Biofuel initiatives in West Africa and the Sahel: potential for success

L. POPOOLA[1], M. LARWANOU[2] and S.O. JIMOH[3]

[1]Centre For Sustainable Development, University of Ibadan, Ibadan, Nigeria
[2]African Forest Forum (AFF), C/o World Agroforestry Centre (ICRAF), United Nations Avenue P.O. Box 30677 - 00100, Nairobi, Kenya
[3]Department of Forest Resources Management, University of Ibadan, Nigeria

Email: labopopoola@yahoo.com, l.popoola@ui.edu.ng, m.larwanou@cgiar.org and jimohsaka@yahoo.com

SUMMARY

Global warming has heightened the need to substitute fossil fuels with biomass-based energy sources. Some West African countries have recorded appreciable progress in this regard though with inadequate documentation. This study documents the extent of production and use of different biofuels and incentives for sustainability in the sub-region. Field visits were conducted in Benin, Ghana, Niger and Nigeria with the aid of structured questionnaire and focus group discussions; and literature search in Mali, Niger and Senegal to assess current scenarios. Biofuel crop production (jatropha, cassava and sugarcane) is on the rise, howbeit, with foreign investments. That cassava and sugarcane are important staples in the sub-region constitutes a possible hindrance to their adoption, arising from food crisis currently being experienced there. Jatropha appears the most appropriate potential species. There is the need for enabling policies to enhance the optimum production and utilization of Jatropha for biofuel production in the sub-region.

Keywords: global warming, biofuel, biofuel crops, Jatropha, fossil fuel

Initiatives en biocarburants dans l'Afrique de l'ouest et dans le Sahel: succès potentiels

L. POPOOLA, M. LARWANOU et S.O. JIMOH

L'effet serre a rendu plus pressant le besoin de substituer des sources d'énergie basées sur la biomasse aux combustibles fossiles. Certains pays de l'Afrique de l'ouest ont enregistré des progrès notables à cet égard, bien que la documentation en soit inadéquate. Cette étude documente l'étendue de la production et de l'utilisation de différents biocarburants, et des mesures incitatives à leur durabilité dans la région inférieure. Des visites sur le terrain ont été effectuées au Bénin, au Ghana, au Niger et au Nigéria, avec l'assistance d'un questionnaire structuré et de groupes de discussion, ainsi qu'avec une recherche dans la littérature du Mali, du Niger et du Sénégal, pour évaluer les scénarios actuels. La récolte de biocarburants (jatropha, cassave et canne à sucre) est en augmentation, mais, il faut le noter, avec l'aide d'investissements étrangers. Le fait que la cassave et la canne à sucre soient des denrées vitales importantes dans la région inférieure est un facteur restreignant leur adoption, du fait de la crise alimentaire actuellement vécue dans cette région. Des politiques de facilitation sont nécessaires pour améliorer l'utilisation et une production optimale de la jatropha en tant que génératrice de biocarburant dans la région inférieure de l'Afrique de l'ouest.

Iniciativas de biocombustibles en África Occidental y el Sahel: potencial de éxito

L. POPOOLA, M. LARWANOU y. S.O. JIMOH

El calentamiento global ha aumentado la necesidad de sustituir los combustibles fósiles por fuentes de energía procedentes de la biomasa. Algunos países de África Occidental han registrado progresos notables en este sentido, aunque inadecuadamente documentados. Este estudio documenta la magnitud de la producción y el uso de varios biocombustibles e incentivos para la sostenibilidad de la subregión. Se realizaron visitas de campo en Benín, Ghana, Níger y Nigeria, apoyadas por encuestas estructuradas y discusiones de grupos focales y una búsqueda bibliográfica en Malí, Níger y Senegal para evaluar los escenarios actuales. La producción de cultivos para biocombustible (jatropha, yuca y caña de azúcar) está en aumento, aunque debido a inversiones extranjeras. El hecho de que la yuca y la caña de azúcar sean alimentos básicos importantes en la subregión constituye un posible obstáculo para su adopción, a raíz de la crisis alimentaria que se vive allí en la actualidad. *Jatropha* parece ser la especie potencialmente más apropiada. Existe una necesidad de políticas favorables para la mejora de la producción y la utilización óptima de *Jatropha* con fines de producción de biocombustibles en la subregión.

INTRODUCTION

Since the energy crisis of the 1970s, developing new energy sources from the agricultural sector has been viewed as an important option for expanding energy supply and mitigating growing dependence on fossil fuels which is characterised by greenhouse gases emission in many developing countries (Akande and Olorunfemi 2009). In the same vein, biofuels have been attracting increasing attention worldwide in the last few years as substitutes for fossil fuels in order to address energy cost, energy security as well as global warming concerns associated with the use of fossil fuels (UNCTAD 2008 and Ambali *et al.* 2011).

The term biofuel has been used to mean any liquid fuel made from plant materials that can be used as a substitute for petroleum-derived fuel (UNCTAD 2008, FARA 2010, Ambali *et al.* 2011 and Van Zyl *et al.* 2011). Biofuels may include relatively familiar energy sources, such as ethanol made from sugar cane or diesel-like fuel made from soybean or Jatropha oil, to less familiar ones such as dimethyl ether (DME) or Fischer-Tropsch Liquids (FTL) made from lingo-cellulosic or woody biomass (UNCTAD 2008 and Van Zyl *et al.* 2011). Biofuel production in commercial quantities is at the infancy stage in many West African countries. According to FARA (2010), the production of bio-energy crops will need to take into account a broader understanding of the extent of the issues and concerns surrounding food to bio-energy conversion as well as the accompanying policy/institutional dimensions as inputs to the development of appropriate and truly responsive food and bio-energy programmes in developing economies. The substitutability of various biofuels for common petroleum-derived fuels has been examined by UNCTAD (2008).

The production of energy from biomass involves a range of technologies that include solid combustion, gasification, and fermentation. These technologies produce liquid and gas fuels from various biological resources, which include traditional crops (sugar cane, maize, oilseeds), crop residues and waste (maize stalk, wheat straw, rice hull, cotton waste), energy-dedicated crops (e.g. *Jatropha curcas*) and the organic component of urban wastes (Akande and Olorunfemi 2009, Ambali *et al.* 2011 and Van Zyl *et al.* 2011). The outcomes are bioenergy products that provide multiple energy services such as cooking fuels, heat, electricity, and transportation fuels. It is this very diversity that provides potential of a win-win development path for the environment, social and economic development, and energy security (EU 2006).

