Jatropha Curcas: A Viable Alternative Source of Clean Energy to Meet Sudan's Growing Energy Demand

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Abstract— **Jatropha (*Jatropha curcas*) is a plant native to Central America and is a source of oil and other by-products with commercial potential and economic value. Recent studies have shown that the oil from Jatropha seeds can be used for the production of biodiesel that meets the EN and ASTM biodiesel specification standards. Biofuel produced from *Jatropha curcas* can be used in a variety of ways to meet Sudan's energy demand, particularly in the rural areas. Such usages range from fuel derived from Jatropha seeds or pelleted seedcake, small-scale equipment suited to rural cooperatives for expelling oil, affordable engines and gensets that run on pure vegetable oil. Use of all of these can be important in helping to stimulate rural and regional economies by creating jobs and keeping money within the region, regardless of whether the Jatropha is grown on an industrial scale or as small-scale plantings. The purpose of this paper therefore, is to detail the processes and the expected outcome for biofuel production at a commercial scale in Sudan from *Jatropha curcas* oil feedstock. The paper covers issues of policy development, sustainability and economics that need to be addressed by Sudan authorities while taking this path toward sustainable biofuel production. The major source of information for the paper was the development of the Roadmap for Sudan Biofuels Production, with the biodiesel component likely to be sourced principally from Jatropha oil.**

Keywords- Jatropha curcas; Biofuel; Energy; Roadmap; Sudan .

I. INTRODUCTION

The use of fossil fuel and its associated by-products have posed a great threat to the planet which is currently grappling with the challenges caused by the increasing concentration of green house gases (GHG - particularly as carbon dioxide), and the resulting consequences of global warming, including increased hurricanes and typhoons and other extreme weather events. Thus; we have a desperate need for a shift towards green or lower GHG solutions in our way of life. It is widely agreed that the production of transport fuel from biomass, in either liquid or gas form, holds the promise of a lowered net fossil-energy requirement and lowered greenhouse gas (GHG) emissions [1]. However, the future scenario of biofuel production on a sustainable basis over the coming 30 years is not yet clearly defined. There are many important issues to be addressed, including but not limited to food security and land use competition, potential impacts of its production on water resources, biodiversity and other environmental aspects such as soil.

However, using non-food biomass feedstock such as *Jatropha curcas* could help to achieve sustainable, very low emission and cost-effective biofuels production through successful development of advanced biofuels technologies. In addition to fuel production, its scope entails a very significant stimulus to the economies of Sudan from creation of many permanent jobs from Jatropha oil production by small holders, and from use of the oil and Jatropha by-products for generating electricity and as a viable alternative for firewood and charcoal.

II. OVERVIEW OF ENERGY RESOURCES AND CONSUMPTION IN SUDAN

Sudan is one of the largest countries in Africa with a total area of 1,882,000 sq km, and it has a population of about 33.5 million (growth rate of 2.84% per year) [2]. Sudan's energy demand has significantly grown through the past 20 years from 6.8 Mtoe to more than 11.2 Mtoe [3]. Crude oil is the main source of fossil energy and its consumption has rapidly increased in recent years owing to the increase in the country's economic and population growth (Fig. 1). Biomass contribution has significantly dropped due to high growth in hydro and oil source. The main source of biomass is wood (83%) in the form of raw and processed wood (charcoal) which highly affects the green area and leads to deforestation in the country (Fig. 2) [3].

The transportation sector is the largest user of the refined fuel products, consuming about 61% from the total crude oil

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volume presently produced. The major fuel form used is diesel. It represents about 50% of the total fuel consumption, whilst gasoline and jet A1 represent 23% (Fig. 3, 4) [3, 4].

