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Life Cycle Analysis of Yellow Oleander Biodiesel Production in Kenya

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***Abstract*—** This research focused on Kenya's life cycle cost analysis (LCCA) of yellow oleander (*Thevetia peruviana*) for biodiesel. It also evaluated the feasibility of biodiesel production from yellow oleander at a 100,000 t/year plant in Kenya using synthesized eggshell-derived waste nanocatalysts. The production costs considered included Estimated Fixed Capital Investment (FCI), Total Capital Investment (TCI), and Total Manufacturing Cost (TPC). The annual production cost was 9,487,834,956.00 (80,809,428.13- dollars/year). The estimated production cost of biodiesel from yellow oleander is 241.65 KES (1.96 dollars/L). In contrast, the estimated cost of the B20 biodiesel blend was KES 163.34 or (US 1.32 - dollars/L), which was 0.53 % cheaper than petrodiesel at 164.21 KES/L or (US 1.33 -dollars/L). Based on the annual production cost, the total raw material cost and labor cost were 74.38% and 0.008%, respectively. In addition, revenue from glycerin sales reduced biodiesel production costs by 13.67%. Labor costs accounted for 0.008% of production costs, making the production of biodiesel from yellow oleander less labor-intensive. The return on investment (ROI) of 810.32% exceeded the acceptable minimum return (MARR), indicating that biodiesel production from yellow oleander is feasible. This study also calculated the energy balance based on the different soil types used when planting yellow oleander plants. In normal soil, the total energy input was 120,729,624.96 MJ. In normal soil, the energy output was 840,000,000.00 MJ and the energy output/input ratio was 7.16. Accordingly, the estimated net energy number was positive, showing high values for the soil used.

***Keywords*—** life cycle analysis, energy life cycle analysis, yellow oleander biodiesel

I. INTRODUCTION

Global demand for petroleum products has grown faster than the increase in availability and supply of crude oil itself. One of the most important aspects of a country's socioeconomic development is its ability to access reliable, affordable, and sustainable energy [1]. The transport sector is one of the leading energy consumers of fossil fuels[2]. An increase in the number of vehicles powered by petroleum fuels has depleted fossil fuel reserves. The use of petroleum products increases greenhouse gas (CHG) emissions. In particular, it causes 20% of methane (CH_4) and nitrous oxide (N_2O) emissions and about 75% of carbon dioxide (CO_2) emissions [3]. The frequent release of these greenhouse gases has contributed to global climate changes. These have led to frequent and ongoing environmental hazards such as El Niño and initiated the search for alternative fuels [4]. Renewable energy includes solar, wind, hydrogen, biofuels, and biomass energy, among others [5]. As a result of all these major energy securities, and environmental, and sustainability concerns, there has been a shift towards alternative, renewable, sustainable, efficient, and cost-effective energy sources with lower emissions [6].

There is a growing interest in biofuels globally, and the sector is expected to perform well in the next two decades [7]. Biofuels are clean, sustainable fuels made from solid, liquid, or gaseous biomass. In the transport sector, liquid biofuels can replace conventional fossil fuels. Compared to petroleum-based fuels, biodiesel fuels are biodegradable and emit fewer pollutants and greenhouse gases. Biodiesel is one of the sustainable and clean fuel options among renewable energy sources [8]. Biodiesel applications in diesel engines show some satisfactory performances [9]. Biodiesel has almost identical physical and chemical properties to petrodiesel, including cetane number, viscosity, calorific value, and flash point [10]. The high oxygen content (10%) of biodiesel fuel promotes and improves the combustion processes in diesel engines. It is biodegradable, can be used without engine modification, and emits fewer harmful gaseous emissions into the environment [11],[12].

Biodiesel production in Africa has become a great prospect as its future is bright. Africa could become the largest single producer of biofuel crops for global biodiesel production [13]. There is currently no commercial production of biodiesel feedstock for biofuel purposes in

Kenya. There is currently no commercial production of biodiesel feedstock for biofuel purposes in Kenya. The Vitality Law No. 1 of 2019, more precisely 75, subsection 2 (h), is the law passed by Parliament to promote the use of renewable vitality sources in transport [14]. The Kenya Bureau of Standards (KEBS) has already drafted standards for biodiesel in preparation for the expected blending program [15].

Kenya has three main sources of energy including biomass, petroleum, and energy accounting for 74.6%, 19.1%, and 5.9% respectively. Transportation, horticulture, commerce, and industry depend significantly on commercial vitality, particularly oil and energy [16]. In 2014 alone, crude oil accounted for around 22% of Kenya's total major energy consumption. The Kenyan authorities have tried to introduce energy-efficient and clean fuels to replace the normal fuels currently used [17]. Studies have been conducted on bioethanol and biodiesel production using cassava, sugarcane, and sorghum as viable raw materials [15]. Biodiesel is a product made from edible and non-edible raw materials. Researchers have extensively studied biodiesel production from non-edible oilseeds in recent years [13], due to rising food costs, gas prices, and global climatic changes [18]. For this reason, the use of low-cost, second-generation biodiesel raw materials is preferred [19]. Biodiesel feedstock includes non-edible oilseeds such as; Among others, *Ailanthus altissima*, *Azadirachta indica*, *Hevea brasiliensis*, *Hura crepitans*, *Jatropha curcas*, *Simmondsia chinensis*, *Madhuca indica*, *Nicotiana tabacum*, *Pongamia pinnata*, *Ricinus communis* and *Thevetia peruviana* [13]. Yellow oleander seed has a high oil content of ~60-67%, making it a suitable biodiesel feedstock [20].

The yellow oleander tree, a member of the *Apocynaceae* family, is a drought-resistant plant that has been discovered in several parts of Kenya, in addition, it is not edible and does not affect food security. It is therefore a suitable renewable raw material for biodiesel production [21]. This plant does well in western parts of Kenya. The yellow oleander plant is commonly referred to as chamama by the Luo community in Kenya's western region. The community uses the plant as a fence, it can grow up to 6 meters high. It has green fruits that turn black as they ripen. The plant also contains one to four seeds in its kernel with an oil content of ~67% [22]. A mature yellow oleander plant produces 400800 fruits (40-50 kg) annually, depending on rainfall and plant age [23, 24]. On one hectare, 3000 samples produce 52.5 tons of seeds (3500 kg of kernels) and about 1750 liters of oil [25]. The yellow oleander plant is so hardy and adaptable that it can be grown in soil unsuitable for conventional agricultural purposes [26].

Biodiesel feedstock cultivation is likely to reduce dependence on crude oil products [27]. Fluctuations in crude oil prices primarily affect a nation's economy [28]. Biodiesel is gaining acceptance as an alternative to petrodiesel due to its renewability, biodegradability, recyclability, and CO_2 neutrality [29, 30]. Much effort has been expended worldwide to establish an economically feasible processing facility for the production of biodiesel from a variety of feedstocks [31]. The supply of cheap raw materials is necessary to achieve competitive prices and increase production [32].