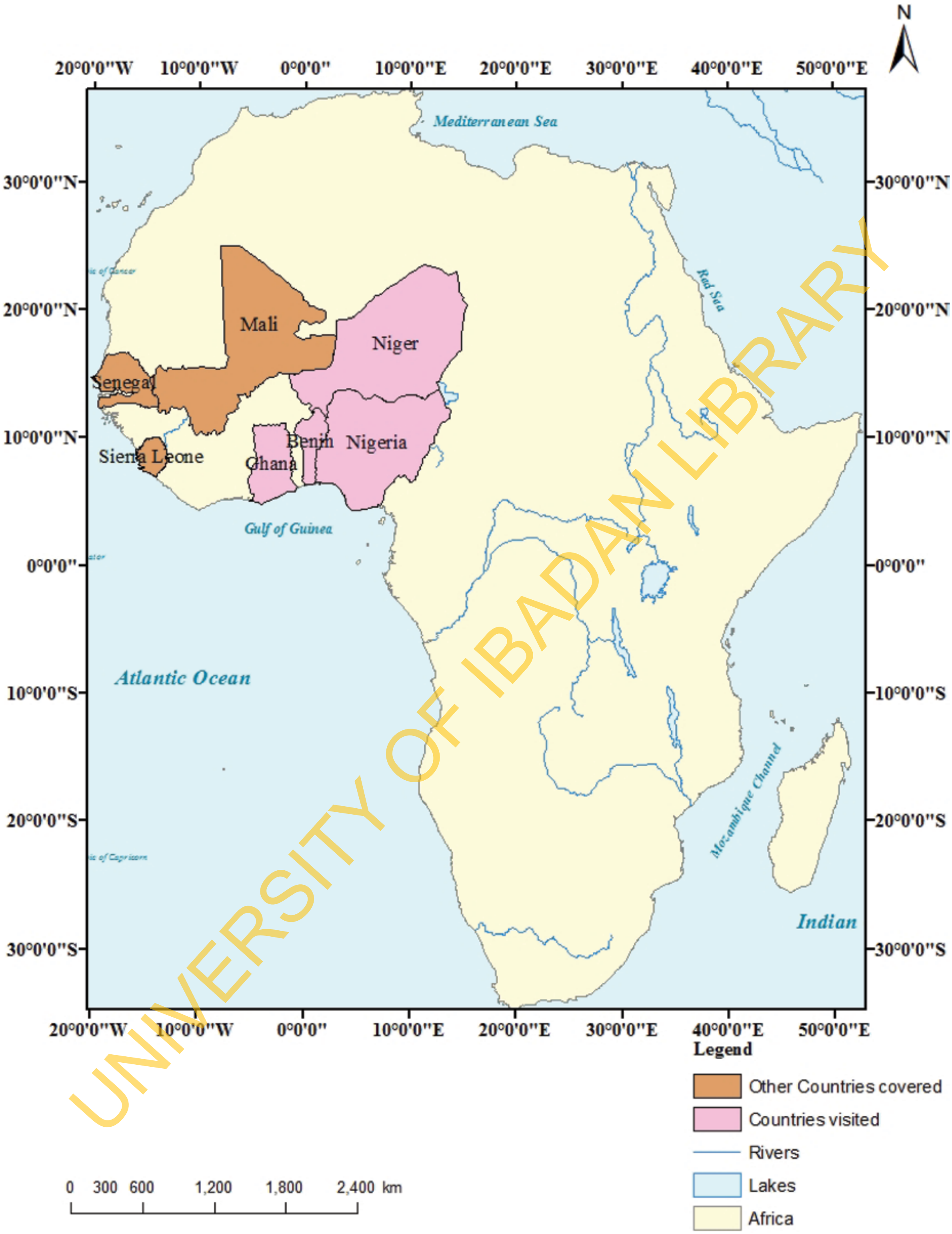
Many industrialized countries are already pursuing the expansion of, or development of new biofuels industries for the transport sector, and there is growing interest in many developing countries for modernizing the use of biomass and providing greater access to clean liquid fuels. Biofuels may be of special interest in many developing countries for several reasons: climate scenarios in many of the countries are well suited to growing biomass; biomass production being inherently rural and labour-intensive, and thus may offer the prospects for new employment in regions where the majority of populations typically reside. Also, restoration of degraded lands through biomass-energy production may be an impetus in some areas. The potential for generating rural income by production of high-value products (such as liquid fuels) is attractive. Equally appealing is the potential for export of fuels to industrialized-country markets. In addition, the potential for reducing greenhouse gas emissions may provide an opportunity for monetizing avoided emissions of carbon through implementation of Clean Development Mechanism (CDM) projects (Ambali *et al.* 2011).

Expansion of biofuel production and use, however, raises some concerns, the most important among, which may be diversion of land away from production of food, fibre and preservation of biodiversity or for other important purposes. Added pressure on water resources for growing biofuel feedstocks is also of concern, especially in the arid regions (UNCTAD 2008). Considering the fact that many developing countries are not yet food secured, there has been concern from many quarters that there would be competition between biofuel production and food security if those crops are considered for biofuel generation. In addition, fears of possible shift from agricultural production to biofuel crop cultivation on previous agricultural farmlands have also been expressed in many countries. To this end, some West African countries have supported the production of biofuels mainly from non-edible crops such as *Jatropha curcas* (Jatropha) and *Azadirachta indica* (neem tree). In recent times, there have been much effort and investments towards the production of green energy for a safe environment. It is common knowledge that many developed and advanced countries of the world have made ground-breaking contributions in this regard, most of which are already in the public domain. Although efforts have been made in some African countries in the production of biofuels, the information on these only exists in scattered literature. For now, not much is known about activities regarding biofuel production and consumption. There is therefore, dearth of knowledge on the potential and conditions for increased biofuel production in theWest Africa sub-region. Such knowledge is very important as a basis for enunciating appropriate national and regional policies on sustainable production of bioenergy. The objective of this study therefore, was to assess and document the extent of production, utilization and potentials for increased and sustained production of different biofuels in West Africa and the Sahel.