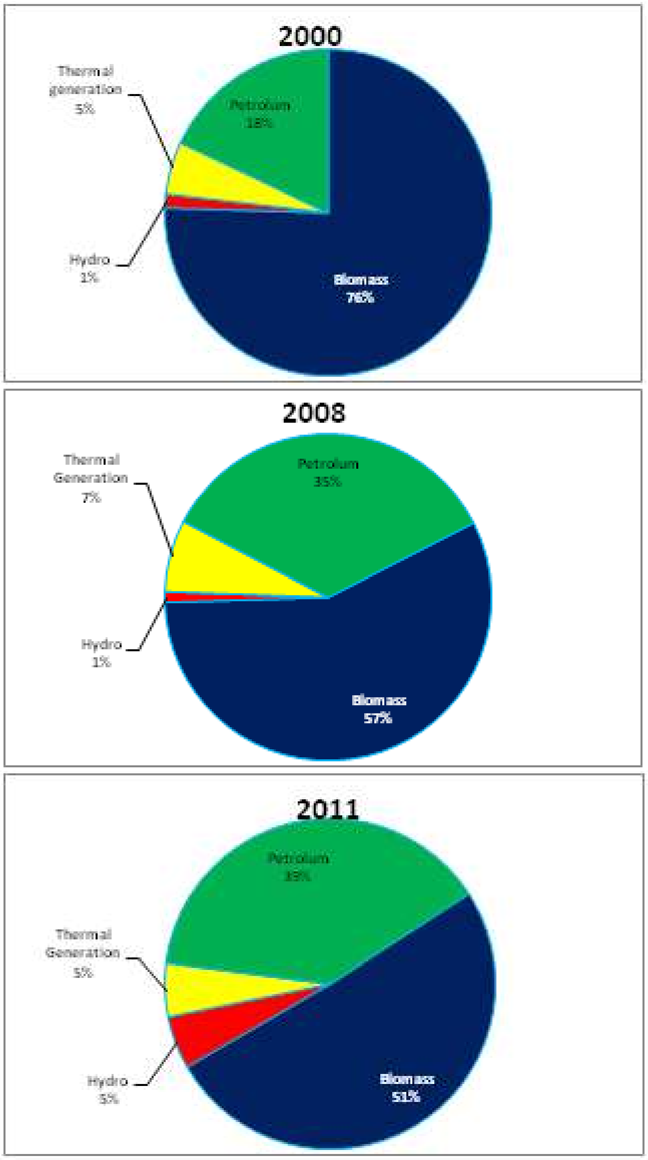

Fig. 1. Energy consumption by source (2000 -2011), Source: Ministry of petroleum, SPC

The secession of South Sudan in 2011 with most of the productive oil fields has left Sudan with sharply reduced oil volumes to export (previously the main source of export revenue). Petroleum product subsidies accounted for about 75% of tax revenues in 2011 and have been on the rise as a consequence of this secession and the related rise in petroleum products in the international market. In addition, South Sudan was the source of most of the fuel wood and charcoal used in households and industries (such as brick production) in the northern states and urban centers. Thus the secession of South Sudan also affected the biomass production and usage.

