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Modeling and Optimization of *Jatropha* Supply Chain for Biodiesel Production in Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author VMI designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors ANA and OJO supervised the study. All authors read and approved the final manuscript.

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ABSTRACT

This work dealt with the development of simulation model for *Jatropha* biodiesel supply chain. It also investigated the effects of *Jatropha* supply chain variables on the system performance criteria and determined the optimum sequence for the *Jatropha* supply chain management. This was with a view to providing an insight into the feasibility of using *Jatropha* as a raw material for the production of biodiesel in Nigeria. The study determined the viability of the feedstock and processing technologies, decision time frame as well as levels in the supply chain and developed a similar model with simple graphical user interface for the biodiesel supply chain. Simulation model software, Arena was used to facilitate the exploration of different conditions that will bring about profitable biomass utilization. The model considered key supply chain activities including the feedstock harvesting/processing, transportation and storage. The model also used feedstock cost, energy consumption, economic analysis and measures of investment ranking: net present value (NPV), benefit cost (B/C) and internal rates of returns (IRR). Statistical and numerical results showed that the development of the biodiesel supply chain in Nigeria requires an increasing use of land to produce oil and biodiesel to satisfy future domestic and external demand. Even though there were no earlier studies of this nature in Nigeria, the template of this study can be used to provide important information for stakeholders and investors of *Jatropha* for biodiesel production as obtainable in other interested countries of the world.

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1. INTRODUCTION

In order to reduce greenhouse gas emissions and reduce dependence on imported oil, renewable biofuels/biodiesel production from biomass has received increasing interest. However, due to the distributed nature of biomass raw materials, the cost and operational procedures of biomass recovery result in huge challenges that retard increased biomass utilization for overall energy generation [1,2]. The lack of experience with time-sensitive collection, transportation and delivery operations to ensure year-round supply of large amounts of biomass feedstock is also a barrier to widespread implementation of bio-refinery technology [3]. Developing a consistent, economically-viable feedstock supply system requires addressing diverse harvesting and transportation scenarios. An optimized network of harvesting and collection, and transportation infrastructure is the key to the viability of a bio-refinery.

Previous works have been conducted on existing biofuels supply chains. Next, an activity model is developed in order to have a visible overview of the proposed supply chain and allow for a comprehensive analysis of the key elements and components to be addressed. A simulation model will be then designed and implemented using Arena Simulation Software [4] to facilitate the exploration of different conditions that will bring about profitable biomass utilization. The model was applied in a case study for Michigan's Lower Peninsula [5] for the development of biomass supply chain in biofuels production. Model simulations provide a number of economic and environmental performance measures for each condition that is considered. Ultimately, it is desired to employ the simulation model to find conditions that minimize the delivered raw material cost, energy consumption, and greenhouse gas emissions. This work will ultimately be desired to employ the simulation model environment of Arena Simulation Software [4] available online to find conditions that minimize the delivered *Jatropha* feedstock costs, energy consumption, and probably GHG emissions. The summary of our research findings will describe important conclusions, and present guidance for future research especially in the area of green supply change management (GrSCM) which is currently drawing the attention of energy and energy management experts.

The works considers the availability of *Jatropha* feedstock; established plantations and locations, quantities attainable stored for existing biodiesel refineries/plants for continuous plant operation within time periods, viability periods of seeds, production processes and quantities of biodiesel produced with the main goal of identifying the best solution for optimal design and operations of the biodiesel and feedstock supply chain for cases considered. This will no doubt aims to the optimization of the biodiesel supply chain from *Jatropha* through raw materials, conversion route, and final product consideration, taking into account the economic and technical characteristics of the problems to be encountered. The model to be developed may be used as a decision support system for the strategic planning of *Jatropha* exploitation and investment selection in Nigeria and at a later stage, for the optimal operation of the supply chain when the basic strategic choices have been implemented.

The main objective of this study is to develop simulation and optimization model for supply chain of *Jatropha curcas* seed feedstocks for biodiesel production in Nigeria. The works intends to consider the availability of *Jatropha* feedstock; established plantations and locations, quantities attainable and stored for existing biodiesel refineries/plants for continuous plant operation within time periods, viability periods of seeds, production processes and quantities of biodiesel produced with the main goal of identifying the best solution for optimal design and operations of the biodiesel and feedstock supply chain for cases considered. In this study, a mathematical model which integrates facility spatiality and time variation of demands into a strategic planning for *Jatropha* biodiesel supply chain systems will be developed using Arena software. The specific objectives of the study are to: investigate the effect of *Jatropha* supply chain variables on the system performance criteria; and to determine the optimum sequence for the *Jatropha* supply chain management. In expecting an outcome in the biomass/bio-fuel/biodiesel supply chain, all the stakeholders have to be considered as individuals. Because of the complexity of the biomass supply chain, each stakeholder (farmer, contractor or refinery) has different characteristics. The tool will provide optimal strategy, personalized on the individual needs, resulting in global optimization.