The trend of research and development work to promote biodiesel fuels in Kenya was detailed in a recent multi-authored report [33]. Others examined the limitations associated with laboratory-scale processes to understand their commercial potential benefits and limitations, while others looked for ways to improve their economic viability in order to get the public to invest in the idea. An economic model is required to analyze the production costs of biodiesel [34]. There is also a need to perform the life cycle assessment of renewable energy generation systems based on their local conditions. This is because an energy source cannot be sustainable for all geographic locations due to variations in resource availability, climate, environmental, economic, and social conditions. and politics, among others [6]. Life Cycle Analysis (LCA) is a standardized method described by the International Standard Organization, ISO 1404014043 [35]. The price of the raw materials determines how much it costs to produce biodiesel, and in some situations, it may be cheaper to build the factory close to the source of the raw material [10].

The relationship between the energy produced (output/kg biodiesel) and the energy consumed (input/kg biodiesel) per production unit is called the energy balance for biofuel production. The energy balance is critical to the financial and environmental viability of a biofuel project [36]. The output/input energy ratio in the production of biodiesel is a helpful point of reference in the technical-economic and ecological feasibility analysis [37]. This type of research helps determine the feedstock to be used in the production of biodiesel in a specific geographic and financial context [38].

II. Related Work

Previous research has dealt with the kinetics and thermodynamics of yellow oleander oil extraction and its physical and chemical properties. CaO nanocatalyst is made from eggshell and its physical and chemical properties have been developed from scratch. The synthesized CaO eggshell nanocatalyst was used to optimize the production of yellow oleander biodiesel based on catalytic load, temperature, and lifetime. The physicochemical, and thermal properties of biodiesel derived from yellow oleander were then determined. Last but not least, the engine performance, combustion, and emission properties of biodiesel from yellow oleander and its mixtures with petroleum diesel were tested with a 4-stroke engine.

This study analyses the cost of life and energy cycle analysis of yellow oleander biodiesel produced in Kenya using a one-step transesterification process. Life Cycle Analysis was used to support yellow oleander biodiesel production in Kenya. First, the biodiesel cost-of-living analysis considered the financial input of the feedstock, production, and transportation, and the expected amount of money from the sale of the biodiesel. Second, researchers used the energy balance to study the biodiesel production efficiency of yellow oleander from oilseeds.

III. METHODOLOGY

Biodiesel is a renewable, stable, cheap, safe, biodegradable, and environmentally friendly alternative to fossil fuels. However, there are different concerns about the possible risks of the growing biodiesel industry. The Life Cycle Analysis (LCA) approach was used to assess and compare the environmental, energetic, and economic aspects of biodiesel production and consumption. LCA is defined as a standardized ISO method that aims to detect the transmission of pollution from one step to another or from one type of environmental impact to another. This approach considers the entire life cycle of a product or the so-called cradle-to-grave principle. The systematic evaluation of material and energy balances in all stages of biodiesel production is an important tool to identify the less effective processes in the production chain and identify opportunities for improving biodiesel production [8].

The life cycle assessment of biodiesel from first and second-generation feedstocks include the following phases: (i) agricultural cultivation, (ii) transport, (iii) oil production, (iv) biodiesel production, and (v) combustion. In addition, the comparison of biofuels with fossil fuels in terms of a life cycle assessment is very important.

In this study, the focus is on the key essential LCA properties of biodiesel production from yellow oleander. Measures of total opportunity cost, total cost, profit, profit and energy balance are also examined. There are currently no tax credits or subsidies for renewable energy generation in African countries, so they are not considered in this work.

3.1. System boundaries

In this study, the production of 10000 tons was considered. The system boundaries for the production of yellow oleander biodiesel are shown in Figure 1

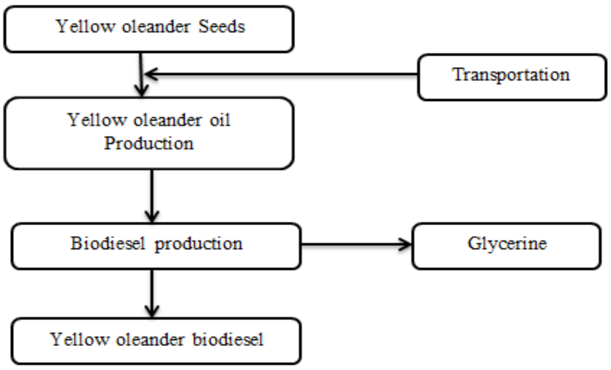

Figure 1: System boundary of yellow oleander biodiesel production

The system boundary of biodiesel production from yellow oleander includes the following life cycle stages and sub-processes; cultivation of the yellow oleander plant, extraction of yellow oleander oil, and production of biodiesel through transesterification reaction.

3.1.2. Data Collection

The data was compiled from a wide range of sources, these included research papers, technical overviews, and reports from subject matter experts, as well as updated market prices and test results. In the absence of a specific dossier on the subject, assumptions were done using appropriate data [39]. In addition, a sensitivity analysis was performed to identify key data and the impact of deviations from true values. In general, the study of the yellow oleander biodiesel production plant was based on a capacity of 10,000 tons. Table 1 shows the costs of the raw materials used and other resources for the yellow oleander biodiesel production.

Table 1: The yellow oleander biodiesel production process unit inventory data

Data	Units	Inputs	Outputs
Yellow oleander oil	Ton	100,000	
Electricity	kWh	256.5	
Methanol	Ton	11,000	
Water	Ton	15,000	
Biodiesel	Ton		10,000
Glycerol	Ton		1,291.99
Yellow oleander oil	Ton		19,000
Methanol	Ton		8,766
Water	Ton		15,000

The methanol, yellow oleander oil, and calcium methoxide required to produce the desired product are supplied to the biodiesel production subsystem. These compound mass input data were based on stoichiometric calculations and information from the literature.

3.1.3. Assumptions for life cost analysis

In the LCA, the following assumptions are made,

a) The life cost analysis of yellow oleander biodiesel production plant generates 10000 tons of biodiesel annually from a 6000 hectares farm.
b) The plant generates 10500000 litres of yellow oleander oil annually
c) Yellow oleander trees are planted at a density of 3000 yellow oleander plants per hectare (18000000).
d) The plantation site's soil quality and rainfall are average.
e) It takes the yellow oleander plant 5 to 10 years to reach full maturity, at which point a complete seed output is anticipated.
f) A hectare of yellow oleander plants yields roughly 3500 kg of dried plant material and 1750 liters of oil.
g) No pesticides, insecticides, or herbicides were used on the crops.

3.1.4. Phases of yellow oleander biodiesel life cycle

The LCA of the yellow oleander system included

a) Cultivation phase: This phase involves raising seedlings in polybags at a nursery, transporting them to the planting site, digging pits, filling pits with home farm manure, planting the seedlings, providing life-saving watering for the first two years, and harvesting fruit for oil recovery after 5 to 10 years, and energy input-output and associated emissions.
b) Oil extraction phase: This phase involves the transportation of the seed to the oil extraction facility, the energy input and output, and the released emissions.
c) Esterification phase: This phase includes conversion of oil into biodiesel, chemicals used, and energy input, output, and associated emissions. This phase includes the conversion of vegetable oil into biodiesel, the chemical compound used, as well as the energy output and input, productivity, and associated diffusions
d) Combustion/usage phase: This phase includes the combustion of biodiesel in a diesel engine, the energy released, and emissions [40].

