state of continuous losses. The pay back Time is, thus, highly sensitive to the price of feedstock (figure 3).

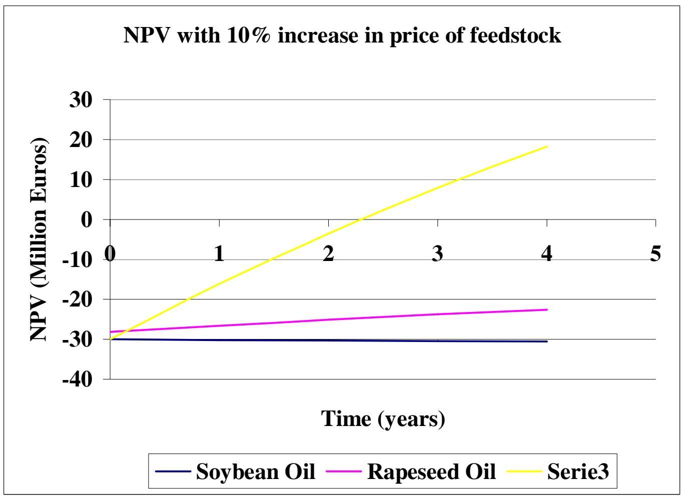

Fig. 4. NPV with 10 % increase in price of oil feedstocks.

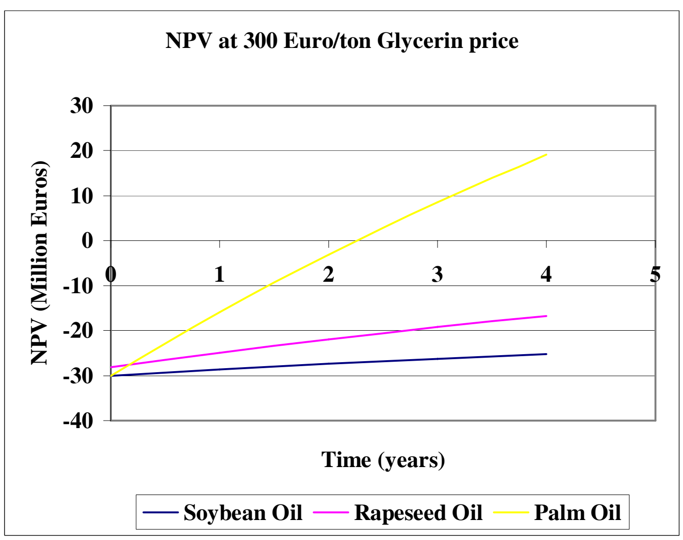

Fig. 5. NPV at reduced selling price of glycerin by-product.

- With an increase in the selling price of the biodiesel product to a uniform price of 0.72 €/l, the plant payback period is reduced to 1.2 years with Palm Oil feedstock; 2.8 years with Rapeseed Oil and 2.57 years with Soybean Oil (figure 4).
- The effect of Glycerol prices is less pronounced; a drop in the price of glycerol from €500 per ton to €300 per ton leads to a delayed payback period of the plant. The new pay back periods are 2.2 years for PO feedstock; 10.4 years for Rapeseed and 15.3 years for Soybean feedstock, respectively as seen in figure 3.

7. OTHER BENEFITS OF COMMERCIAL PO BIODIESEL PRODUCTION

In the short term, the envisaged commercial production of biodiesel from palm produce would increase their demand and thus put more pressure on the fragile local supply. However, this could become a boost for the agriculture sector of the crude-oil-dependent economy and serve as a job creation measure for new farmers who would have to go into oil palm farming because of increased demands. It would also impact positively on the availability of raw materials for existing industries, since every part of the tree is useful! For instance, the waste palm head is very rich in Potassium Oxide (K_2O) and has been used for the preparation of Potassium hydroxide (KOH) in local soap making for many decades. Palm fronds are used for fencing in rural settlements, whereas the tree trunk serves as a vital source of timber. Proposals have also been made elsewhere, recently recommending the use of waste fibre from oil palm head as source of raw material for electricity generation.

Furthermore, an increased acreage of oil palm plantations could lead to a reversal of the problems associated with deforestation, which has been a menacing trend on the entire Nigerian landscape for the past few decades i.e. increased erosion in the South and desertification in the North. Indeed, the overall environmental benefits vis-à-vis the ecosystem cannot be overemphasized; biodiesel is extremely low in sulphur, has a high lubricity and fast biodegradability potentials and is adaptable to existing engines without major modifications.

Again, since developing countries are now aware that as the mechanisms of the Kyoto Treaty come into force to reduce industrial and commercial greenhouse gas emissions, the planting of biofuel crops may well create carbon sinks that can earn them cash through the sale of emissions credits to polluting industries in developed countries. This could add a further inducement to plant more palm trees to act as an energy-producing carbon sink, should the Clean Development Mechanism (CDM) created by Kyoto Protocol make credits available for planting energy crops.

8. MARKET FOR PALM OIL BIODIESEL

Another important aspect of any feasibility study is to assess the potential market outlet for the product. This is made more difficult by the fact that petrodiesel sells for 0.39 €/l in Nigeria, which is comparable to the estimated production cost of biodiesel from crude or refined waste palm oil produce. However, a first step could be to export the product as 5-20 % blends to neighbouring West and Central African countries, where petrodiesel sells above 0.50 €/l, such as Liberia (2.22 €/l), Burkina Faso (0.87 €/l), Central Africa Republic (0.96 €/l), Chad (0.87 €/l), Mali (0.86 €/l), Niger (0.76 €/l), Cote d'Ivore (0.82 €/l), Cameroun (0.67 €/l) and Guinea (0.56 €/l) [29]. Since these markets usually rely on refined products from Nigerian oil refineries, palm oil biodiesel would compete favourably in view of its relatively lower price.

9. CONCLUSIONS

The following conclusions could be drawn:

- The use of refined waste palm oil as starting raw material for biodiesel production is more cost effective than CPO, although this raw material has a limited supply in addition to being a conventional input for vegetable oil production.

- The NPV analysis of a large biodiesel plant with IRR using crude palm oil as starting raw material indicates that it has a payback period of about two years only.
- The pay back period of a Biodiesel plant is sensitive to three major factors: Price of feedstock , Price of Biodiesel product, Price of Glycerol by-product, respectively. For Biodiesel production to become profitable, prices of vegetable oils must remain stably low, amidst increasing price of crude oil.

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