METHODOLOGY

The study was carried out in West Africa. Using a combination of purposive and random sampling, seven countries were covered through literature review. They are: Nigeria, Ghana, Benin, Senegal, Niger, Mali and Sierra Leone. The countries were selected based on the availability of data, their ecology and the production and market potential for biofuels. For more intensive studies, four countries (Benin, Ghana, Niger and Nigeria) were visited (Figure 1). Different parts, covering all geo-political zones/regions and settlement types (rural, peri-urban and urban areas) of the four visited countries were sampled using structured questionnaire, which captured such

FIGURE 1 *Map of Africa showing the studied countries in West Africa*



issues as biofuel feedstock production, processing and consumption. Focus Group Discussions were also organized in several communities within the countries to ensure the gathering of as much useful information as possible on the subject matter. Details of the countries (with communities) covered are presented in Table 1.

RESULTS AND DISCUSSION

There was evidence of current production of biofuels in at least five countries including: Benin Republic, Ghana, Nigeria, Mali and Senegal while there was sufficient awareness and prospect in the other countries to embrace the production and

TABLE 1 *West African countries and localities visited during the studies*

Countries	Geo-political zones/regions	State/Province covered	Site visited
Nigeria	South-west (*Dry High and Moist Forest*)	Oyo Lagos/Ogun Ondo	Eruwa/Olokemeji, Ibadan Lagos, Ikorodu, Sagamu Ondo/Ore, Akure, Akoko/Owo
	South-south *(Moist Forest & Mangroves)*	Cross River, Delta	Calabar, Oban axis, Ikom axis Asaba, Abraka/Ugheli axis, Warri
	South-east *(Moist Forest)*	Enugu	Enugu, Nsukka, Obolo-afo
	North- central *(Derived Savanna/Savanna)*	Kwara Kaduna Benue	Ilorin, Omuaran, Offa Kaduna, Zaria Makurdi, otukpo and Oju
	North-west (*Sahel*)	Kano Sokoto Katsina	Kano, Sokoto, Katsina,
Ghana	Great Accra, Central & Western *(Moist Forest)*	Accra	Accra, Cape coast, Sekondi
	Ashanti, Brong-Ahafo& Volta *Dry high/Moist Forest)*	Ashanti	Kumasi, Sunyani, Agogo
	Northern, Upper West *(Savanna/Sahel)*	Tamale	Tamale, Wa, Bolgatanga
Niger	Agadez *(Sahel)*		-
	Maradi *(Sahel)*		Maradi, Zinder Tanout
Benin	Litoral, Mono, Antkaligu *(Moist Forest)*		Cotonou, Port-Novo, Lokossa
	Borgou& Donga *(Derived Savanna)*		Parakou, Djougou, Ndali
	Atakora, Alibori *(Savanna)*		Guene, Founogo, Banikoara

utilization of biofuels. Details of country-specific current levels of production and consumption; and future potentials are presented in the following sections.

Benin

In Benin, the main liquid biofuels used are bioethanol produced from sugar cane and cassava, and biodiesel produced from Jatropha. Bio-ethanol is used in the Sudano-Guinean zone, while biodiesel is used in both climatic zones. The extent of land area used for biofuel production currently in Benin includes: 11420 ha for bio-ethanol and 55 ha for biodiesel. The crops used for biofuel production in Benin are sugar cane, cassava and Jatropha. However, the country's biofuel policy supports production from four other sources, which include corn, soybean, oil palm, sorghum. Details of the land areas used for the cultivation of the biofuel crops and the associated previous uses are presented in Table 2.

Biofuel, biodiesel and bioethanol are used for electricity generation in Benin without any combination with fossil fuels. The extent of the available land (in hectares) for further production of biofuels is as presented in Table 3.

The currentproduction and consumptionof each biofuel type in the country is shown in Table 4. Similarly, the potential for future production and the projected consumption of each of the biofuel types are presented in Tables 5 and 6, respectively. The projections for future consumption were made based on the current production and consumption as well as the country's population growth rate of 2.88% (Government of Benin 2012 estimates). It was not possible to quantify the current production and consumption of fossil fuel component (Diesel, Petrol and Kerosene)in Benin because these products were mostly illegally traded by local people. Worse still, most of it (80%) is smuggled into the country from Nigeria (IMF 2012), since the country is not a producerof fossil fuel.

TABLE 2 *Land area used for cultivation of biofuel crops and their previous uses*

Agro-ecological zone	Crop	Land area (ha)	Previous uses
Sudano-Guinean	Cassava	5420	Fields and fallows
Sudano-Guinean	Sugar cane	6000	Forest and fallows
Sudano-Guinean	Jatropha	25	Fields and fallows
Guinean zone	Jatropha	30	Fields and fallows

TABLE 3 *Extent of the available land area for further production of biofuels in Benin*

S/N	Crop	Land area (ha)
Sudano-Guinean zone	Cassava	260000
Sudano-Guinean zone	sugar cane	10000
Sudano-Guinean zone	Jatropha	1000
Guinean zone	Jatropha	800

Ghana

In Ghana, a draft bio-energy policy was made in 2010, which aims to supplement national petroleum fuel consumption with up to 10% biofuel by 2020 and 20% by 2030. The policy intends to make use of the country's vast biomass potential and resources in modern applications for the production of transport fuels and electricity generation. Biomass already dominates the energy consumption pattern in Ghana, accounting for over 63% of total energy consumed (Kemausour *et al.* 2011), but used mainly in traditional cook-stoves as fuel-wood and charcoal.

Liquid biofuel uses are not commercialised in the country but there are plans to begin commercial production as soon as the infrastructure is in place. Plans for biodiesel production are at a more advanced stage as opposed to those for ethanol production. The draft bio-energy policy is open to the commercial-scale production of biofuel feedstock to sustain supply but it is not targeting any specific energy crop(s) to meet the demand targets. The interest of the Ghanaian government in promoting the cultivation and use of Jatropha for biodiesel production is based on the plant's ability to grow in a wide range of environments, and also the potential to

TABLE 4 *Current production and Consumption of each of the biofuel types in Benin*

Biofuel type	Current production (tonnes)	Current production (litres)	Current consumption (tonnes)	Current consumption (litres)
Biodiesel	N/A	250	N/A	250
Ethanol	15000	N/A	2 510	-

N/A = Not Applicable

TABLE 5 *Projected Production of each o=f the biofuel types in the next 5 and 10 years Benin*

Biofuel type	Production in the next 5 years (tonnes)	Production in the next 5 years (litres)	Production in the next 10 years (tonnes)	Production in the next 10 years (litres)
Biodiesel	N/A	600	N/A	2000
Ethanol	30000	N/A	100000	N/A

TABLE 6 *Projected Consumption of each of the biofuel types in the next five and 10 years*

Biofuel type	Consumption in the next 5 years (tonnes)	Consumption in the next 5 years (litres)	Consumption in the next 10 years (tonnes)	Consumption in the next 10 years (litres)
Biodiesel	N/A	600	N/A	2000
Ethanol	5020	N/A	5050	N/A

create jobs for a large number of people (Ahiataku-Togobo and Ofosu-Ahenkorah 2009). Jatropha oil is utilised to power multi-functional platforms (MFPs) driven by diesel engines, mostly by women for the improvement of their livelihoods. The oil is also used in soap making, mostly in some rural communities in the three northern regions (Duku *et al.* 2011).