3.1.5. Estimation of the cost of biodiesel production

The total production costs of biodiesel in a production plant include the sum of all operating costs. Although not limited to labor, maintenance, insurance, operating expenses, contingencies, general expenses such as administration, sales and marketing, and costs associated with the amortization of the capital investment. The cost analysis steps are adopted from Hass *et al.,* [41].

3.1.5.1. Life cost analysis

The cost-of-living analysis evaluates the production costs of yellow oleander biodiesel according to key performance indicators. Direct production costs included Total Capital Investment (TCI) and Operating Costs (OC). The TCI is given by Equation 1,

Total Capital Investment (TCI) = Direct Costs (DC) + Indirect Costs (IC) + Working Capital (WC) ……..…Equation 1

Working Capital (WC) Include; raw materials, stock, and among others. About 10 - 20% of TCI [42].

Working Capital (WC) = 0.25×FCI ………Equation 2 [41]

FCI = Direct Costs (DC) + Indirect Costs (IC)...Equation 3.

Total Capital Investment (TCI) = Fixed Capital Investment (FCI) + Working Capital (WC) = 1.25×FCI ….Equation 4.

Fixed Capital Investment (FCI) is the amount of money needed to pay for the equipment, pipelines, electrical installations, land, structures, legal fees, and control systems; Working Capital Investment, or WCI, refers to the amount of money required to cover operating costs prior to commencement of product sales, and; Start-up costs (SUC), which consider employee training, advertising, and legal fees.

3.1.5.2. Profitability Analysis

The return on investment (ROI) was used to assess the profitability of the proposed production facility for yellow oleander biodiesel. Equations 5 through 7 represent the investment criteria used to calculate ROI. These included Gross Income (GI) and Net Profit (NP).

SP = the selling price of fuel

GI = SP×V – COM……………………. Equation 5

NP = GI× (1 - TR) ……………..…... Equation 6

$$ROI = \frac{NP}{TCI} \times 100$$ ……………….... Equation 7

Where TCI stands for Total Capital Investment, SP for Selling Price, V for Biodiesel Volume Produced, ROI for Return on Investment, COM for Manufacturing Cost, NP for Net Profit, GI for Gross Profit and TR for the Tax Rate [31].

3.1.5.3. Energy balance calculation

Energy balances deal with the reduction of non-renewable fossil fuels in the production chain, this is compared to biodiesel. The criteria are assessed are evaluated using the Net Energy Yield Ratio (NER). The net energy yield ratio (NER) was computed using

Equation 8:

$$Net\ energy\ ratio\ (NER) = \frac{Energy\ content\ in\ biodiesel\ (MJ/L)}{Energy\ content\ in\ fossil\ fuel\ (MJ/L)} ...Equation\ 8$$

The values of NER is categorized as either energy gain if the value was greater than 1 or energy loss if it is less than 1.

3.1.6. Extraction of yellow oleander oil

Yellow oleander seeds were handpicked in Siaya County, Kenya, Kenya and shipped to the Technical University of Kenya, School of Chemistry and Material Science Laboratory. The seeds were first dried in the sun for at least two weeks, weighed, weighed and ground into a powder. They were then placed in a Soxhlet tube and heated at 80°C for three hours. After extraction, vacuum distillation was used to separate the oil and petroleum ether mixture in a rotary still. Finally, the pure yellow oleander oil was weighed and the oil content in the yellow oleander seed was determined using Equation 9.

$$Yellow\ oleander\ oil\ (\%) = \frac{Weight\ (gms)\ of\ oil\ extracted}{Weight\ (gms)\ of\ powdered\ dry\ seed\ used} \times 100 ....Equation\ 9$$

3.1.7. Transesterification reaction.

The transesterification process was performed in a 100 mL three-necked round-bottom beaker. In each of the 15 experiments, 50g of oil paint was used. For each experiment, the yellow oleander oil was transferred exactly into the beaker and preheated to reaction temperature on a hotplate. The mixture of 0.3 g of the synthesized nanocatalyst in hot methanol was combined with preheated yellow oleander oil in the beaker while stirring with a magnetic stirrer. After the transesterification, the mixture was separated in a separating chute for six hours. The products were centrifuged and the upper phase containing the biodiesel was decanted to remove the residual unreacted catalyst/glycerol mixture. The biodiesel phase was dried in an oven at a temperature of 110°C for four hours to evaporate the remaining methanol. The nanocatalyst was separated from the residual admixture of glycerol and the nanocatalyst and reused.

3.2. Energy analysis

Energy consumption starts from the nursery to the transesterification process, this production process is divided into six different categories which are explained below.

3.2.1. Mathematical modelling

Mathematics models adopted by Yadav *et al.* were used (RSC), Formulas for different stages of plant growth and biodiesel conversion were used to evaluate the life energy cycle [43]. The life cycle energy balance analysis functional unit is one hectare.

3.2.2. Plant nursery

It includes the energy used for soil preparation, soil bag filling, soil bag watering, machinery and labor used, maintenance, and security for up to a month [43].

3.2.3. Ploughing

The first step is to prepare the soil for the plant nursery. Equation 10 calculates the energy expenditure for ploughing with a tractor.

$$E_{N1} = v_f \times \rho \times CV \times k \text{..........} Equation \quad 10$$

Where; E_{N1} is energy input in ploughing for nursery (MJ), ρ = power consumption in oil extraction (kWh/ton of seed), CV = calorific value of diesel fuel (MJ/kg) and k = 1.0, for normal soil [43].

3.2.4. Irrigation

In order to calculate the energy requirements for watering nurseries Equation 11 is used. Suppose the water requirement per plant is 0.5 kg in the normal rainy season. Also, considering the normal water depth, a 1kWh water pump was used to pump 1000kg of water in 1 hour.

$$E_{N2} = 3600 \times R_p \times t \times d \times r \text{.........} Equation \quad 11$$

Where; E_{N2} is the energy input used in irrigating the plants in the nursery. R_p is the power of the water pump (1 kWh) pumping 1000 kg of water in 1 hour at a normal water depth, t = time(hours/annum), d = 1, for normal depth up to 80 m, r = 2.5 [43].

3.2.5. Manpower

According to Laureen Sherwood's Fundamentals of Physiology: a human perspective, the energy expenditure of a human worker is 1 MJ/h for normal work, 0.84 MJ/h for light work, and 1.2 MJ/h for heavy work. The amount of work is calculated using Equation 12 based on the above estimates [43]

$$E_{N4} = E \times \left[(l_1 \times t_1) + (l_2 \times t_2) + (l_3 \times t_3) + l_4 + l_5 \right] \times k \text{........} Equation \quad 12$$

Where; E = energy expenditure rate (MJ/h), normal rate 1 (MJ/h). $l_1 = 1.0$ is the labour type factor used in ploughing the field. $l_2 = 1.2$ is the labour type factor used in soil preparation with manure. $l_3 = 1.0$ is the labour type facto used to fill earth bags. $l_4 = 1.0$ is the labour type factor used in watering the plants/irrigation and $l_5 = 1.0$ is the work type factor for maintenance and safety for 1 month. The total energy supplied to the nursery is the sum of the energies using Equation 13;

$$E_N = E_{N1} + E_{N2} + E_{N3} + E_{N4} \text{.....} Equation \quad 13$$

Where; E_N is the energy input to the nursery (MJ), E_{N1} is the energy input from plowing to the nursery (MJ), E_{N2} is the energy input to irrigation to the nursery (MJ), E_{N3} is the energy input to slurry for the nursery (MJ) and E_{N4} is the energy used in labor for the kindergarten (MJ) [44].