Biomass supply chain management (SCM) involves coordinating and integrating activities and processes among different parties for the benefit of the entire supply chain. The integration of multiple functions in a global supply chain context is complex. Information technology systems have been recognized to facilitate the processes of supply chain management through integrated information sharing, process automation, and relationship management programs [6].

1.1 Modeling Supply Chain Systems

"A supply chain system is a network that mediates the flow of entities involved in a product life cycle, from production to vending" [7]. Such a network is made up of nodes and arcs. Nodes represent manufacturers, distributors, vendors and suppliers (e.g., retail stores, process plant, plantations), also incorporating their inventory facilities for storage of products and lastly transportation facilities for transmitting them among nodes. 'Arcs represent routes connecting the nodes along which goods are transported in a variety of modes (trucking, railways, airways, and so on)' [7]. From advantageous point of view, 'supply chains have essentially a feed-forward network structure, with upstream and downstream components arranged in echelons (stages), such that raw materials, parts, products, and so on flow downstream, payments flow upstream, and information flows in both directions' [7].

The main supply chain echelons include:

a. Supply echelon allows feedstock or parts to the production process or operation;
b. Production echelon converts raw-material to finished product;
c. Distribution echelon is made up of a distribution network which moves finished products to distributors; and
d. Distributor echelon sells products to customers.

1.2 Arena Modelling Software

'Arena is a discrete event simulation and automation software developed by Systems Modeling and acquired by Rockwell Automation in 2000' (www.amrresearch.com). It uses simulation language and SIMAN processor. Its version as at June 2012 is version 14 (first version with online 3D visualization tool). In using Arena, an experiment model is built by the user by placing modules (figures of different shapes) which represent processes. A connector is used to link up modules together which specify the flow of entities. While modules have specific actions relative to entities, flow, and timing, the precise representation of each module and entity relative to real-life objects is subject to the modeler. Data, such as cycle time and work in process levels, can be recorded and outputted as reports. Arena can be integrated with Microsoft technologies.

"It includes Visual Basic for Applications so models can be further automated if specific algorithms are needed. It also supports importing Microsoft Visio flowcharts, as well as reading from or outputting to Excel spreadsheets and Access databases"(www.amrresearch.com).

1.3 Simulation using Arena

"A generic model of a production/inventory system consists of a production facility that is subject to failure, which supplies a warehouse with one type of product. This generic model illustrates how an inventory control policy regulates the flow of product between production and inventory facilities" [8]. A production/inventory system is where any production process is comprised of the sethree stages:

1. Initial process unit (e.g., filling of bottles, packets, bags);
2. Packaging each unit; and
3. Labelling each unit.

For the purpose of modeling, the processing periods of each individual stage(s) are combined into a single processing period. Fig. 1 is the schematics of the system while Fig. 2 is the typical process flow chat of Arena architecture. A feedstock storage source feeds the first production process line while the finished product units are stored in a store house. Customers arrive with product demands, and when a request cannot be satisfied by on-hand inventory, the unsatisfied portion represents lost sales. The following assumptions are made:

There are always sufficient raw materials in storage, so the process is continuous.

Product processing is carried out in five units, and finished lots are placed in the storehouse. Lot processing time is fairly distributed between the range of 10 and 20 minutes. Arena display window is as shown in Fig. 3 where the tools and icons are deployed for modeling and simulation

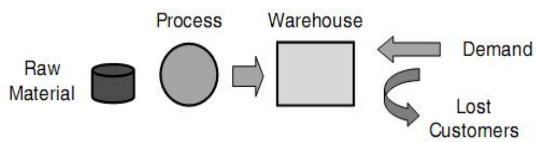

Fig. 1. A generic production/inventory system

1.4 Arena as a Tool for Supply Chain Modeling of Biodiesel Feedstock

In a context of growing interest for renewable energy sources liquid bioenergy production from vegetable oils is proposed as one of the possible options to reduce greenhouse gas (GHG) emissions. Against this background bio-diesel production from *Jatropha curcas* L. has become a booming business. The supply chain of *Jatropha* to be modelled in this study is represented in Fig. 5. The cultivation of *Jatropha* trees for the production of oil-bearing fruits is considered the first production step towards bio-diesel production (Fig. 5). The main inputs are land area including the prevalent site characteristics, plantation establishment practices and plantation management practices including the production and use of all machines, infrastructure and energy (transport, power, etc.) needed for those inputs. The oil produced from this seed can be converted to biofuel which meets the global professional specification [8,9]. In addition, the cake may be used as fertilizer while the organic waste products may be further digested to produce biogas (CH_4) [10,11]. The plant on its own is known to prevent and control soil erosion or to reclaim waste land [12-16]. *Jatropha* is still a wild plant, which can grow without irrigation in a broad spectrum of rainfall regimes, from 250 up to 3000 mm per annum [17]. Furthermore, *Jatropha* is reported to know few pests and diseases [10,14], but this may change when it is grown in commercial plantations with regular irrigation and fertilization. Based on these interesting properties, potentials and hyped claims a lot of investors, policy makers and Clean Development Mechanism project developers are interested in *Jatropha* to tackle the challenges of energy supply and greenhouse gasemission reduction [11,18].