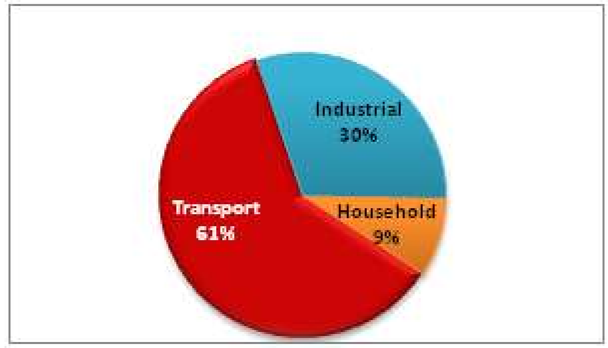

Fig. 2. Biomass consumption by source, Source: Ministry of petroleum, SPC

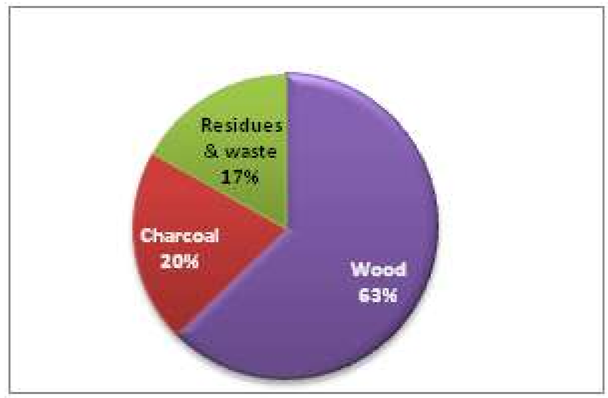

Fig. 3. Oil Consumption by sector, Source: Ministry of petroleum, SPC

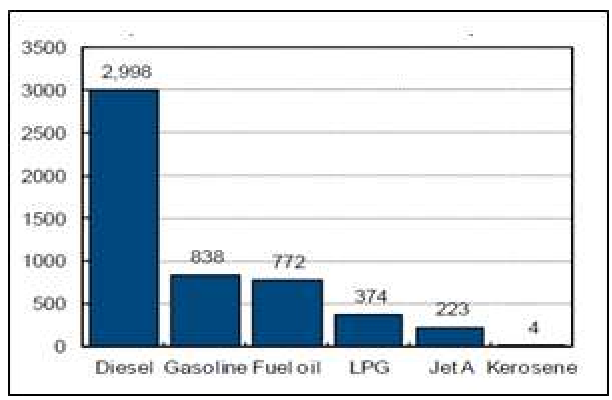

Fig. 4. Fuel Product Consumption in Sudan, 2012, (Thousands of metric tons), Source: IMF Country Report No. 12/299

III. The Potential and Development of Jatropha Curcas as a Source of Alternative Biofuels for Sudan

Jatropha curcas is a perennial plant native to Central America and West Asia, which yields multipurpose non-edible oil from its seeds. Its common name was physic nut or purging nut. *Jatropha curcas* belongs to the family Euphorbiaceae. The plant produces bitter latex and hence even goats do not browse the plant [5].

Jatropha curcas grows as a small tree or large shrub, up to 5–7m tall; with a soft wood and a life expectancy of up to 50 years. It can grow under a wide range of rainfall regimes from 250 to over 1200mm per annum. Jatropha prefers well-drained soils with good aeration and is well-adapted to marginal soil with low nutrient content. It sheds the leaves in dry season. In plantations it can be planted at spacing of 2m×2m, 2.5m×2.5 m, or 3m×3m depending on rainfall or watering [6].

Where evaporation rate is high and rainfall is low irrigation with adequate good quality water is necessary to allow good yields of seed. This irrigation can be by buried piping systems usually about 25-30 cm underground. This means that evaporation is minimised and it also means that fertiliser tailored to the plants needs can be added as required. Ability to irrigate jatropha plantations is likely to be needed for some parts of the year in all but the most southern or highest rainfall regions of Sudan. Where good irrigation supply is available a hot dry climate appears to be a positive for jatropha oil production, as pest insects and fungal diseases are far less of a problem in these conditions.

For large scale production of biodiesel from vegetable oils a major obstacle is the relatively low volumes of oil available per hectare from conventional annual crops such as sunflower, rapeseed or safflower. While oil palms are the highest yielding source at about 4 tons oil/ha, most vegetable oil yields are well under 1 ton oil/ha. In general, these crops require good arable soils, temperate climate and relatively high rainfall. It is this situation that explains the strong interest in oil-producing perennial or tree species like Jatropha, Castor, Pongamia, Croton and Neem, among others. Among these Jatropha has attracted the most attention and investment recently due to its perceived potentials to produce well in marginal sites with low and variable rainfall. With optimal management on good sites, Jatropha is now seen as having potential to produce the next highest yields (after the oil palm) at over 1.5 tons of oil per ha.

However, to get this sort of yield, intensive early pruning, genetically improved trees, good soil quality and depth and a well irrigated site and fertilizing program, are necessary conditions that must be attained for optimal yield of the Jatropha plant. Furthermore, the site has to be within the Jatropha plant's range of required conditions of average maximum summer temperatures and minimum winter temperatures, and have shelter from excessive wind or driven sand. Adequate pollinating insects, pest insect prevention and control are also needed for the good flowering, fruit development, and plant health respectively. Finally, the picking has to be done efficiently – as this process can constitute up to 80% of the variable costs. Overall, the pressed oil and seedcake must have a market value that well exceeds all the annual fixed and variable costs incurred (in addition to labour, interest on investment in land acquisition, seedlings, site establishment, and depreciation of capital equipment).