3.2.6. Plantation

Factors such as soil type, tillage, irrigation, care, and, safety are analyzed for energy consumption during planting and care up to the age of one year. The calculations are the same as for the nursery, except that the plantation covers a unit area of 1 ha. As a result, the total energy expended can be calculated using Equation 14;

$$E_P = E_{P1} + E_{P2} + E_{P3} + E_{P4} \text{.....} Equation \quad 14$$

Where; E_P is energy used for planting and cultivation for 1 year (MJ), E_{P1} is the energy used for tillage (MJ), E_{P2} is the energy used for irrigation (MJ), E_{P3} is the energy used in manure (MJ) and E_{P4} is the energy spent in manpower (MJ) [43].

3.4.2. Growth

Care and safety are considered from the plant age of 1 year to 3 years. Therefore, labor is the input for 2 years of growth. After that, no more energy supplies are required. Although rainfall and tree biomass are sufficient to sustain tree growth, a few splashes of water are given in a year. The maintenance and safety of the plantation require 2 hours of work every day for 2 years. This is 1 year to 3 years. Total energy for care and safety and water sprayers assume 2.5 times more water needs than in the plantation. This is calculated using Equation 15.

$$E_G = E \times t \times 2.5 \times E_{P2} \text{.......} Equation \quad 15$$

Where; E is the energy expenditure rate in MJ/h. The normal rate is 1 MJ/h. E_G is the energy input during growth for the second and third years [43], and t is the time taken for the growth of the plant ~ 2 years.

3.4.3. Seed collection

Kernel collection, kernel drying, dehusking, and seed drying are performed manually and therefore no machine inputs are considered. There are four different activities in this category. First, the seeds are collected twice during harvest and dried in the sunlight for at least 4 days. Four workers are required to dry the kernel. The third activity is the manual peeling of the seed kernels [43].

Finally, drying of the seed is done for 2 days; The amount used in the process is calculated using Equation 16.

$$E_{SC} = E \times (t_1 + t_2 + t_3 + t_4) \times k.... \textit{Equation } 16$$

Where; E_{SC} is the energy input for seed collection (MJ)

t_1 is the time in hours/year spent collecting seeds (assuming one man collects 40 trees per day and the second collection is 75% of the first and 15 men per day).

t_2 is the time in hours required to dry the fruit. Six workers are required after every for four days/week/annum.

t_3 is the time in hours required to de-husk the seeds from the fruit (15 workers/day and 300 working days).

t_4 is the time in hours required for seed drying. Four workers are required for two days in a week [43].

3.2.9. Transportation of seeds

The energy input was analyzed when transporting the seed from the field to the biodiesel plant using a tractor with a combustion engine. After drying, the seeds are transported to the biodiesel production plant about 24 km away. Oil extraction and transesterification are carried out in the same place. The seeds are transported to the factory by tractor, which consumes 2 liters of diesel and takes half an hour. Two workers are employed; they take 4 hours to charge and discharge. The energy consumed is calculated using Equation 17.

$$E_{TP} = v_f \times \rho \times CV + E \times t......\textit{Equation } 17$$

Where; E_{TP} is the energy expended in transporting seed (MJ) and v_f is the diesel fuel used per hectare in liters [43]. The yellow oleander seeds are transported by tractor, which consumes 2 liters of diesel and takes half an hour. It employs two workers each spends four hours loading and downloading [43] .

3.3. Oil extraction

Oil from the seed is extracted in an oil extraction plant with a capacity of 1 ton/h. The energy consumed for the extraction is given by equation 18;

$$E_{OE} = (P \times M + E \times t) \times y..... \textit{Equation } 18$$

Where E_{OE} is the energy required to produce oil (MJ), t is the man-hour time spent producing oil, P is the electricity consumed in producing oil (kWh/tonne of seed), and M is the total mass of oil in tonnes [43].

3.3.1. Transesterification

The transesterification process was carried out in a biodiesel plant with a capacity of 100,000 tons/year. With a conversion efficiency of 92%, the energy consumption of a plant is 36 kWh per ton of oil. Assuming that two men are needed for 2 h, the energy expenditure in the transesterification process results from Equation 19;

$$E_T = P \times M + E \times t.........\textit{Equation } 19$$

Where t, is the man-hour in the transesterification process. The energy content of the alcohol used for the transesterification is not considered here. Assuming that an equivalent amount (slightly less than the mass of the alcohol) of glycerol is produced as a by-product during the chemical process. All of the above methods result in the total energy requirement for biodiesel production.

Total biodiesel production lifecycle energy demand/use can be calculated using some of the equations above and is given by Equation 20;

$$E_{INPUT} = E_N + E_P + E_G + E_{SC} + E_{TP} + E_{OE} + E_T .... \textit{Equation } 20$$

This is the total energy requirement of the system under consideration [43].

3.3.2. System Outputs

The yellow oleander biodiesel contains energy, which is given by Equation 21;

$$E = CV_{YOBD} \times T \times 1000 ......\textit{Equation } 21$$

Where CV_{YOBD} is the calorific value of the yellow oleander biodiesel in MJ/Kg and T is the quantity of biodiesel in tons. Putting into consideration the brake efficiency of the C.I engine, the output energy can be calculated using the Equation 22:

$$E_{output} = 0.20 \times E..... \textit{Equation } 22$$

Where; $E^{'}$ energy contained in biodiesel produced from 1 ha land crop and E_{output} = total energy output (MJ) [45].

IV. Results and Discussion

4.1. Life cycle analysis of yellow oleander biodiesel

The Biodiesel Production Cost (BPC) is the detailed analysis of a small biodiesel production plant with an installed operating capacity of 100,000 tons/year. See Tables 3, 4, 5, 6 and 7 for economic analyses. Industrial factors such as capital and plant operating costs affect biodiesel production. Others included costs for processing facilities, services, catalysts, raw materials and product storage, and buildings [48]. The starting material used in the production can consist of lipids and alcohol [8]. The glycerin by-product provided a secondary revenue stream for biodiesel production. It helped offset the overall cost of producing biodiesel.

4.1.1 Economic analysis

Some assumptions were made for the techno-economic analysis of the production of biodiesel from yellow oleander. According to the disclosed methods, the prices of the raw materials, biodiesel and glycerol are estimated. These reports determine the Total Equipment Cost (TEC) for each specific catalyst used in the biodiesel synthesis process (Table 2).