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2. MATERIALS AND METHODS

Extensive and comprehensive literature survey was conducted. Data from Forestry Research Institute of Nigeria, Biodiesel Nigeria Limited, Pauman Resources Limited were synthesized and used for simulation and modeling. Research focus and trends in the area of supply chain, modeling and simulation, optimization process of *Jatropha* seeds and biodiesel were based on the understanding of the use of Arena software simulator and Microsoft Excel; which provided the platform to run the optimizer and other statistical analysis as well as transform the optimization models into solver (spread sheet) models which can be handled by the optimizer.

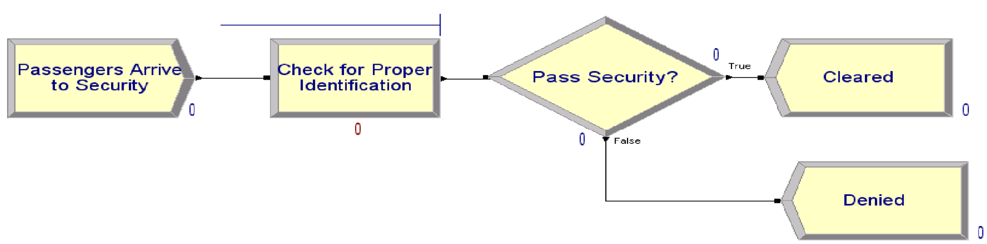

Fig. 2. A typical flow chart of arena software

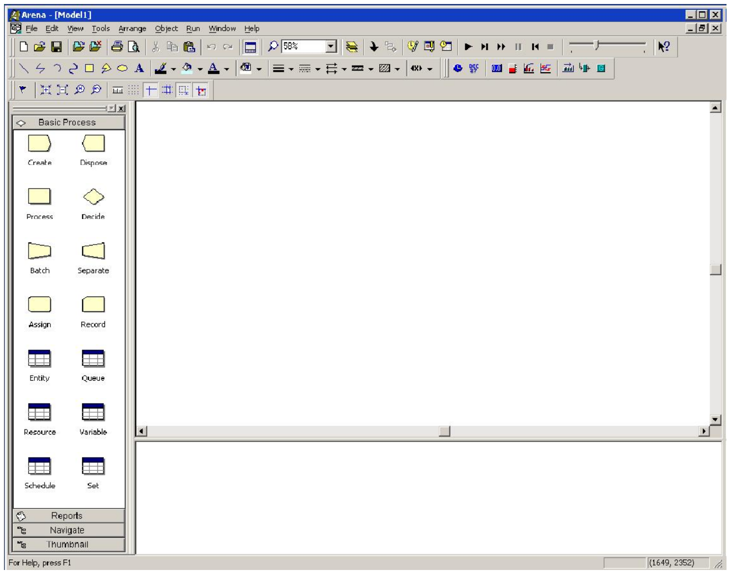

Fig. 3. Graphical user interface (GUI) of arena software

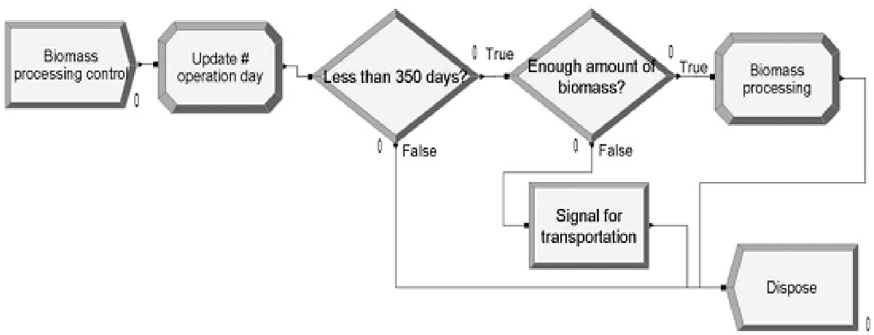

Fig. 4. Sub-model design for biomass

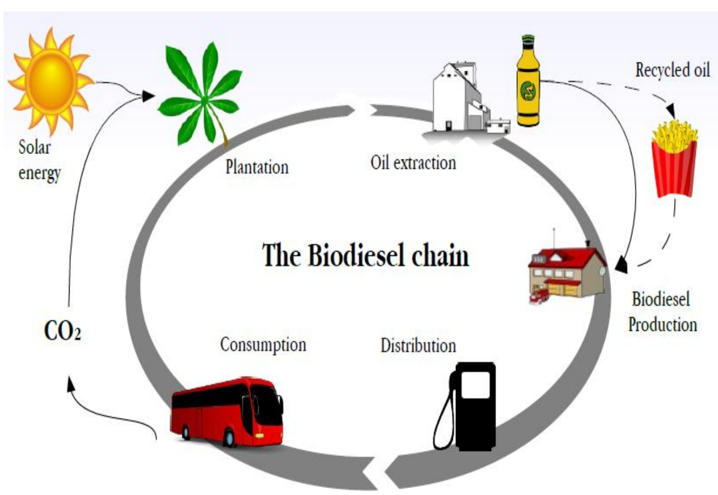

Fig. 5. *Jatropha* biodiesel supply chain

Fig. 6. *Jatropha curcas* plantation at Kwali farm settlement, FCT, Abuja

Sigma Plot spread-sheet based software and data analysis tool pack were used for implementing inference statistics adopted; regression models, ANOVA, randomized complete block system, t-stat and graphs. Arena software (version 14.1) process simulator provided the platform for supply chain and inventory simulation model. Statistical package in Excel provided the platform for statistical modelling and analysis, optimization of the supply chain and inventory processes from nursery to finished products.

2.1 Methods

2.1.1 Data collection

The study used primary data: three major *Jatropha* cultivating sites, namely Pauman Resources Limited, Abuja under the Kwali-Abuja Farm settlement; Forestry Research Institute of Nigeria; Eastern Shelter Belt, Umuahia; Kano Shelter Belt (FRIN), Kano and Biodiesel Nigeria Limited, Lagos. The primary data refers to cultivation cost, yields, input sources, marketing and other economic systems regarding *Jatropha* cultivation. From each case, selections were made based on the availability of *Jatropha* plantations. Three villages from each quarter: six from each district were randomly selected and then ten *Jatropha* growing farmers from each villageas respondents for conducting interviews. In all, sets of *Jatropha* plantation were sampled from each case. The researcher also visited two biodiesel manufacturing units, one each in Lagos and the other in Abuja to obtain detailed information on *Jatropha* processing. Other secondary sources which include published reports and websites resources were also used, in the process of evaluation and analysis.

For a system with m flows (*Jatropha* as a resource) and n sectors, the first equation in the model is based on a balance of the flows of goods at each time interval t as recommended by Vogt et al. [19] as:

$$A_{xt} = y_t \quad (1)$$

Where A is the technical coefficient matrix (mxn), xt the sectoral total output vector at t and yt is the sectoral net output vector at t. First a model is named model 1, and an equation are presented which will be used. Then for minimizing total cost or maximizing total benefit of supply chain, a generic model is introduced as model 2.