A. Biodiesel and Aviation Biofuel From Jatropha Oil

Jatropha oil is a triglyceride type of non-edible vegetable oil and in its pure form is a potential alternative to fossil diesel fuel. This is due to the fact that its methyl ester properties are similar to diesel fuel and also due to its plant origin its carbon content has been derived from the atmosphere, so it is considered a near-carbon-neutral fuel [7]. However, direct burning of Jatropha oil in a diesel engine faces many problems related to viscosity. This is due to the oil's high molecular weight (as well as its chemical structure) which is around ten times higher than that for diesel. Therefore, the reduction in viscosity is very important to make Jatropha oil a suitable alternative fuel far from diesel and this can be achieved by the trans-esterification process [5, 7].

The cost-effective large-scale production of biodiesel from non-edible oil feedstock such as Jatropha oil requires that free fatty acid (FFA) levels be below 1%, or if higher, that a highly effective system should be developed to deal with high FFA levels. In practice, while properly extracted Jatropha oil should normally have FFAs below 1%, it is not unusual for levels to rise due to a number of prevailing factors during the storage and transport phases [8]. In parallel with Sudan's Biofuel Roadmap, the process of production of biodiesel from Jatropha oil has been the subject of experimentation in the laboratory, and successful pre-treatment of high FFA percentages in Jatropha oil has been recorded, reducing these to less than 1%. With this low level of FFA a high yield of biodiesel was obtained and validated as complying with the international biodiesel standards specification (ASTM D6751). Table 2 shows a comparison between fuel properties of Jatropha oil, Jatropha methyl esters (JME) and ASTM D6751/EN 14214 specification [7], while Table 3 shows the Sudan-sourced Jatropha oil properties and the validation results of the laboratory experiments of the basic properties of the methyl ester of Sudan-sourced Jatropha oil according to ASTM D6751 [9].

TABLE I. COMPARISON BETWEEN FUEL PROPERTIES OF JATROPHA OIL, JATROPHA METHYL ESTERS AND ASTM D 6751/EN 14214 SPECIFICATION

Properties	Jatropha oil	JME	ASTM D 6751	EN 14214
Density at 15°C (kg/m^3)	917±1	879	875–900	860–900
Kinematic viscosity at 40°C (mm^2/s)	35.98±1.3	4.84	1.9–6.0	3.5–5.0
Acid value (mg KOH/g)	3.4-25.3	0.24	0.5 (Maximum)	0.5 (Maximum)
Flash point °C	229±4	191	130 (Maximum)	>101 (Minimum)
Cetane number	38	51	47 (Minimum)	51 (Maximum)
Sulfated ash	–	0.014 wt%	0.02 wt%	0.02 wt%
Water	5%	0.16mg/kg	0.05 mg/kg	0.05 mg/kg
Iodine number (g/100 g)	101.7	86.5	–	<120
Free glycerol	–	0.015 wt%	0.02 wt%	0.02 wt%
Total glycerol	–	0.088 wt%	0.25 wt%	0.24 wt%

TABLE II. FUEL PROPERTIES OF SUDAN JATROPHA OIL (CJO), AND SUDAN JATROPHA METHYL ESTERS (JME)

Property	Sudan CJO	Sudan JME	ASTM D 6751
Acid value (mgKOH/g)	8.99	0.36	0.5 (Maximum)
Viscosity@40ºC (mm^2/s)	41	4.71	3.5–5.0
Density @ 20ºC (g/cm^3)	0.918	0.874	-
Iodine value (mg I2/g)	103.87	97.94	-
Calorific value (MJ/Kg)	-	38	-
Total glycerol wt %	8.27	0.100	0.25
Free glycerol wt%	-	0.009	0.02

It has been found that carbon dioxide emissions can be decreased by 65-80% by using jet fuel from renewable feedstock such as *Jatropha curcas*, compared to petroleum-derived aviation kerosene [10]. The annual fuel consumption of the aviation industry worldwide is in the order of 1.5 to 1.7 billion barrels of traditional jet fuel, which contributes about 2% to the current global greenhouse gas (GHG) emissions. The International Air Transport Association (IATA) thinks a 6% share of sustainable 2nd generation biofuels is achievable by 2020. On the other hand, The European Advanced Biofuels Flight Path Initiative plans to use 2 million tons of biofuels in the EU civil aviation sector by 2020, while Boeing supports a target of 1% of global aviation fuels by 2015 [11]. The target of the Sudan Biofuel roadmap is to introduce a certified bio jet fuel by 2018, and for this aviation biofuel to have a share of the aviation fuel market by 2024 [12].