The available plants that are suitable for the production of biofuels in Ghana include oil palm, coconut, groundnut, Shea nut, Jatropha, sugarcane and cassava. Currently, Ghana places emphasis on the development of Jatropha as feedstock for biodiesel production. Ghana has a suitable climate for Jatropha plantations and the government has developed a plan for its production. The production cost of biodiesel from Jatropha in Ghana is estimated at US$460 per tonne of oil equivalent (i.e. 8% higher than the price of imported petroleum diesel). Local biofuel industry and a series of small-scale initiatives are stimulated and supported in Ghana. For example, the government has created a fund of 15 billion Cedis (7.5 billion US$) for the development of Jatropha plantations across the country. Some three billion Cedis (1.5 billion US$) have been allocated to the production of seeds and seedlings, and the remaining 12 billion Cedis (6 billion US$) are available at banks for organisations interested in the cultivation of Jatropha (Grados and Janssen 2008). Also, in 2006, quality seeds were made available for the cultivation of about 2500 ha of land and the government ensured that by 2007 seeds were available to cultivate 5000 ha of land. Community-Based Rural Development Projects (CBRDP) made available, a five million US$ fund managed by the Natural Resources Management component of the CBRDP. This fund addresses the rehabilitation of degraded ecosystems, thereby providing opportunities also for Jatropha projects due to their positive impact on soil erosion (Grados and Janssen 2008).

A portion of uncultivated arable agricultural land in Ghana is dedicated to cultivating four potential energy crops identified (maize, cassava, oil palm and sweet sorghum). Besides being the most cultivated bio-energy crops in terms of land area, Ghanaian farmers are familiar with their cultivation and the crops are also well suited to the climatic and soil conditions in Ghana. With regards to sorghum, it is expected that the "sweet sorghum" variety will be cultivated for energy crop purposes. In 2010, approximately 2480 ha of land was dedicated to these four crops in Ghana. Of this amount, maize and cassava constituteabout 75%.

Public awareness and education on biofuel production and consumption in Ghana is on the rise and this has contributed immensely to several individuals and corporate organizations initiatives to undertake to cultivate Jatropha and extract oil. More importantly, the price of Jatropha-based oil being more affordable than fossil fuel has encouraged production and utilization of the former. Table 7 shows comparative prices of Jatropha-based oil and petroleum products in Ghana in US dollars while Table 8 shows the extent of cultivation of Jatropha plans in the country.

Though 425 706 ha of land is already under Jatropha cultivation in various parts of Ghana, it is important to state that there is still several millions of hectares of land lying fallow

TABLE 7 *Comparative prices of Jatropha-based oils and petroleum products*

Product Jatropha oil versus kerosene	Price (US$/litre)
1. Jatropha oil	0.07
2. Kerosene ex-refinery	0.61
3. Kerosene ex-pump	0.82
Jatropha-based Biodiesel versus Petroleum Diesel	
1. Biodiesel	0.78
2. Gas oil ex-refinery	0.62
3. Gas oil ex-pump	0.97
4. Gas oil Import Parity	0.67

Source: Hagan (2007)

in the three northern regions and some parts of the Brong Ahafo Region as revealed in this study. This may be used to expand Jatropha plant cultivation and the extraction of Jatropha oils, which can subsequently complement fossil fuel in due course.

A number of biofuel initiatives have evolved in Ghana over the years. They include Anuanom Industrial Bio Product Ltd. (AIBP) was the first company to build Jatropha oil processing factory in Ghana. As at 2005, AIBP had installed a 500-tonne plant for processing Jatropha seed oil into biodiesel. The company also installed a 2000-tonne equipment for producing organic fertilizer from by-products of biodiesel and or seed-cake. Biodiesel 1, Ghana Ltd. also installed a Jatropha processing plant which, processes 2000 tonnes of seeds per month. New Energy, Ghana has installed Jatropha processing plants in five (5) communities in the Northern Region, which process Jatropha seeds into Jatropha oil. Gbimsi Women Group engaged in the production of Jatropha oil to run a multi-functional platform (MFP) for cereals processing. BioFuel Africa Ltd. established Jatropha plantation in March 2008 in three villages in the Yendi District of Northern Ghana. The company first began the Jatropha project in Alipe, a village in the Central Gonja district of Northern Ghana in 2007 but suffered local opposition in Ghana from Non-governmental Agencies (NGOs), individual environmental activists and media debates on the grounds of perceived dire implications on local livelihoods and food security (Boamah 2010). The project was abandoned after a month-long of operation and the company subsequently moved to a new project site, where 23762 ha of Jatropha plantation was established for biodiesel production in the Central Gonja and Yendi Districts of Northern Ghana.