Table 2: Total equipment cost (TEC)

Item	Unit Price (KES ,000)	Quantity	Estimated cost, KES ('000)
Grinders (Ball or vertical roll mills, 10ton/hr capacity, 46kW) -Chaina	11,000.00	2	22,000.00
Oil storage tanks (200 m3)- Chaina	900	10	9,000.00
Mechanical Screw Press, 1000 tons capacity; (Mohit International - India: HCT35)	36	10	360
Biodiesel Reactor (V R Process Engineering Consultants Private Limited- India: 380-400 V); 250 tons/day capacity)	2,400.00	2	4,800.00
Above ground oil storage tankers (Bomaque Steel Fabricators – Nairobi)	550	1	550
Above ground biodiesel oil storage tankers (Bomaque Steel Fabricators – Nairobi)	550	1	550
Above ground glycerol storage tankers (Bomaque Steel Fabricators – Nairobi)	550	1	550
Tractor (Tractors – Kenya); Massey Fergusson MF 2600 series	1,600.80	1	1,600.80
Irrigation pump (Diesel engine) biashara.co.ke; 20hp (14.7kw)	90	1	90
Motor Vehicle, Pickup truck (Toyota Vigo)	5,000.00	1	5,000.00
Mitsun Automatic Filter Press (Mutsin Engineering – India); Capacity 500 tons/day	475	2	950
2 Megapixels 8 cameras kit dome and or bullet cameras (CCTV solutions Nairobi)	60	2	120
Stainless Steel Liquid Mixing Tank - 10 000 lts (B & M Water Tower Industries LLP -India)	7,000.00	1	7,000.00
Computer and computer accessories -Total (Bright source Investments Kenya)	1,690.00	Various	1,690.00
Total cost of apparatus and equipment			54,260.80

From Table 2 above, the total cost of apparatus and equipment is KES 54,260,800.00 (US$ 440,071.37). Taking that the equipment work for 15 years and taking 6% interest rate, [49].

Apparatus and equipment cost for 15 years =

$$54,260,800\left(1+\frac{6\times 15}{100}\right)=103,095,520.00$$

Purchased cost of equipment (PCE) = KES 103,095,520.00 or US$ 834,781.53.
Physical plant cost (PPC) = 3.4 * PCE = 3.4 * 103,095,520.00 = KES 350,524,768.00 or US$ 2,838,257.20.
Auxiliary plant cost (APC) = 0.45 * PPC = 0.45 * 350,524,768.00 = KES 157,736,145.60 or US$ 1,277,215.74
Fixed capital investment (FCI) = PPC + APC = KES 508,260,913.60 or US$ 4,115,472.94

4.1.2. Total capital investment (TCI)

The total capital investment is the sum of the fixed capital investment and the working capital investment, i.e., TCI= FCI + Working Capital Investment (WCI).
Calculated parameters are presented in Table 3 below.

Table 3:

Type	Cost/KES
Fixed capital investment (FCI)	508,260,913.60
Working capital investment (WCI) = 0.25 * FCI	356,040,102.70
Total capital investment (TCI) = FCI + WCI	864,301,016.30 (US$ 6,998,388.72)

The working capital investment is approximated as 15% of TCI [50]. The total capital investment (TCI) for the large-scale biodiesel production plant was estimated at KES 864,301,016.30 (US$ 6,998,388.72). The purchase of equipment and apparatus cost about 11.93%, fixed capital investment about 58.81% and working capital 40.56 % of the total capital investment. Because the products yellow oleander biodiesel and glycerine are easily marketable [51].

4.1.3. The annual cost of electricity for the production of biodiesel

The electricity costs for the various production stages are determined from 1 kWh electricity price = 12.00 KES [52], the specific heat of water = 4.18 kJ/kg/K, the specific heat of yellow oleander oil = 6.74 kJ/kg / K [53], and heat loss due to radiation and convection = 10%.

4.1.3.1. The cost of electricity used during transesterification

The cost of electricity used in heating oil from 20°C to 60°C during transesterification was derived from the amount of heat energy required for the reaction by the Equation
25;

$$Q=\frac{mC_p\Delta T}{efficiency}=\frac{9\ 955\ 201.593\times 6.74\times 40}{0.9}=2\ 298\ 135\ 944.00\ kJ$$

Where; Q = heat required (kJ), m = mass consumed in the production of 100,000,000 kg of biodiesel, Cp = specific heat (kJ/kg C), = temperature difference (C) and efficiency = 0.9 [54]

Equivalent kWh

$$= \frac{298{,}213{,}594{,}400}{3{,}600} = 82{,}837{,}109.56\ kWh$$

The annual cost of electricity used during transesterification =

$$82{,}837{,}109.56 \times 12.00 = KES\ 994{,}045{,}314.70$$

$$or\ US\$\ 8{,}466{,}445.06$$

The cost of using the mixing machines four times = KES 33,865,780.25 or US$ 288,440.34. The cost of electricity used in stirring methanol and synthesized eggshells catalyst when the motor's power was 45 kW. The duration used for thorough stirring was 30 minutes, and the annual cost of electricity used in stirring (300 working days).

$$300 \times 45 \times \frac{30}{60} \times 12.00 = KES\ 81{,}100.00\ (US\$\ 747.03)$$

The cost of running the mixing machine four times = KES 324,000.00 or US$ 2,759.56.

4.1.3.2. The cost of electricity used in stirring during the heating process

Assume power of the motor was 45 kW, and the duration used for thorough stirring was 1 hour/day for 300 working days in a year. The annual cost of electricity cost for this process =

$300 \times 45 \times 1 \times 1200 = KES162{,}000.00$ or US$ 1,379.78

The cost of running the machine four times = KES 648,000.00 or US$ 5,519.12

4.1.3.3. The cost of electricity used in heating biodiesel

The cost of electricity used in heating 100 000 000 kg biodiesel from 20°C to 70°C to remove residual methanol. The heat energy used in the heating process was;

$$Q = \frac{mC_p \Delta T}{efficiency} = \frac{100000000 \times 6.74 \times 50}{0.9}$$

$$= 37{,}444{,}444{,}444.44\ kJ = 10{,}401{,}235.00\ kWh$$

The annual cost of electricity cost for this process was;

$$10{,}401{,}235.00 \times 12.00 = KES\ 124{,}814{,}820.00\ (US\$\ 1{,}063{,}068.05)$$

The cost of running the mixing machine four times was, KES 499,259,280.00or US$ 4,252,272.21.

4.1.3.4. The annual cost of electricity used in biodiesel production

The annual cost of electricity used in the production of biodiesel = 33,865,780.25 + 324,000.00 + 648,000.00+ 499,259,280.00 = KES 534,097,060.25 or US$ 4,548,991.23

The annual amount of electricity used for administration purposes (150,000 kWh/annum [55]) @ 12.00 = KES 1,800,000.00 (US$ 16,600.57), when combined the overall amount of money used on electricity yearly becomes; KES 535,897,060.25 (US$ 4,346.29).

4.1.6 Biodiesel Production Cost (BPC)

The breakdown of the total manufacturing costs of a biodiesel production plant with an installed operating capacity of 100,000 tons/year is given in Tables 4, 5 and 6..