2.2 Modeling and Simulation of Supply Chain in Arena

The production facility of the system to be modeled produces product types (*Jatropha* seeds, oil and biodiesel) 1, 2, and 3, and these are supplied to three distinct incoming production streams, denoted by types 1, 2, and 3, respectively are represented in Fig. 7. The production facility produces batches of products, switching from production of one product type to another, depending on inventory levels. However, products have priorities in production, with product 1 having the highest priority and product 3 the lowest. The raw-material *Jatropha* feeds the production system while finished units are stored. Customers arrive with product demands, and when a demand cannot be satisfied by inventory on hand, the unsatisfied portion will represents lost sales. The parameters of each product are as shown in Table 1.

3. RESULTS AND DISCUSSION

Table 2 is the details of *Jatropha* cultivation at various farm levels in selected location. Forestry Research Institute of Nigeria has marginal, small and medium scale plantations in different locations in the country and is pioneering *Jatropha* development in the country. Biodiesel Nigeria Limited Lagos is a private investor that has marginal small and medium scale cultivation, inclusive of processing of biodiesel for immediate use and needs.

They have constant supplies of seed from local farmers across the breath of Southern Nigeria which harnessed for biodiesel production. Pauman Resources Limited, Abuja and others represent stakeholders who are interested in medium and large scale cultivation and processing of biodiesel. The Tables give information of various areas under cultivation, ages of seedlings, number of seedling per hectare, survival rate of seedlings and yields per hectare.

Table 3 describes the activities that take place from nursery to harvest of *Jatropha* within the operators of these plantations. The activities form part of the eventual feedstock that kick start the supply. The number of *Jatropha* plantation determines the supply base of the industry under focus. Pauman Resources recorded the highest age of seedling cultivated (4.0 – 4.15 years) while Biodiesel Nigeria has the least (2.7 – 2.8 years) irrespective of farming categories, be it marginal, small or medium. The survival rate of seedlings were highest in small and medium scale category (78% and 82%), (88% and 84%) from FRIN and Biodiesel Nigeria respectively. These are small and medium scale producers as against Pauman Resources which operated large and medium scale (71% and 72 %) respectively. There is general lesser room for competition within the threshold of small and medium scale cultivation. The overall influence is also reflected in the yields as well [20,21]. In the work of Zhang and Zhang [22], ANOVA of this nature was used to interpret, test and validate simulation results. The outcome of which was that there were huge significant differences amongst different plantation sizes which in turn influence the turn-over of the availability and supply of seeds which is also an essence in the production and supply chain of the final product (biodiesel) for whatever end use.