Mali

In Mali, there are two types of biofuels namely, the oil-based biofuel (or biodiesel) or oilseeds primarily produced from Jatropha in the region of Koulikoro and the alcohol-based biofuel primarily produced from sugar cane by the sugar

TABLE 8 *Cultivation of Jatropha in Ghana*

Institution	Crop	Land area under cultivation (ha)	Product
Biodiesel 1 Ghana Ltd.	Jatropha	700	Biodiesel
ADRA/UNDP	Jatropha	800	Biodiesel
New Energy	Jatropha	6	Biodiesel
Gbimsi Women Group	Jatropha	4	Biodiesel
Anglo-Gold Ashanti Ltd.	Jatropha	20	Biodiesel
Valley View University	Jatropha	4	Biodiesel
BioFuel Africa Ltd.	Jatropha	23 672	Biodiesel
Scan Fuel AS	Jatropha	400000	Biodiesel
Europian Union	Jatropha	500	Biodiesel
Sub-total		**425 706**	
Banket Ltd.	Cassava	1 180	Ethanol

Source: AHIATAKU-TOGOBO and OFOSU-AHENKORAH (2009)

company, SUKALA. Other vegetable oils, such as cotton and peanut oil, have a high demand (and margins) in an unsatisfied local alimentary oil market, which makes them unsuitable candidates for biofuel operations. In 2006, Mali developed its national strategy for the development and promotion of biofuels over the period 2008–2023. The creation of the National Agency for the Development of the Biofuels (ANADEB) in 2009 is an essential element of this strategy. The growing interest for biofuels in Mali has occurred in a context of constant price growth of various petroleum products. Moreover, concerns over the depletion of fossil fuel stocks and growing interest to increase energy security for the country have been prevalent concerns over the past few years. The country has been at the centre of Jatropha oil as biofuel development in West Africa. This biofuel plant was introduced in Mali with a role as live fence, territory demarcation and erosion protection (Yossi *et al*. 2006). Although it was estimated that Mali has more than 20 000 km of Jatropha hedges, the hedges are geographically dispersed and with little or no maintenance (UNIDO 2008). There are approximately 2 to 15 km per village, which represents a production potential of 1.7 million litres of oil per annum. The yields were estimated between 1 and 2 kg per lineal meter. The main zones with Jatropha concentration are the regions of Kayes, Koulikoro and Sikasso.

The hedge plantations significantly increased by 76% during the 2000–2007 period going from 17000 km to 30000 km. Based on a hypothesis of productivity of 2 kg seeds per lineal meter of hedges, the production potential increased by 34000 tonnes to 60000 tonnes during this period. In 2007, in addition to the hedges 2000 ha were planted as part of a biofuel project. The model in Mali (5000 ha already in place) is 1000 plants per hectare. This surface allows for production of a tonne of Jatropha seeds and 1.5 tonne per hectare, on average, for associated food crop (mostly maize or sorghum). Several private ventures and NGO projects have been initiated over the past five years to increase the intensity of Jatropha seed production and develop oil extraction to power agricultural machinery and small-scale electrification. One private venture has also started to produce biodiesel (fatty-acid methyl ethers) from Jatropha oil. These ventures and projects are active in specific regions, collaborating with formal farmers' associations or informal village level organizations, such as the cotton production committees (developed by the CMDT) and women groups. In the ON (*Office du Niger*) zone, various Jatropha ventures are in the process to start-up with land allocated but Jatropha planting and development of infrastructure is yet to materialise.

Niger

Generally, the potential of Niger Republic for biofuel production is low. This is because the main crops that could be used for biofuel production are in short supply for human consumption; hence the utilization of such crops for biofuel production is less likely. A identified crop with potential for biofuel production in the country is corn with the average national production of about 4000 tonnes per year. The production capacity is less than the feeding needs of populations. Cotton Seed is used mainly for the production of edible oil for domestic consumption. Therefore, production of biofuels from cotton seed oil might lead to a shortage of edible oil. Other potential biofuel species such as peanut and sesame are also very important locally for the production of cooking oils for domestic consumption and in the case of sesame, for export to food industries. Therefore their oils are more expensive than conventional diesel. This implies that it might not be economically feasible to utilize such plants in biofuel production in the country. Neem is another possible crop. Its seeds appear to be an option for the production of biofuels. It is estimated to be able to produce1000 tonnes of biofuels per annum at the national level. Jatropha is another crop but the opportunity for pure cultivation of Jatropha is limited by the competition for land and other resources from food crops. For alcohol-based bio-ethanolproduction, the crops identified includesweet sorghum, sugar cane, sweet potatoes and cereals. However, the potential of using these crops for ethanol production are weak because their total production is below the national demand as food. Hence there is serious competition between utilization of the crops for energy and food with the food utilization gaining the upper hand.

Nevertheless, the country has some good potential for biofuel production from municipal wastes, animal wastes and water hyacinth which were actually identified in the course of this study. Substantial deposits of animal waste (Figure 2); municipal wastes and water hyacinth found in Niamey, Maradi and Dosso are shown in Figures 3 & 4.

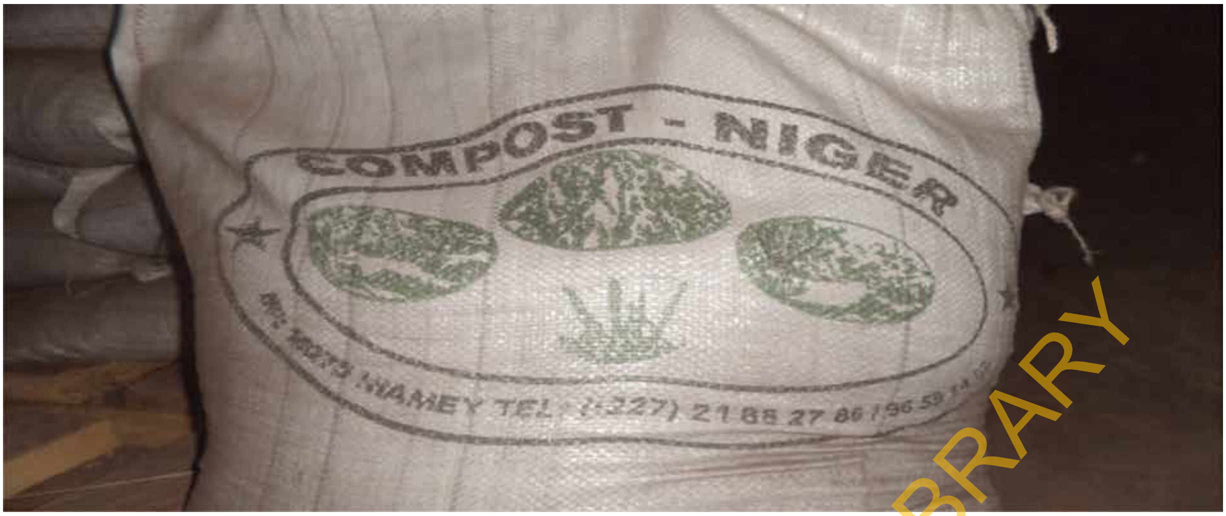
Furthermore, a small scale experimental biogas production was observed at the Faculty of Agriculture and Environmental Sciences, University of Maradi from municipal wastes. The small machine was designed and fabricated by a lecturer in the Department of agricultural engineering mainly for demonstration purposes. Field observation in the this study supports the earlier report by Oumarou (2012) that Niger Republic has some potential for biofuel generation from municipal and animal wastes. He indicated that the potential energy obtainable from municipal wastes from Dosso, Niamey, Maradi, Zinder and Diffawas 21.30 GJ of net usable heat energy per annum (Table 9). Similar amount could be generated from animal wastes from major abattoirs in Tahoua,