B. Commercial Uses of Jatropha By-Products

Interest in producing Jatropha curcas for oil production is growing in many countries. It is driven by the perceptions that Jatropha can grow and produce on land that is marginal for agriculture, the production of oil from Jatropha can both reduce imports of petroleum products and stimulate rural and regional economies, the plantings can be as a combination of industrial-scale plantings and small-holder plantings, and because there is potential for a number of different products from the oil and by-products.

A key aspect of production of Jatropha oil and for optimizing the economics of the industry is that there are a number of other products that need to be fully utilized. These include the seedcake and the glycerin by-product of the transesterification process used to convert the oil to biodiesel. Both these by-products will occur in large volume in industrial scale production and they each have multiple potential uses. The seedcake that elsewhere is simply returned to the plantation site as fertilizer, can be a feedstock for biogas production at smaller or larger scale, or may be compressed into pellets or briquettes to be a fuel for use in industry like bakeries or brick kilns, or in more efficient household stoves, displacing charcoal or wood.

The gross specific energy in each Jatropha biomass fraction compared with that of other biomass and fossil fuel is illustrated in Table III. (According to the specification of ASTM D5865-02a) [13]. While more trials need to be done on this, within a larger scale Jatropha industry there is potential that fuel made from Jatropha seedcake may significantly reduce deforestation or desertification driven by this constant high demand for wood and charcoal.

In addition to Jatropha-based biodiesel and Jatropha oil being used as a feedstock for production of jet engine biofuel, research and development have produced affordable household cook stoves that can work well when fuelled by Jatropha seed or pelleted seedcake, cost-effective systems for pelleting or briquetting seedcake, small-scale equipment suited to rural cooperatives for expelling oil, and affordable engines/gensets that will run on pure vegetable oil (Fig. 5). All these can stimulate rural and regional economies, as a combination of industrial-scale plantings and small-holder plantings [14].

By-products of biodiesel production can also be used to generate electricity. It is estimated that if Sudan is to produce enough biodiesel from Jatropha to replace even 5% of its diesel fuel (5% is about 150,000 tons) seedcake volumes will be very large. Production of 150,000 tone of biodiesel will require up to 625,000 tons of Jatropha seed, and so up to 437,000 tons of seedcake will be produced as a residue. In this form it has an energy value of about 5 megawatt-hour (MWh)/tonne, and could be used as a fuel in smaller or larger energy plants, including in combined heat and power plants. In total the 437,000 tons of seedcake have an approximate energy value of 2,185 gigawatt-hours (GWh), and if used as a fuel in efficient combined heat and power plants could produce about 87 MW of electricity annually (assuming about 5000 ton to produce a MW-e). These CHP plants could be of any size from 5 MW-e outputs to 20 MW-e capacities or more.

TABLE III. GROSS SPECIFIC ENERGY OF JATROPHA BIOMASS VS OTHER BIOMASS & FUEL (ASTM D5865-02A)

Biomass		Gross Specific Energy (Kcal/Kg)
Jatropha Biomass	Seedcake	4496
	Shell	3123
	Leaves	3624
Rice Husk		3000
Palm Shell		4200
Coal		5500

C. Potential for Rural Development and Empowerment

A Jatropha oil industry can help regional and rural communities become less reliant on imported fossil energy, gain better access to more reliable electricity supplies, develop small scale enterprises and reduce regional deforestation. The use of Jatropha pressed seedcake for biogas production, or for compression into briquettes for use as a fuel to substitute for firewood, are both possible and cost-competitive options. Another possibility is to use the seed seconds, husks, prunings or diseased trees to be a feedstock for gasification on small or large scale to produce electricity (Fig. 6). Clearly these options are possible for local or regional energy production. So any overall project strategy needs to look at the way regional communities will fit into a national Jatropha oil production industry, so that the outcome will positively impacts on regional economies as well as on smallholder and family incomes and health.