Table 4 shows the application inputs pattern at initial *Jatropha* plantation establishment. These inputs include fertilizer application, labour (human), and irrigation as the case may be. These inputs generally assumed reductive pattern with respective to years so that resources and raw materials expended drop. Table 5 is an economic analysis of *Jatropha* cultivation of the

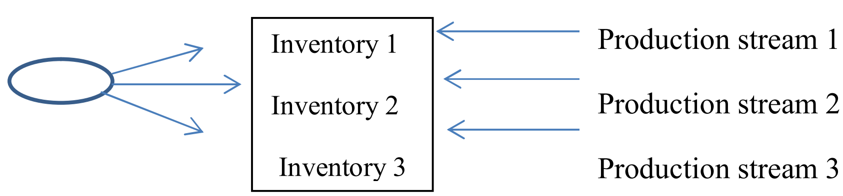

Fig. 7. Production/inventory model with three products (seeds, oil and biodiesel)

Table 1. Parameters of the production/inventory model with three product types

Product type	Target level	Reorder point	Initial inventory	Processing time (Hrs)	Demand inter-arrival time (Hrs)	Demand quantity
1	100	50	75	1	Exp(16)	U(4,10)
2	200	100	150	0.6	Exp(8)	U(10,15)
3	300	150	200	0.3	Exp(4)	U(20,30)

study from land preparation through plantation establishment, seedling costing, fertilizer application, weeding, irrigation, maturation, and harvesting, total costs of return, internal rate of returns, net returns and profit margin derived from *Jatropha curcas* in its supply chain process. The pattern can be seen to have an increasing rate of returns from the first year to the third year considering the fact that the critical years of operation were more of input than output. These are important parameters at the upstream, midstream and downstream operations which drives the chain. The optimum benefits are derivable in financial values.

Table 6 goes further to present total cost of production of biodiesel from *Jatropha* seeds/feedstock and the accruable revenue the refrom. For Pauman resources, the cost of production of 1 ton per day of *Jatropha* seeds production to biodiesel and the revenue generated is shown. Biodiesel Nigeria has a higher capacity of production of 10 tons per day. The net cost incurred by Pauman Resources for biodiesel production per kilogramme is NGN 292.20 while Biodiesel Nigeria has a net cost per kilogramme of NGN 176.20. This same pattern affects the revenue generated as well with NGN 20,500 and NGN 228,000 for Pauman Resources and Biodiesel Nigeria respectively. The general effect is derivable from their different capacities of operation. These facts are quite succinct in Nigeria because no such data or information is available for use in modelling of supply chain either for seed supplies or biodiesel supplies in Nigeria. Presently, the biodiesel distribution does not follow any well-developed supply chain, even though several public sector undertakings and private companies have ambitious plans to enter into the sector in a big way. The above discussion makes it clear that the development of a commercial biodiesel industry based on *Jatropha* and other non-edible oilseeds is at a very nascent stage in Nigeria at present.

Table 7 is the regression model equations of *Jatropha* supply chain for the three operators studied with the total cases in year 1, 3 and 5 and extrapolated for up to ten (10) years. The model equations depicted by FRIN is $y = 21.3x^2 - 26.8x + 16.3$ which is polynomial in nature. Pauman's model is $y = 36.3x^2 – 56.8x + 46.3$ also polynomial in nature while Biodiesel Nigeria's model is $y = 27.5x^2 – 41.5x + 35$ also polynomial. The model for the general study is $y = -212.5x^2 + 907.5x – 260$ with coefficient of determination (CoD) as 1. The entire models have their CoD ≥ 0.98.

Table 2. Different operations of *Jatropha* cultivation at farm levels in the study

Operator	Land ownership	Rights on harvest	Government role
Farmer	Farmer	Farmer	Subsidy on seedlings
Farmers (Kwali) FCT	Community	Pauman	Lease of land, subsidy on inputs, employment guarantee
Corporate	Private/Community	Corporate	Subsidy for setting up processing plants

Table 3. *Jatropha* cultivation at farm level in selected locations

Operators	Farmer category	Area under *Jatropha* (ha)	Age of seedlings) (years)	Number of seedlings per ha	Survival rate of seedlings (%)	Yield (t/ha)
FRIN, Kano and Umuahia	Marginal (26)	0.075	3.2	1852	73.5	2.12
	Small (22)	0.105	3.0	1912	78	2.51
	Medium (12)	0.26	3.5	2244	82	2.82
Biodiesel Nigeria Ltd, Lagos	Marginal (16)	0.73	2.7	3655	86	2.42
	Small (36)	0.61	2.8	2568	88	2.52
	Medium (18)	0.72	2.7	2282	84	2.80
Pauman Resources Ltd, Abuja	Medium	3.89	4.15	2051	71	2.32
	Large	50	4.0	2500	72	3.01

Source: Field Data (2013).