FIGURE 2 Animal *Wastes in a Cattle Market in Niamey*

FIGURE 3 *Municipal waste deposits on Airport-Dosso Road, Niamey*

FIGURE 4 *Water hyacinth on the water surface on Niger bridge, behind Hotel Gaweye, Niamey*

FIGURE 5 *Organic Fertilizer Produced from Municipal and Animal Wastes*



Maradi, Dosso, Zinder and Diffa. However, a potential hindrance to the use of municipal and animal wastes in energy generation in Niger is that most of the wastes are currently being used in organic fertilizerproduction (Figure 5).

The major constraints to biofuel production identified in Niger include food insecurity, declining soil fertility, social problems emanating from land management and a possible worsening of the precarious economic situation. Climate change also remains a key threat to biofuel feedstock production, particularly, with competition from livestock for pastures and other feed sources. Nevertheless, possible strategies developed by Niger to overcome the above constraints are addressed in the National Biofuel Development Plan and are underlined under the following strategic axes: developing apolicyand legalframework andincentivizeinstitutional environment; promoting research and action plans focused at the development ofbiofuels; productionof energy cropsas raw materials; promotion of biofuelsfor accessto sustainable energy servicesto local population and capacity building ofdifferent actors. In addition, some potential biofuel sources have been suggested for different cities in Niger Republic as presented in Table 9.

Some of the conditions that may encourage the production of biofuel in the country may include the provision of economic and environmental incentives for biofuel crop production. The biofuels to be produced should be readily available and easily affordable. Simple technology should be provided for small-scale producers and should be made profitable. At the political level, measures to establish a favourable institutional arrangement should focus on sectors, which do not compete with food production and food security particularly the use of crop residues, municipal and animal wastes.

Nigeria

In Nigeria, the major feedstock currently employed in the production of liquid biofuels is Jatropha for the production of biodiesel. Land areas deployed for these purposes in most of the farms visited were marginal, fallows and abandoned farmland. In cases where fertile lands were used, Jatropha

TABLE 9 *Suggested renewable energy schemes for cities in Niger Republic*

Region	Potentials	Scheme type
Agadez	Municipal wastes	Incinerators, biogas, gasification
Diffa	Biomasses, water hyacinth, municipal wastes and animal wastes	Incinerators, biofuels, gasification
Dosso	Sugar cane, biomasses, municipal wastes	Incinerators, gasification, biofuels
Maradi	Sgar cane, biomasses, municipal wastes	Incinerators, biofuels, gasification
Niamey	Water hyacinth, biomasses, municipal wastes	Gasification, incinerators, biofuels
Tahoua	Animal wastes, municipal wastes	Incinerators, biofuels, gasification
Tillabery	Biomasses, water hyacinth, municipal wastes	Incinerators, gasification, biofuels
Zinder	Sugar cane, animal wastes	Incinerators, gasification, biofuels

Source: Oumarou (2012)

FIGURE 6 *Jatropha intercropped with cassava and plantain, Eku, Delta State, Nigeria*

was intercropped with cassava (Figure 6). Massive land areas are still available for production in the country. Over 4 000 ha of land has been projected for Jatropha in Nigeria.

Currently, the use of biofuels for electricity generation and automobiles is unpopular in the country. Nevertheless, biodiesel is being produced and used to power some Mobile Network Service providers'base stations across the country. In addition, in very few instances, biofuels were reportedly used in combination with fossil fuels in the order 20% biofuel: 80% fossil fuel; 50% biofuel: 50% fossil fuel. There are also confirmed cases of biofuel usage for domestic cooking in Nigeria (Figure 7). Solid wastes are also used in the production of solid biofuels in form of briquettes. Wastes are collected from farms, grazing locations, sawmills and abattoirs/kraals.

The current production of biodiesel in Nigeria is still largely in the crude form except in Lagos, where three companies (Biodiesel Nigeria Limited, Avatar Energy Limited and Canrex Biofuel Limited) are engaged in the refining of biodiesel for final consumption by GSM providers. The larger proportion of feedstock for biodiesel production in Nigeria comes from *Jatropha curcas* nut oil. It was estimated that a hectare of Jatropha plantation is able to yield between 0.5 and 12 tonnes of nuts per annum depending on the age of the plantation and management practices adopted, and if the right inputs such as booster fertilizers and hybrid seeds for plantation establishmentare used. In addition, one metric tonne of Jatropha nuts yields up to 139 litres of crude biodiesel. On the average, 100 kg of *Jatropha curcas* nuts are produced per hectare in a year. Estimated yields of raw materials used in biofuels production as reported by the Nigerian National Petroleum Corporation (NNPC 2012) are given in Table 10. Current consumption of biodiesel in the study area is around five litres per month per household. Also, according to FAO *et al.* (2011) there are several emerging bioethanol projects in Nigeria based on sugar cane and cassava plantations. The

FIGURE 7 *Biofuel cooking stove in Ibadan(left) and the extracted bio-crude(right) in Makurdi, Nigeria*

TABLE 10 *Typical yields of raw materials used in biofuel production*

Crop	Yield (ton/ha/yr)	Ethanol/Biodiesel yield (litre/tonne)	Ethanol/Biodiesel yield (litres/ha/yr)
Sugar cane+	50–90	70–90	3,500–8,000
Sweet sorghum++	45–80	60–80	1,750–5,300
Sugar beet	15–50	90	1,350–5,500
Wheat	1.5–2.1	340	510–714
Rice	2.5–5.0	430	1,075–2,150
Maize	1.7–5.4	360	600–1,944
Sorghum	1.0–3.7	350	350–1,295
Cassava+	10–65	170	1,700–11,050
Sweet potatoes	8–50	167	1,336–8,350
Oil Palm	16–35	136	4760
Jatropha++	6–10	151.36	1513.6
Castor bean	0.75–1.5	753.6	1130.4