(a) (b)

Fig. 5. (a) Small jatropha oil extraction machinery being used in Zambia (b) Crude-jatropha-oil filtering systems in use in Zambia to produce oil clean enough for fuelling modified diesel motors (in pumps and generators and vehicles)

Fig. 6. An Indian-made 10 kW-e gasifier, designed to run on dry woody biomass (i.e., chunks of dried jatropha prunings)

D. The Role of Jatropha in deforestation and desertification

The climate of Sudan is classified as desert, semi-desert and dry in the utmost north. Only 11.7% of the total Sudan landmass is covered by forests and woodlands, with most of this forested area characterized by desert and semi-desert trees and shrubs. Desert encroachment is reportedly expanding southwards at up to 8km per year. Despite all these, firewood and charcoal remain the dominant cooking fuel with high consumption figures of 45% and 30% for firewood and charcoal respectively. Therefore, for Sudan to provide biomass and fully offset the rate of desertification, the estimate is that reforestation of about 1 million ha per year is required. Planting of Jatropha can play a part in this strategy, with the added benefit of offsetting the loss in forest area due to firewood removal and charcoal production, since Jatropha by-products serve as a very affordable and accessible alternative cooking fuel.

IV. Roadmap for Sudan Biofuels Production

Though Sudan is facing a suddenly change in the outlook for its fuel sector following the separation of the south, there has not been any detailed and developed biofuels policy. Therefore, an explicit, transparent, and integrated roadmap of biofuel development should be devised to guide and promote the development of biofuels production and availability in Sudan. The Aeronautical Research Centre in Sudan initiated the development of a National Roadmap for Sudan's biofuel production, based on using Jatropha oil as the main feedstock. This Roadmap will investigate the resources related to industrial scale production, detail the technology approaches of all stages of development, and schedule planning policies and incentives to industry within a specific timeline. It also will promote cooperation and development activities with local government, the public and smallholders. This latter part will focus on establishment of pilot Jatropha oil production projects in rural areas to demonstrate greater energy self-sufficiency and the benefits of this to rural economies, as well as better utilization of available forms of biomass for energy production. This roadmap should contribute to national energy security and reduce Sudan's GHG emissions contributing to global warming and climate change. It should provide specific detail for agricultural production of biofuels feedstock and for infrastructure optimization solutions. An effective biofuels policy has the potential to reduce the problems presently facing agriculture, rural areas and farmers.

A. Economic and Logistical Issues

Obviously, to enter into large scale production of Jatropha oil; any scheme or project needs to be revenue-positive over time for investors. Any investment on the scale needed may expect net annual return from year four (i.e., income to the project after all costs and interest on investment for that year) to be positive, so that by year 10 all initial investment is paid off. Hence any overview of the economic and logistical aspects of the project must assess the realistic return on the investment, through making certain assumptions of costs, yields, etc.

The assumption made is that Sudan will produce enough biodiesel to provide adequate volume for a 5% blend with current fossil diesel use. This equates to needing 150,000 tons of biodiesel. At a yield of 5 ton of seed per hectare and recovered oil yield of 35% this will require about 125,000 hectare of plantings, with a processing plant for every 5,000 -10,000 hectare to allow necessary economies of scale in the pressing plant. While preparation and establishment of the sites will be up to $3000/hectare, the first years of any site will also produce no net income until perhaps year three or four.

Manual harvesting will require a very large workforce from year 4 onwards. At a harvesting rate of 50kg/person/day, to harvest 1 hectare (5 tons) in a day requires 100 people. At this manual harvesting rate 5000 people would take about 100 days to harvest the seed of 5000 hectare (25,000 tons). The daily transportation of 5000 people will take a fleet of perhaps 100 trucks or buses. Each site will possibly be requiring harvest at the same time and this affect the moving of the harvest teams from site to site. Obviously, a mechanical or more efficient manual harvesting systems need to be urgently developed.

The transportation of the estimated 25,000 ton of seed from each 5000 hectare of plantings will require 2,500 return truck loads (assuming 10-ton capacity), over a return distance of about 100 km, so entailing truck travel distance total of 250,000 km per harvest. Assuming at least 50,000 tons of seed being processed at any one pressing plant the same or other trucks will be engaged in moving about 35,000 ton of seedcake from this plant to some other site, and 15,000 ton of Jatropha oil to a central processing plant.