*Notes: *Community allocated to self-help groups in which marginal farmers were growing Jatropha. Marginal represents Less than 1 ha; Small represents 1-2 ha; Medium represents: 2-10 ha and Large Scale: up to 50 ha*

Table 4. Application input pattern at initial *Jatropha* plantation establishment

Operator	Labour (human days/ha)			Uric acid NPK		% of Irrigation/yr		
	Family	Hired	Total	(t/ha)	(t/ha)	Once	Twice	> Twice
FRIN	15	80	95	0.80	0	45	20	5
Biodiesel	10	85	95	1.75	120	0	0	0
Pauman	14	90	104	1.98	150	30	10	0

Source: Field Data (2013)

Table 5. Economic analysis of *Jatropha* cultivation

Operation	FRIN			Biodiesel Nigeria limited			Pauman resources Ltd		
	1 yr	2 yr	> 3 yr	1 yr	2 yr	> 3 yr	1 yr	2 yr	> 3 yr
Land preparation	50,000	0	0	60,000	0	0	48,000	0	0
Plantation	40,000	0	0	40,000	0	0	42,000	0	0
Seedling cost	75,000	0	0	80,000	0	0	75,000	0	0
Planting	47,500	10,000	0	40,000	15,000	0	50,000	15,000	0
Fertilizer (initial)	40,000	0	0	0	0	0	25,000	0	0
Fertilizer (second)	40,000	0	0	0	0	0	20,000	0	0
Weeding	30,000	30,000	30,000	50,000	50,000	55,000			
Irrigation	10,000	10,000	10,000	0	0	0	8000	8000	8000
Harvesting	10,000	25,000	50,000	25,000	50,000	75,000	15,000	30,000	40,000
Sub-total	342,500	75000	90000	295,000	115000	130000	283,000	53000	48000
Miscellaneous (10%)	34,250	7,500	9,000	29,500	11,500	13,000	28,300	5,300	4,800
Total cost	375,750	82,500	99,000	324,500	126500	143000	311300	58300	52800
Gross returns	120,000	240,000	600,000	120,000	240000	600000	120,000	240000	600000
Net returns	**-256750**	**157500**	**501000**	**-204500**	**113500**	**457000**	**-191300**	**181700**	**547200**

Source: Field Data (2013).

Information: The figures are mean scores across sampled farmers. Fertilizer cost: N 1200 / kg of DAP and manure @ N 5000 per ton. Cost of irrigation: N 5000 per irrigation per hectare Price of seeds of Jatropha produced is in Table 8 (Naira/ha)

Table 6. Cost of production of biodiesel and optimized revenue in the studied cases

Inputs	Pauman resources Ltd		Biodiesel Nigeria limited	
	Qty	Value (Naira)	Qty	Value (Naira)
Jatropha seeds	1 ton/day	60,000	10 ton/day	520,000
Unskilled labour	2 human days	8,000	6 human days	38,000
Managerial labour	1 human day	10,000	I human day	80,000
Administrative labour	1 human day	5,000	4 human days	46,000
Chemicals				
Methanol	60 litres	35,000	600 litres	200,000
Sodium hydroxide	2 kg	12,000	30 kg	100,000
Electricity	32 units	5000	380 units	35,000
Interest on fixed capital	@10%	5,000	@10%	38,000
Depreciation on Machinery	@10%	3500	@10%	30,000
Depreciation on other assets	@4%	4500	@ 4%	37,000
Freight and other incidentals		4000		20,000
a. Total cost		**152,000**		**1,144,000**
Revenue from by-products				
Glycerol	65 kg	6500	550 kg	70,000
Oil cake	700 kg	14000	7000 kg	158,000
b. Total revenue		**20,500**		**228,000**
Net cost incurred (a-b)		131500		916,000
Recovery of biodiesel per ton of seeds	450 kg		5200 kg	
Net cost/kg of biodiesel		**292.2**		**176.2**

Source: Field Survey (2013)

Tables 8, 9 and 10 present optimized cost of production of biodiesel and optimized revenue in the studied cases and the developed regression equations thus determining the optimum sequence for *Jatropha* supply chain management as intended in the objectives of this study. The regression model equations for the chain sequence across ten years of projection elucidates equations of polynomial nature with their coefficient of determination almost attaining unity giving it a perfect line of best fits for all the models developed for the study cases. The quantities of optimized *Jatropha* seeds for the projected years brought perfect correlation between production and supply and the analysis of variance confirms no significant difference at 95% confidence level across the study cases but significant across plantation sizes for the production and supply of seeds and biodiesel respectively.