*Suitable feedstock+; Alternative feedstock++; Low yield feedstock
Source: NNPC 2012

sugar cane projects are being implemented in Kupto (Gombe State), Buruku and Agasha (Benue State). Cultivation is on a scale of land greater than 15 000–20000 ha to produce 1.8 million tonnes of cane to yield 75 million litres of ethanol per annum. Out grower scheme covers less than 1000 ha (Osu 2009). Two Cassava projects are also located in Okeluse (Ondo State) and Ebenebe (Anambra State). Cultivation is on a scale greater than 15,000 ha. Cassava production target is put at 3–4 million tonnes per year to yield 40–60 million litres of ethanol. Less than 1,000 ha are allocated for out grower schemes. Similarly, the Energy Commission of Nigeria (ECN), National Centre for Energy Research and Development (NCERD), Nsukka and the Sokoto Energy Research Centre (SERC) are reported to have constructed bio-digesters in Nigeria. In addition, Alconi/Nosak, UNIKEM and Intercontinental Distilleries with a production share of 118.6 million litres, representing nearly 90% of the total production, rely on crude ethanol precursors, mostly imported from Brazil. DURACLEAN, which recently acquired the former Nigerian Yeast and Alcohol Manufacturing Company (NIYAMCO), is yet to begin full operations. Only the Allied Atlantic Distilleries Ltd. (AADL), which began operations in 1999, is producing 30000 litres of ethanolperday from locally sourced cassava feedstock.

Nigeria has in recent time's imported large quantities of ethanol from Brazil. Import value from Brazil was put at 11.4 and 23.8 million USD for the year 2003 and 2004 respectively (FAO *et al.* 2012). In 2007, the country imported 123 million litres of ethanol from the same country, which translates to about 2% of the current national demand. In all, a supply gap of over 5 billion litres per annum of ethanol exists in the country. This is an indication that there is a huge market potential to absorb biofuel if produced in the country. It is also an incentive to encourage private investors to engage in the production of ethanol-based biofuel such as gasohol since there is market assurance.

Senegal

Biomass fuels make up approximately 60% of the total primary energy supply, and up to 90% of all household energy needs in Senegal. Majority of the population in rural areas use fuel-wood, while charcoal is mostly used in urban areas (Table 11). Biomass consumption (wood-energy and agricultural residues) remains the main source of domestic energy, and energy in small-scale commercial sectors.

Senegal's energy stability is largely dependent on global oil prices as a result of the fact that the country spends enormous sums to import energy. In 2005, roughly 55% of Senegal's expenditures on imports were spent on oil. As a result, price fluctuations in the global energy market have a profound impact on Senegal's ability to purchase oil for its transportation and industrial sectors, which consume most of the oil imports, as well as for domestic consumptions. Senegal's vulnerability to oil price fluctuations became

TABLE 11 *Fuel-wood and Charcoal consumption in Senegal*

Area	Fuel-wood (%)	Charcoal (%)
Urban Dakar	3%	8%
Other towns	32%	21%
Urban areas	15%	14%
Rural areas	82%	8%

Source: UNEP (2013b)

exceedingly obvious in 2006 and 2007 when the country suffered widespread blackouts as a result of rising oil prices. Many believe that when oil prices rose, Senegal was unable to afford to import enough oil to provide adequate national energy resources.

Biofuels are being considered as an attractive option for Senegal because they could enable the country to decrease its dependence on foreign oil, a huge source of financial and energy instability. The Senegalese population is in need of employment opportunities as it was estimated in 2007 that 48% of the population was unemployed due to the limited size of Senegal's agricultural and industrial sectors. Biofuel production could improve the lives of the Senegalese and help stem the rapid exodus of youngsters from the country in search of employment.

The biofuels sector, although relatively recent in Senegal, is supported by a strong political will to expand feedstock production from sugarcane and Jatropha in order to partially meet domestic fuel demand (IRENA 2012). Both the biomass and oil products used in Senegal are sources of concern: the use of traditional fuel-wood and charcoal is putting great pressure on forests and contributing to a degradation of the environment. In order to decrease traditional biomass consumption, Senegal has had a policy of subsidising liquefied petroleum gas (LPG) supplies for more than two decades (IRENA 2012).

Biofuel production is minimal at present. Bioethanol production has slowed to a halt due to absence of national demand, lack of policy support, and the need for technological advances. Moreover, the Senegalese government has banned exporting biofuels, despite foreign demand. Though small private farmers produce biodiesel from Jatropha, currently there is no large-scale production. Among a number of constraints, farming technology is inefficient and produces low Jatropha seed yields.

Sierra Leone

Fuel-wood and charcoal are the major renewable solid biofuels used in Sierra Leone for cooking. Roughly, 30% of harvested wood is used for charcoal production. About 85% of energy used in Sierra Leone comes from biomass (AfDB 2013). The vast majority of households still use traditional biomass fuels for their domestic energy needs. There is currently limited use of agricultural wastes, estimated at 656 400 tonnes per annum (Ministry of Energy and Power 2006). This may constitute a great potential source of biofuel if properly harnessed.

In terms of liquid biofuels, a recent initiative led by Addax Bioenergy, a Swiss group, with financing from a number of international development organizations, is to construct a biomass-fuelled power plant and sugar cane ethanol refinery in the country, at a cost of €258 million. Addax biofuel project is to a large extent financed by European Development Finance Institutions and the African Development Bank, and applies IFC Performance Standards, Equator Principles and the African Development Bank policies. In order to meet EU sustainability criteria, the project will also adopt international best practices for the sugar and biofuels industry as defined by the Roundtable on Sustainable Biofuels (RSB) and the Better Sugar cane Initiative (BSI), of which Addax is a member.

The refinery is expected to produce up to 350,000 litres per day and 90,000,000 m^3 per annum, and will be powered entirely through the conjoined biomass station, which will also feed renewable power into the national grid system. The Project will grow sugar cane, produce ethanol and generate electricity. As at the time of the survey, Addax had established a processing plant with a capacity of 950,000 tonnes of sugar cane per year as the only feedstock.

There is every possibility for a successful take off and sustained production of biofuel in Sierra Leone since there is sufficient awareness on the deleterious effects of fossil-based fuel and there are commendable efforts both locally and internationally to engage in the production of biofuels.