Therefore, for a successful implementation of a Biofuels production in Sudan, the following policy issues must be in place for a successful introduction of Biofuels:

- Legislation should be in place mandating a set blending ratio (usually 5-10%)
- subsidies on fuel should be replaced with more effective measures, so that the country can be more in line with trading partners but poor citizens or rural populations not to be economically disadvantaged
- distribution and storage issues need to be resolved to maintain adequate supply and high quality
- quality and blending ratio of fuels need to be constantly monitored by a competent testing authority
- introduction of incentives for vehicles able to run on higher proportions of biofuel need to be considered
- issues of excise or tax need to be resolved so that the biofuel is able to compete in price
- the possibility of using excess revenue raised on fossil fuel to cross-subsidized biofuels
- the industry – distributors, refiners and major users - must be supportive and part of the process from the beginning and not be financially negatively affected
- neighbouring countries need to be encouraged to develop common polices on pricing and blending to prevent cross border smuggling and to allow transport vehicles to run between countries with no fuel grade or quality issues.

B. Sustainability

Ensuring the sustainability of a biomass feedstock-to biofuel system requires an integrated assessment of the economic, environmental and social dimensions [15]. The genuine sustainability of the overall large scale production of Jatropha oil is important, not only because of its positive or negative impacts within Sudan, but also because being able to qualify for an internationally recognised certification of sustainability means that crude Jatropha oil can be sold into the international market to the many buyers seeking a large, reliable and certified-sustainable source of supply.

Within the Roadmap, in addition to the detailing of the biodiesel production from Jatropha to accord with these sustainability criteria, is the awareness that the planting of vast areas of a Jatropha monoculture comes with inherent risks. These include: risk of negative impact on the labour pools in regional areas; on water availability for food crops or over-use of water from aquifers meaning inadequate long-term irrigation flows; of the possibility of insect pests or fungal disease impacting the viability of whole plantations and decrease in final yields due to lack of development of management best practice. While these risks or issues may not make the Jatropha oil or biodiesel production fail the criteria of environmental sustainability, they would certainly have the capacity to affect economic sustainability or social sustainability of the whole venture.

V. Conclusion

Sudan has a steadily increasing requirement for fossil diesel for both transport and generation of electricity in regional areas beyond the national electricity grid. There is a growing awareness that biodiesel produced in Sudan could be blended with the available fossil diesel, resulting in many positive economic, social and environmental benefits. While in Sudan biodiesel is presently only being produced in small trial amounts, one strong reason to look at increasing this is to help reduce deforestation, by the substitution of very significant volumes of biodiesel production byproducts for wood and charcoal. At present, while transportation sector is the largest user of the refined fuel products, consuming about 61% from the total crude oil volume, biomass makes up the largest source of Sudan's primary energy, and according to recent reports provides about 51% of total energy needs. This is mostly as wood and charcoal, used mainly for cooking and providing industrial heat (bakeries, brickworks, etc), and chiefly sourced from forest clearance (so causing extensive deforestation) and as agricultural residues.

Though Sudan is facing a suddenly change in the outlook for its fuel sector following the separation of the south there has not been any detailed biofuels policy developed. Therefore the Aeronautical Research Centre in Sudan initiated the development of a National Roadmap for Sudan's biofuel production, based on using jatropha oil as the main feedstock to guide and promote the development of biofuels production and availability in Sudan.

The process of formulation of the Roadmap investigated the resource requirements and other issues related to industrial scale production, details of the technology approaches of all stages of development, and schedule planning policies and incentives to industry within a specific timeline. The Roadmap addressed the potential of Jatropha oil for biodiesel production for transportation sector, jet fuel for aviation sector and better utilization of available forms of biodiesel byproducts for regional energy production. A key part of this is the use of the very large potential volumes of jatropha by-products (mainly jatropha seedcake) as a source of energy to substitute the use of wood and charcoal in households and industry, or as a feedstock for biogas production at smaller or larger scale. The glycerin by-product of the transesterification process used to convert the oil to biodiesel will occur in large volume in industrial scale production and have multiple potential uses.