Table 4: Estimated Operating labour cost

Item	Unit Price (KES)	Quantity	Estimated cost, KES ('000)
Managers	200,000.00	2.00	400.00
Engineer	150,000.00	1.00	150.00
Chemist	80,000.00	1.00	80.00
Technologists	80,000.00	3.00	240.00
Secretary	50,000.00	1.00	50.00
Messenger	30,000.00	1.00	30.00
Labourers	90,000.00	1.00	90.00
Operating labour (OL)			**1,040.00**

4.1.5. Total Manufacturing Cost (TMC)

It is necessary to know the manufacturing cost of a product in order to set its selling price, make a profit and sell it. Direct and indirect costs are separated from manufacturing costs. Details in Table 5 & 6 below.

Table 5: Estimated Total Manufacturing Cost (TMC)

Category	Factor	Unit cost (KES)'000	Total Unit cost (KES)'000
Seedlings/kg	200,000.00	0.025	5,000,000.00
Methanol (1:3 stoichiometric ratio with oil)	11,000,000	0.4	4,400,000.00
Total amount used in Electricity (From section 3.1.1) /kWh	12	861.33	10335.96
Electricity (manufacturing Section: 4.1.5)			535,897.06
Shipping & packaging	0.02 * raw materials	9,400,000.00	188,000.00
Plant overheads	0.5*(OL + M &O)	36,092.48	18,046.24
Property insurance cost	5% PCE	103,095	5,154.75
Maintenance labour	0.01*FCI	609,913.10	6,099.13
Maintenance and operational cost (M & O)	0.1*PPC	350,524.77	35,052.48
Other fixed operating costs	0.1*FCI	609,913.10	60991.31
Depreciation	0.15 * FCI	609,913.10	91486.96
Interest	0.08 * FCI	609,913.10	48793.048
Insurance	0.01 * FCI	609,913.10	6,099.13
Rent	0.02*PCE	103,095.00	2,061.90
Royalties	0.01 * FCI	609,913.10	5,082.61
Supervision	0.2* Labour	1040	208
Operating	0.15*	45,743.48	6,861.52

supplies	Maintenance		
Laboratory charges	0.15 *Labor	1,040	156.00
Direct Production Cost (DPC)			10,420,326.10

The cost of raw materials, other expenses, supplies, shipping and packaging, labor, administration, operating overheads, depreciation, interest, insurance, rent, royalties, and maintenance are all included in direct production costs (DMC). The cost of raw materials in this project accounts for 72% of the BPC, which accounts for a significant part of the manufacturing cost because it significantly affects the production cost. Labor costs accounted for 0.008% of production costs, which means that the production of biodiesel from yellow oleander is not labor intensive.

Table 6: Indirect Production Cost (IPC)

Category	Factor	Unit cost (KES)'000	Total Unit cost (KES)'000
Research and Development	0.05* DPC	10,420,326.10	521,016.31
Sales	0.2* DPC	10,420,326.10	2,084,065.22
General expenses	0.25* PCE	103,095.52	25,773.88
Packaging & storage	0.1* OL and M&O costs	36,092	3,609.25
Indirect Production Cost (IPC)			2,634,464.65
Biodiesel Production Cost (BPC)			13,054,790.75

Indirect production costs (IDPC) accounted for 20.18 % of BPC. Whereas, research and development, and sales accounted for 3.99, and 15.96 % of BPC, respectively.

4.1.6. Income generated from the sale of glycerine (a by-product)

The stoichiometry of the biodiesel production reaction requires that 3 moles of methanol and 1 mole of triglyceride react to give 3 moles of fatty acid ester and 1 mole of glycerol. In this case, the amount of glycerin produced in one year was 1,025,385.76 liters, and the annual income from glycerin per year (@ KES 1,730 (US$ 14.03) per litre [56].

The income generated from glycerine sales

= KES 1,784,171,222.00 or (US$ 14,470,163.86)

The income generated reduced the cost of production by 18.80%. By the mid-20th century, more than 1,500 uses for glycerine had been discovered, although traditionally the substances were mainly used in the soap industry [57].

4.1.7. Cost of production of yellow oleander biodiesel

The volume of yellow oleander biodiesel produced can be calculated using the following equation (Density of biodiesel = 0.88 g/cm^3)

In one year, the following volume of biodiesel is produced

$$= \frac{100000000}{0.88} = 113{,}636{,}363.60\ L$$

This volume can assist in calculating the annual production using Equation 25.

Annual production cost = 13,054,790.75- 1,784,171,222.00 = KES 11,270,619,528.00 (US$ 91,223,144.55)

$$\text{Production}/L = \frac{Annual\ production\ cost\ (KES)}{Annual\ production\ rate\ (L)} \quad \text{.........Equation 25}$$

$$= \frac{11{,}270{,}619{,}513.36}{113{,}636{,}363.6} = KES\ 99.88\ (US\$0.80)$$

The net cost of biodiesel production from yellow oleander has been estimated at 99.18 (US$ 0.80)/L. That was 32.28 % cheaper compared to the selling price, KES 164.21 or US$ 1.33/l for petrodiesel in Kenya. In this study, raw material and labor costs accounted for 74.38 % and 0.008 % of annual production costs, respectively. A major challenge in producing commercial biodiesel is the high cost of pure vegetable oils. They account for between 70% and 85% of the total production costs of biodiesel [58], [59]. In this study, the raw materials were within the recommended range.

Hamacher *et al.*, (2010), found that the production cost of biodiesel from used frying oil is US$0.73/L [60]. Aveco *et al.*, (2020), found that the production cost of crude palm oil biodiesel was US$3.75/gallon (US$0.99/L). These included raw material costs, which accounted for the highest percentage (73%), followed by material costs (21%) and finally maintenance costs (1%)[61]. Kumar *et al.*, (2015) also found that the production cost of palm oil biodiesel was US$0.99/L [62]. In this study, the production costs of biodiesel from yellow oleander oil were similar to those of used cooking oil biodiesel. But lower than that of palm oil biodiesel, which is actually an edible oil.

Mizik & Gyarmati, (2021) in Economics and Sustainability of Biodiesel Production stated that current biodiesel prices cannot be competitive but also depend on other factors such as government support, a steady supply of raw materials, and the use of glycerol as a raw material by-product that Reduce costs. They also found that a selling price of $1.48/L can yield a profit of $0.080.1/L [63].

4.1.8. Income from yellow oleander biodiesel

The sales expenses = 0.2 DPC = KES 2,741,293,306.00.

The income from yellow oleander biodiesel production cost = BPC + Sales expenses.

= KES 13,054,790,753.00 + 2,084,065,220.00 = KES 15,138,855,973 (US$ 122,631,477.74).

This is equivalent to KES 133.22 (US$ 1.08)/L. The revenue from the sale of glycerine reduced the annual production cost of the yellow oleander biodiesel plant by 13.67 %.

Selling Price = Cost Price + (% Profit Margin x Cost Price)

$$= 133.22 + \left(\frac{20}{100} \times 133.22\right) = KES\ 159.86$$

$$or\quad US\$\,1.29$$

The selling price of yellow oleander biodiesel was estimated at 159.86 (US$ 1.29)/L. Ganev *et al.*, (2020), analysed the optimal design of a sustainable integrated biodiesel/diesel supply chain using first and second-generation bioresources. They found that the average price of biodiesel (B100) from 2016 to 2020 was KES 18.66 (US$0.15)/L. This was 14% above the average biodiesel price based on the economic standard of KES US$16.48 (0.13/L [63].