CONCLUSION AND RECOMMENDATIONS

Biofuel production in the selected West African countries has been on the rise in the last few years. Benin, Ghana and Nigeria possess millions ofha of idle lands, which could support biofuel crop cultivation. In most of the countries covered in this study, there are national biofuel policies supporting the production of biofuels. In some few instances, both edible and non-edible crops are adopted for biofuel production, while only non-edible crops are approved for biofuel production in others to avoid competition with food needs of those countries. In general, there has been little consideration for complementarity and substitutability among food and non-food crops for biofuel production particularly as it concerns land availability and food security.

Although, there are proven records of biofuel production in most of the studied countries, fossil fuels seem to be more preferred for now. Nevertheless, while fossil fuels are generally out of the reach of the average rural, peri-urban and even some urban dwellers in Nigeria and the other countries, their prices are also not affordable when compared to the procurement of traditional fuelwood and charcoal. Considering the spate of biofuel adoption and cultivation in the selected countries as well as the policy support, there is great potential for a shift from fossil fuel, particularly, petroleum products.

In view of the foregoing, the following recommendations are made for enhanced development of the biofuel system in West Africa:

- there should be concerted efforts within, and among the countries in West Africa to ensure sustainable production of biofuel crops in ways that will minimize conflict with other land uses;
- countries in the region are advised to embark on land classification and land use reforms (where they do not exist) to ensure easy access to land for large scale biofuel crops production;
- small growers of biofuel crops should be organized into out-growers cooperative groups and incentivized to produce profitably;

- there is a need to domesticate the production technology so as to make it accessible, affordable, efficient and compatible with the prevailing socioeconomic environment;
- the extant fossil fuels subsidies in some countries in the region should be extended to biofuel production at least for its added advantage of employment and revenue generations coupled with its minimal negative environmental impact and;
- there is a need for a Biofuel Convergence Plan (BCP) by ECOWAS governments with the support of African Forest Forum (AFF) and other bilateral and multilateral agencies. This will facilitate trans-boundary production and trade in biofuel crops and products.

ACKNOWLEDGEMENT

This paper draws primarily, but not exclusively, from a body of review articles commissioned by the African Forest Forum in 2012/2013, funded by the Swiss Agency for Development and Cooperation (SDC), and covering several countries in West Africa and including the Sahel region. The authors are grateful to anonymous referees for their helpful advice.

REFERENCES

AFDB. 2013. *Sierra Leone: Transitioning towards Green Growth; Stocktaking and the Way Forward.* African Development Bank Group. 103 p.

Africa Biofuel Network. 2010. Biofuels – A Failure for Africa http://www.africanbiodiversity.org/sites/default/files/PDFs/Biofuels.

AHIATAKU-TOGOBO, W. and OFOSU-AHENKORAH, A. 2009. Bioenergy policyimplementation in Ghana. In: COMPETE *International Conference*, http://www.competebioafrica.net.

AKANDE, S.O. and OLORUNFEMI, F.B. 2009. Research and development potentials in biofuel Production in Nigeria. *African Research Review* **3**(3): 34–45.

AMBALI, A., CHIRWA, P., CHAMDIMBA, O. and VAN ZYL, W.H. 2011. A review of sustainable development of bioenergy in Africa: An outlook for the future bioenergy industry. *Scientific Research and Essays* **6**(8): 1697–1708.

BOAMAH, F. 2011. The relationship between land grabbing for biofuels and food security, a bane or boon? The food security implication of Jatropha biodiesel project in Northern Ghana. *Global Land Grabbing* (pp. 1–21). Sussex: Institute of Development Studies: Land Deals Politics Initiative.

BOCCANFUSO, D., COULIBALY, M., TIMILSINA, G.R. and SAVARD, L. 2012. The prospects of developing biofuels in Mali. Groupe de Rechercheen Économieet Développement International (GREDI). University of Sherbrooke. Working Paper. 26 p.

FARA. 2010. Mapping food and bioenergy in Africa. A report Prepared for FARA. 126 p.

FAO, IUCN and UNEP. 2011. *ECOLEX – the gateway to environmental law.* Available at: http://www.ecolex.org/start.php.

FAO, World Bank, AU-IBAR and ILRI. 2012. Livestock Assets, Livestock Income and Rural Households. *Institut National de la Statistique (INS) (2008) Analyse De La Politique Fiscale Au Niger Et Ses Impacts Sur La Pauvreté; Rapport Final, pp. 4, Ministère de l'économie et des finances, Juin*

GRADOS, K. and JANSSEN, R. 2008. National policies and strategies on bioenergy in Africa Case Study: Ghana. Competence Platform on Energy Crop and Agroforestry Systems for Arid and Semi-arid Ecosystems – Africa (COMPETE). Sixth Framework Programme FP6-2004-INCO-DEV-3 Priority A.2.3.: Managing Arid and Semi-arid Ecosystems. 9 p.

HAGAN, E.B. 2007. Biofuels assessment report – ECOWAS Sub-Region. Paper presented at the AU/Brazil/UNIDO Biofuels Seminar in Africa, July 30–August 1, 2007, Addis Ababa, Ethiopia. 19 p.

IRENA. 2012. Senegal Renewable Readiness Assessment, 2012. 76 p.

KEMAUSUOR, F., OBENG, G.Y., Brew-Hammond, A. and Duker, A. 2011. A Review of Trends, Policies and Plans for Increasing Energy Access in Ghana. *Renewable and SustainableEnergy Reviews* **15**(9): 5143–5154.

NNPC. 2012. Sustainable Biofuels Industry in Nigeria – A gateway to economic development. Paper presented by Group General Manager, Renewable Energy Division of NNPC at the second Nigerian Alternative Energy Expo 2012 in Abuja, Nigeria.

OUMAROU, M.B. 2012. Energy problems, potentials and alternatives in Niger Republic. *Continental J. Engineering Sciences* **7**(2): 52–61.

UNCTAD. 2008. Biofuel production technologies: status, prospects and implications for trade and development. New York and Geneva. 49 p.

VAN ZYL., W.H., CHAMPHANGO, A.F.A., DEN HAAN, R., GÖRGENS, J.F. and CHIRWA, P.W. 2011. Next generation cellulosic ethanol technologies and their contribution to asustainable Africa. *Journal of Royal Society Interface* **1**: 196–211.