The cost of production in Table 10 was also a significant factor with positive correlation. In isolating Pauman Resources Limited as a biodiesel production company in the study, the model equations developed for seed production and yields across the projected years in Table 7 has positive correlation with the equations of Table 9. Table 10 is the optimized production process and cost of *Jatropha* biodiesel per ton in the studied areas for all the biodiesel production process. The results is an insight to any investor who wishes to drive biodiesel production in Nigeria and the financial angle nonetheless presents greater performance opportunity (See Table 11) for net present value (NPV), internal rate of returns (IRR) and benefit-cost (B/C) ratio. These are important engineering/process financial measures of performance or investor's attractiveness in any industrial establishment especially involving demand and supply chains.

Table 7. *Jatropha Curcas* supply chain (seed production) regression model equations

Number of years of production	FRIN (tons)	Pauman resources (tons)	Biodiesel Nigeria Ltd (tons)
1	10	25	20
3	50	80	65
5	125	200	155
10 (projection) By Extrapolation	250	400	310
Regression model equations of seed production and supply			
Producers/suppliers	**Model equations**	**Equation type**	**Coefficient of determination (R^2)**
FRIN	$y = 21.3x^2 - 26.8x + 16.3$	Polynomial	0.9997
Pauman resources Ltd	$y = 36.3x^2 – 56.8x + 46.3$	Polynomial	0.9997
Biodiesel Nigeria Ltd	$y = 27.5x^2 – 41.5x + 35$	Polynomial	0.9996
Total case study	$y = -212.5x^2 + 907.5x – 260$	Polynomial	1

y = Quantity of optimized seeds produced; x = the number of years of production across ten years
R^2 = Coefficient of Determination (CoD) of equation

Table 8. Cost of produced *Jatropha* seeds @ $600 per ton (International price)

Number of years of production	FRIN cost of seeds (N)	Pauman resources (N)	Biodiesel Nigeria Ltd (N)
1	960,000	2,400,000	1,920,000
3	4,800,000	7,680,000	6,240,000
5	12,000,000	19,200,000	14,880,000
10 (projection) By Extrapolation	24,000,000	38,400,00	29,760,000

Source: Field Survey (2013)
Note: USD (cost in the international market) was converted to N160 per dollar

Table 9. Optimized cost of production and yields of *Jatropha Curcas* in Pauman resources limited

Hectares of land	Quantity of seeds produced			Optimized yield
	Yr I (tons)	Yr III (tons)	Yr V (tons)	Yr X (tons)
20	45	80	225	450
50	120	200	600	1200
100	250	400	1250	2500
160	420	640	2100	4200
Regression model equations of cost of production in biodiesel in tons				
Years of production	**Model equation**	**Equation type**	**Coefficient of determination (R^2)**	
Yr I	$y = 23.8x^2 + 6.8x = 13.8$	Polynomial	0.9997	
Yr III	$y = 30x^2 + 38x + 10$	Polynomial	0.9996	
Yr V	$y = 118.8x^2 – 33.8x + 68.8$	Polynomial	0.9999	
Yr X	$y = -237.5x^2 + 67.5x +138$	Polynomial	1	

y = Cost of production of biodiesel from Jatropha seeds; x = the yearly quantity of seeds from plantation across ten years; R2 = Coefficient of Determination (CoD) of equations

Table 10. Optimized production process and cost of JATROPHA biodiesel per ton in the studied area

Production process (per ton)	Pauman resources (Naira/tons)	Biodiesel Nigeria Ltd (tons)
Harvesting	20000	25000
Bagging/storage	15000	16000
Oil extraction	50000	60000
Oil refining	40,000	45000
Pre-treatment	25000	30000
Transesterification	50000	52000
Washing/recovery	10000	12000
Packaging	15000	20000
Total cost of production	225000	260000
Cost of biodiesel	*	*

*Source: Field Survey (2013). * is dependent on the producer's discretion, demands and supply as well in Nigeria. The price is elastic because the market is deterministic*

Table 11. Financial measures for evaluating the feasibility of investment in Jatropha cultivation

Projected years	Pauman resources limited			Biodiesel Nigeria limited			FRIN, Kano		
	NPV (Naira)	BCR	IRR (%)	NPV (Naira)	BCR	IRR (%)	NPV (Naira)	BCR	IRR (%)
Year 5	-12197	0.76	-5	22033	3.47	72	5105	1.19	24
Year 10	17461	1.23	20	61023	6.13	85	26853	1.63	42
Year 15	35876	1.39	24	85233	8.17	85	40358	1.75	44
Year 20	47310	1.47	25	100265	10.18	85	48743	1.81	45

4. CONCLUSION

In this work, simulation modeling and optimization of the supply chain of Nigerian *Jatropha curcas* feedstock for biodiesel production was carried out. Existing *Jatropha* production and processing facilities and their field work interaction were used as data information up to the final products for intermediate and final product distribution in internal and external markets. Numerical results show that the development of the biodiesel supply chain in Nigeria requires an increasing use of land for cultivation and cost-effective processing techniques to produce oil as main products and other bye products like glycerine to satisfy future domestic and external demands. The plantations used as case studies provided useful information for the modeling and simulation activities used in the study.