4.1.9. Income from yellow oleander biodiesel

The sales expenses = 0.2 DPC = KES 1,904,392,399.00.
The income from yellow oleander biodiesel production cost = BPC + Sales expenses
= KES 9,521,961,994.00 + 1,904,392,399.00
= KES 11,426,354,393.00 (US$ 97320112.37).

This is equivalent to KES 100.55 (US$ 0.86)/L. The revenue from the sale of glycerine reduced the annual production cost of the yellow oleander biodiesel plant by 18.74 % to 7,737,790,772.12 (US$ 65,904,018.16), which is equivalent to KES 68.09 or (US$ 0.58)/L.
Depression = 0.15 FCI = 0.15*508,260,913.60 = KES 76 239,137.04 or (US$ 649,341.09)

SP = the selling price of B20 fuel is KES 148.13
GI = SP*V – COM……………………. Equation 5

GI=148.13 (113,636,363.60) – 9,521,961,994.00
GI = KES 7,310,992,551.33
NP = GI*(1 - TR) ………………..…... Equation 6 NP = 7,310,992,551.33 (0.9) = KES 6,579,893,296.00

$$ROI = \frac{NP}{TCI} \times 100$$ ……………….... Equation

$$ROI = \frac{6,579,893,296.00}{635,326,142.00} \times 100 = 1035.67\ \%$$

A positive ROI calculation result indicates that the net returns on the investments net returns are positive because as the total returns outweigh the total costs.

Non-edible vegetable oils such as yellow oleander oil does well in arid and semi-arid areas with relatively lower production costs. Hamacher *et al.*, (2010), found that the production cost of biodiesel from used frying oil is US$0.73/L [60]. Aveco *et al.*, (2020), found that the production cost of crude palm oil biodiesel was US$3.75/gallon (US$0.99/L). These included raw material costs, which accounted for the highest percentage (73%), followed by material costs (21%) and finally maintenance costs (1%)[61]. Kumar *et al.*, (2015) also found that the production cost of palm oil biodiesel was US$0.99/L [62]. In this study, the production costs of biodiesel from yellow oleander oil were similar to those of used cooking oil biodiesel. But lower than that of palm oil biodiesel, which is actually an edible oil.

Mizik & Gyarmati, (2021) in Economics and Sustainability of Biodiesel Production stated that current biodiesel prices cannot be competitive but also depend on other factors such as government support, a steady supply of raw materials, and the use of glycerol as a raw material by-product that Reduce costs. They also found that a selling price of $1.48/L can yield a profit of $0.080.1/L [63].

4.1.10. The price of the biodiesel blends

The estimated diesel blendstock price was based on average reported blends each year, the price of biodiesel and proportion of the blended fuel. The price of diesel blends can be solved using the Equation 27.

$$P_{composite} = (\%\ BD) \times P_{BD} + (1 - \%\ BD) \times P_{diesel} ..... Equation \quad 27$$

Where;
$P_{composite}$ is the composite price/litre of blended diesel
$P_{biodiesel}$ is the price/litre of pure biodiesel (BD)
P_{diesel} is the price/litre of ptrodiesel; and
% BD is the specified biodiesel blending [64].

Using the current market price of petrodiesel fuel in Kenya at KES 164.21/L. For B5:

$$P_{composite} = (0.05 \times 159.86) + (0.95 \times 164.21) = 163.99$$

The calculated composite prices of blended diesel are represented in Figure 2 below.

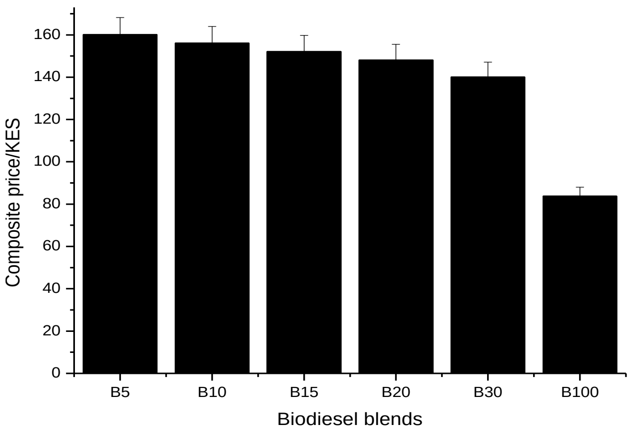

Figure 2: Price of biodiesel blends

The price of all blends was lower than the market price for petrodiesel fuel in Kenya (KES 164.21 or US$1.33)/l. These prices of biodiesel blends decreased as the level of petrodiesel in the blends increased. B5 is the most expensive blend, priced at 163.99 KES (US$ 1.33)/L. The market price of B20 is KES 163.34 (US$ 1.32/L, 0.52 % cheaper than petrodiesel. The B30 and B100 were priced at KES 162.91 (US$1.32)/L and 159.86 KES (US$1.29)/L, respectively. Most biodiesel users prefer to buy B20 or lower blends from biodiesel marketers. B20 is a standard blend; it has the right balance between cost, emissions, cold-weather performance, and material compatibility [65]. Kumar *et al.*, (2019) found that the price of B20 tallow biodiesel was US$0.72/L, this price was lower than the price recorded in this study.
SP = the selling price of B20 fuel is KES 179.69
GI = SP×V – COM……………………. Equation 26
GI = (163.34 × 113,636,363.60) - 13,054,790,750.00 = 5,506,572,880.42
NP = GI × (1 - TR) ………………..…... Equation 27
Where; GI for Gross Profit

$$NP = 5{,}506{,}572{,}880.42\left(1 - \frac{10}{100}\right)$$

$= 5{,}506{,}572,\ 880.42 \times 0.9$

$= KES\ 4{,}955{,}915{,}592.00$

or US$ 40,112,613.1 9

$$ROI = \frac{NP}{TCI} \times 100$$ ………………..... Equation

TCI = KES 864,301,016.30

$$ROI = \frac{4{,}955{,}915,\ 592}{864{,}301{,}06\ 1.30} = 573.40\ \%$$

The ROI for yellow oleander biodiesel production was 573.40, a positive ROI value indicates that the net returns on investments are positive as total returns exceeded total costs.

4.2. Energy Analysis

The energy balance or fossil energy ratio is an energy-in/energy-out ratio. It considers the total amount of energy used in biodiesel production and compares this to the amount of energy contained in the fuel produced [66].

4.2.1. Ploughing

The energy expenditure using a tractor for ploughing given by; $E_{N1} = V_f \times \rho \times CV \times k$ [43]

Where; k = 1.0 for normal soil; ρ = 55L/hectare/year [67]

E_{N1} = 55 l × 804 kg/l × 43.20 kJ/kg × 1.0 = 1,910,304.00 MJ

4.2.2. Irrigation

The energy expenditure for irrigation is given by;

$$E_{N2} = 3600 \times R_p \times t \times d \times t =$$

$$3600 \times 1\,kWh \times (8 \times 300) \times 1 \times 2.5 = 21\,600\,000\,MJ$$

.