This Roadmap has the potential to significantly contribute to national energy security and reduce Sudan's GHG emissions, so helping to mitigate global warming and consequent climate change. It has the objective of providing specific detail for production of biofuels from agricultural feedstock, and of infrastructure optimization solutions. An effective biofuels policy has the potential to reduce the problems currently facing energy production, agriculture, rural areas and farmers. In a scenario of global warming lifting average annual temperature by over 2 ^{0}C, agriculture and all other aspects of life in Sudan would be significantly negatively affected, to the country's great cost.

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REFERENCES

[1] IEA (International Energy Agency) (2011), *Biofuels for Transport Technology Roadmap*, OECD/IEA, Paris, Retrieved October 19, 2012 from the IEA Web Page:

http://www.iea.org/publications/freepublications/publication/biofuels_roadmap.pdf

[2] Ministry of Information, "Sudan, the land of opportunities", July 2011, ISBN 233/2011.

[3] Ministry of petroleum, Sudanese Petroleum Corporation (SPC), Data of 2012.

[4] International Monetary Fund, (2012). Sudan: Selected Issues Paper. *IMF Country Report No. 12/299*, Retrieved December 21, 2012 from the World Wide Web: http://www.imf.org/external/pubs/ft/scr/2012/cr12299.pdf.

[5] A.E. Atabani, A.S. Silitonga, Irfan Anjum Badruddin, T.M.I. Mahlia, H.H. Masjuki, S. Mekhilef. A comprehensive review on biodiesel as an alternative energy resource and its characteristics 2012 16: p. 2070– 2093.

[6] Divakara BN, Upadhyaya HD, Wani SP, Gowda CLL. Biology and genetic improvement of Jatropha curcas L.: a review. Applied Energy 2010; 87(3):732–42.

[7] A.S. Silitonga, A.E. Atabani, Irfan Anjum Badruddin, T.M.I. Mahlia, H.H. Masjuki, A S. Mekhilef. Review on prospect of Jatropha curcas for biodiesel in Indonesia; Renewable and Sustainable Energy Reviews 2011.15: p. 3733–3756.

[8] Meher, L.C., D. Vidya Sagar, and S.N. Naik, Technical aspects of biodiesel production by transesterification—a review. Renewable and Sustainable Energy Reviews, 2006. 10(3): p. 248-268.

[9] Hazir Farouk Abdelraheem, Mohammad Nazri, Tirto Prakoso, Sabir Mohammed. 2013. Biodiesel Production from Crude Jatropha Oil (CJO) in Pilot Plant. In *Proceeding of Fourth International Graduate Conference*. University Technology Malaysia, Johor, Malaysia. 16-17 April 2013.

[10] James D. Kinder and Timothy Rahmes (2009). Evaluation of Bio-Derived Synthetic Paraffinic Kerosene (Bio-SPK). *Sustainable Biofuels Research & Technology Program*, The Boeing Company, Retrieved February 15, 2013 from the Boeing Web Page: http://www.boeing.com/commercial/environment/pdf/PAS_biofuel_Exec_Summary.pdf.

[11] IATA ETS (2013). EU Emissions Trading Scheme - A World of Difference. *IATA press release*, Retrieved February 15, 2013 from the IATA Web Page: http://www.iata.org/publications/airlinesinternational/june-2012/Pages/eu-emissions.aspx

[12] Aeronautical Research Centre strategic plan, 2012-2016.

[13] Biopellet Production from Jatropha Seedcake –Emission Reduction, windililiana, Dwi setyaningsihIrzaman. Presented On: International Sustainable Development Research Conference30may –1 June 2010, Hong Kong.

[14] Andrew Lang, Hazir Farouk. (2013*). Jatropha oil production for biodiesel and other products – a study of issues involved in production at large scale*. Aeronautical Research Center-Sudan, World Bioenergy Association, Stockholm, Sweden.

[15] Aziz Elbehri, Anna Segerstedt, Pascal Liu 2013. Biofuels and the Sustainability Challenge: A global assessment of sustainability issues, trends and policies for biofuels and related feedstocks. Food and Agriculture Organization of the United Nations, Rome.