No existing models or studies in Nigeria have been found in literature and therefore the study focused on determining the viability of the feedstock and processing technologies, decision time frame, as well as levels of supply chain (upstream, midstream and downstream) in order to develop similar model with an easy to use graphical interface for the supply chain which was adopted in Arena software simulator. The model considered key supply chain activities including the feedstock harvesting/processing, transportation and storage. The model also used feedstock cost, production cost, production yields of seeds and biodiesel, demand and supply as system performance criteria.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Iakovou E, Karagiannidis A, Vlachos D, Toka A, Malamakis A. Waste biomass to-energy supply chain management: A critical synthesis. Waste Manag. 2010;30:1860 – 70.
2. Rentizelas AA, Tatsiopoulos IP, Tolis A. An optimization model for multi biomass tri-generation energy supply. Biomass and Bio-energy. 2009;33:223-33.
3. Sokhansanj S. Feedstock supply technologies: essential support for bio-based industries, Bioenergy feedstock program. Oak Ridge National Laboratory; 2000.
4. Arena Study Guide. Getting Started with Arena version 14. Rockwell Automation Publication PN-111648. 2012;1-199.
5. Fengli Z, Dana MJ, Mark AJ. Development of a simulation model of biomass supply chain for biofuels production. Renewable Energy. 2012;44:380–391.
6. Lancioni R, Schau HJ, Smith MF. Internet impacts on supply chain management. Journal of Industrial marketing Management. 2003;32(3):173–175.
7. Simchi-Levi D, Kaminsky P, Simchi-Levi E. Designing and managing the supply chain: concepts, strategies, and case studies, Irwin McGraw-Hill; 2000.
8. Aviso KB, Tan RR, Culaba AB. Designing eco-industrial water exchange Networks using fuzzy mathematical programming. Clean Technologies and Environmental Policy. 2010;12:353–363.
9. Tagaras G, Vlachos D. A periodic review inventory system with emergency replenishments. Management Science. 2001;47(3):415–429.
10. Gupta A, Whitman L, Agarwal RK. Supply Chain Decision Agent System. Paper presented at the Proceedings of the 2001 Winter Simulation Conference; 2001.
11. Rao VR. The *Jatropha* hype: promise and performance. In: Singh B, Swaminathan R, Ponraj V, editors. Biodiesel conference toward energy independence—focus of Jatropha. India: Hyderabad. 2006;16–20.
12. Hill J, Nelson E, Tilman D, Polasky S, Tiffany D. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. Proceedings of the National Academy of Sciences. 2006;103(30):11206–11210.
13. Liao ZW, Wu JT, Jiang BB, Wang JD, Yang YR. Design methodology for flexible multiple plant water networks. Industrial & Engineering Chemistry Research. 2007; 46(14):4954–4963.
14. Openshaw K. A review of *Jatropha curcas*: An oil plant of unfulfilled promise. Biomass Bioenergy. 2000;19:1–15.
15. Francis G, Edinger R, Becker K. A concept for simultaneous wasteland reclamation, fuel production, and socio-economic development in degraded areas in India: need, potential and perspectives of *Jatropha* plantations. Nat Resource Forum. 2005;29:12–24.
16. Foidl N, Foidl G, Sanchez M, Mittelbach M, Hackel S. *Jatropha curcas* L. as a source for the production of biofuel in Nicaragua. Bioresource Technology. 1996;58:77–82.
17. Hongtao L, Maréchal F, Burer M, Favrat D. Multi-objective optimization of an advanced combined cycle power plant including CO2 separation options. Energy. 2006;31:3117 -34.
18. Vogt WG, Mickle MH, Aldermashian H. A dynamic Leontief model for a productive system. Proc IEEE. 1975;63:438–43.

19. Lee YH, Cho MK, Kim SJ, Kim YB. Supply chain simulation with discrete continuous combined modeling. Computer and Industrial Engineering. 2002;43:375–392.
20. Chan FTS, Chan HK. Simulation modeling for comparative evaluation of supply chain management strategies. Journal of Advanced Manufacturing Technology. 2005;25:998–1006.
21. Zhang C, Zhang C. Design and simulation of demand information sharing in a supply chain. Simulation Modeling Practice and Theory. 2007;15:32–46.

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