4.2.3. Manpower

The manpower spent is calculated as follows;

$E_{N4} = E \times [l_1 \times t_1 + l_2 \times t_2 + l_3 \times t_3 + l_4 \times t_4 + l_5 \times t_5] \times k =$ 1.0 × [1 × (8 × 300) + (1.2 × 8 × 300) + 1 × (1×8 × 300) + (1× 8 × 7 × 4)] × 1.2 = 9,484.80MJ

$E_N = E_{N1} + E_{N2} + E_{N3} + E_{N4}$ [43]

E_N is energy input (MJ) in the nursery, E_{N3} = 0, E_{N3} is the energy input (MJ) in placing manure in the nursery.

4.2.4. Plantation

The total energy used in plantation may be calculated using the following equation;

$E_p = E_{P1} + E_{P2} + E_{P3} + E_{P4}$ [43].

For normal soil:

E_p = 1,910,304.00 + 21,600,000.00 +0 + 9,484.80= 23,519,788.80 MJ

4.2.5. Growth

The total energy for nurturing and water sprays is given by E_G = E × t + 2.5 × E_{P2} = (1 × 12 × 365 × 2) + 2.5 × 21,600,000.00 = 54,008,760.00 MJ.

4.2.6. Seed collection

The energy used in seed collection is calculated as;

$$E_{SC} = E \times (t_1 + t_2 + t_3 + t_4) \times k$$

For normal soil;

E_{SC} = 1.96 × [(15×8×20) + (6 × 4 × 300) + (15 × 8 × 300) + (4×2×52) × 1.0 = 156,047.36 MJ

4.2.7. Transport of seeds

Seeds transported using a tractor which consumed 4 litres of diesel/day [43]. The energy used was calculated using the equation;

E_{TP} = $v_f \times \rho$ × CV + E × t = 4 litres × 300 × 804 kg/l × 43.200MJ/kg + 1.0 × 2 ×4 × 300 = 10,422,240.00 MJ.

4.4.3. Oil extraction

Oil extraction from the yellow oleander seed uses an extraction unit a capacity of 1 ton/h [43]. The energy consumed in oil extraction is given by E_{OE} = (P ×M + E × t) × y = [(55 kWh×100,000) + (1.0 × [(8 ×300)] × 1.0 = 5,502,400.00 MJ.

P = 55 kWh of seeds input [68]

4.2.9. Transesterification

The energy expenditure in transesterification process is given by; E_T = P ×M + E × t = 36 ×100,000 + 1.0 × (2 ×300) = 3,600,600.00 MJ

P = 36 kWh tons of oil [69]

4.3. Total Energy Demand/Input

Total energy demand/input in the life cycle of the biodiesel production was calculated using the equation;

$E_{Input} = E_N + E_P + E_G + E_{SC} + E_{TP} + E_{OE} + E_T$ [43].

E_{input} = the total energy input used for transesterification reaction in MJ.

For normal soil;

E_{input} = 23,519,788.80 + 23,519,788.80 + 54,008,760.00 + 156,047.36 + 10,422,240.00+ 5,502,400.00+ 3,600,600.00 = 120,729,624.96 MJ

4.3.1. Energy Output

The energy contained in the biodiesel produced from 10 000 tons of oil is given by;

$E' = CV_{BD} \times T \times 1000$ [43];

Where CV_{BD} is the calorific value of the yellow oleander (MJ/Kg) and T is the quantity of the biodiesel in tons.

E' = 43.20 × 100,000 × 1000 = 4,320,000,000 MJ.

Taking into consideration the thermal efficiency of a C.I engine as 20 % [43]., the remaining energy can be calculated as;

E_{output} = 0.20 × E $\Rightarrow$ E_{output} = 0.20 × 4,320,000,000 = 864,000,000 MJ

4.3.2. Net Energy Ratio

The net energy ratio is the ratio of the available energy of the end product (yellow oleander biodiesel) to the energy invested in the conversion process. This can be obtained using the equation;

$$Net\ energy\ ratio = \frac{E_{output}}{E_{input}} = \frac{864{,}000{,}000}{120{,}726{,}624.96} = 7.16$$

This research found that biodiesel production from yellow oleander is energy efficient. For every 1 MJ of energy invested in the production of yellow oleander, 7.16 MJ of energy is produced. The net energy ratio for yellow oleander biodiesel was greater than one. Less indirect energy input during the growth of the yellow oleander plant can be sustained under unfavourable environmental conditions such as precipitation and soil conditions in semi-arid areas [70].

Yadav *et al.,* [43], found that the energy ratios were greater than one (1.06081.4549) regardless of biodiesel yield for jatropha cultivation under normal soil conditions. Energy ratios are higher at low, normal, and high yields for good/soft soil conditions, ranging from 5.23 to 5.32. Under normal soil and crop conditions, the Karanja biodiesel life cycle had an energy ratio R2 = 1.64, and the energy ratio ranged from of 1.26 to 3.18 for all considered cases. Karanja biodiesel had a minimum energy ratio value (1.26) for low yield under adverse system conditions such as land and precipitation, and groundwater depth, among others.

V. Conclusion and Future Scope

The market price of the B20 yellow oleander biodiesel blend was KES 163.34 (US$1.32)/Litre confirming that the yellow oleander biodiesel is affordable. It may be integrated into government strategies for rural development to assist in job creation and poverty alleviation.

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The main issue facing second-generation biofuels, like yellow oleander biodiesel, is economic. They are still simply too expensive to produce compared to the fossil fuels they could replace when compared on a private production cost basis.

Advances in biotechnology could reduce the production costs of raw materials and accelerate the increase in the yield of biofuels per unit area. These increases may be the result of increased biomass yield growth, the development of biomass with higher conversion efficiencies that are more easily converted into biofuels, or a combination of both. It is clear that the productivity of various feedstocks per unit area has significant potential to improve the energy balance and reduce the environmental impact of biofuels, in addition to reducing overall production costs.

Future research should aim to increase the productivity of the yellow oleander plant. Increasing production will ensure systems that are environmentally, socially, and economically viable. This is done on marginal land in poor rural areas. Further studies on waste materials such as catalysts derived from waste eggshells to develop improved new catalysts for biodiesel synthesis. Development of a highly active and selective heterogeneous catalyst that will enable the future commercialization of heterogeneous catalysts. In short, the performance of biomass-derived catalysts for biodiesel production and other important chemical processes needs to be improved and further developed. This catalyst should be able to provide and support interconnected systems of appropriate pore sizes within catalysts. The development of waste into catalysts requires government support through tax breaks or relief and the introduction of favorable regulations that encourage the use of recycled waste products. In other words, if supported waste-derived catalysts have the potential to create jobs and support the industry. The environmental impact potentials were not evaluated in this work. Future assessments of the more detailed environmental impact potential should be carried out.

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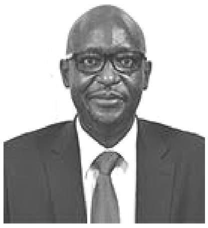

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