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A sustainable approach to boosting liquid biofuels production from second generation biomass resources in West Africa

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Abstract. West African region has abundant second generation biomass resources consisting of agricultural residues, forest resources; municipal solid wastes; and animal wastes that could be harnessed to produce liquid biofuels. A number of countries in the region have developed energy policies to foster bioenergy production. Despite the national intent expressed in various countries' bioenergy policies, development of bioenergy facilities and liquid biofuels production from cellulosic sources in the region are essentially at the research and development stage. This study, through comprehensive reviews of various bioenergy policies, news reports, related journal articles and development reports, examined the reasons for the delay in the development of bio-refineries in the region. The study then articulated feasible solutions to address the challenges. Among the discovered causes of the delay are over-dependence on fossil fuels and defective energy policy implementation manifesting in the form of lack of continuity. Other issues include poor private sector's involvement and inadequate incentives necessary for private investors' participation. This study concludes that boosting liquid biofuels production in West Africa would require public-private collaboration that is built from bottom-up. Successful bioenergy facilities' development in the region would need to be community level scaled rather than being mega projects, and it would need to involve participation of communities as collaborators. In addition, to ensure sustainable production, it would be necessary to incorporate public enlightenment, and grant tax incentives to investors. Moreover, it would need to include a sustainable technology training package that would empower local engineers and technicians to not only develop bioenergy facilities that are suitable for the locality but also to maintain and improve them. Furthermore, Continuity and consistency in policy implementation and financing prioritization are essential to boosting liquid biofuel production in the West African region and to enable West African region to occupy its rightful place in the global bioeconomy.

Key words: bioeconomy, bioenergy, liquid biofuels, sustainability, West Africa.

INTRODUCTION

There is an increasing demand for transition from fossil fuel based energy source to biofuels. The clamor for the change is essentially driven by three main factors, namely: 1) Climate change trigger by greenhouse gas emissions from fossil fuel combustion; 2) impending depletion of natural resources, especially the fossil fuels being non-renewable natural resources, and 3) an increased worldwide population with increasing need for energy supply. Other important reasons while transitioning to advanced biofuel production and use include the need to eliminate various negative consequences of using solid biofuels. For example, quoting World Health Organization, Ndiaye (2018), stated that 'over 4 million people die prematurely from illness attributable to the household pollution from cooking with solid fuels'. He further stated that 'More than 50% of premature deaths due to pneumonia among children under 5 are caused by the particulate matter (soot) inhaled from household air pollution'. There is therefore a need for the development of advanced biofuel technologies to produce liquid biofuels. Production of liquid biofuels from second generation biomass have been hailed as a viable renewable energy source that would not only enable us to satisfy the increasing energy demand, it is also seen as a carbon-neutral source of energy that would enable us reduce the impending climate change danger. Such endeavor is also expected to help eliminate or at least reduce other negative consequences of using petroleum products and solid biofuels. Second generation biomass sources of liquid biofuel production are derived from cellulosic sources such as forest and agricultural residues, and market/household organic wastes (Jokiniemi & Ahokas, 2013).

Second generation biomass availability in West Africa

The West African region is blessed with abundant cellulosic biomass resources. That is why according to Ndiaye (2018), 'Wood accounts for more than 80% of all primary energy in West African countries'. The West African regional vegetation zones range from the dense tropical forest in the south to the savanna grassland in the north (Fig. 1). The amount of residues from harvesting and processing these abundant woody resources in the form of logging and saw-milling are enormous and they are readily available for use as feedstock for the production of liquid biofuels.

Figure 1. West African vegetation zones.
Source:https://eros.usgs.gov/westafrica/sites/default/files/inlineimages/160823_Climate _zones.jpg

Liquid biofuels and necessity to boost production of liquid biofuels

All over the world, due to its being a carbon-neutral source of energy, there is an increasing demand from liquid biofuels. Consequently, there is also an increasing emphasis on the production of liquid biofuels, especially from cellulosic sources rather than from first generation biomass sources like grains and other food crops. While Brazil and the USA are the largest producers of liquid biofuels, many other countries like China and India have developed aggressive programs of liquid biofuels production. However, the production of liquid biofuels in the West African region is still at an infancy stage. Most of the countries in the region depend mainly on petroleum fuels for transportation, for cooking and for electric energy generation. Apart from seasonal scarcity of the petroleum fuels in some countries, the use of fossil fuels is causing a lot of environmental pollution. It is thus necessary that having been endowed with abundant sources of lignocellulossic biomass, the region has a lot to benefit by pursuing aggressive liquid biofuel production and utilization like other regions of the world (van Zyl, 2011).

The aim of this paper was to review the status of liquid biofuels production in West Africa, to articulate the driving factors and challenges to its abundant production in the region, and to provide some insights on how to boost sustainable production of liquid biofuels in the region.

MATERIALS AND METHODS

The methodology of this study involved a comprehensive review of bioenergy literature and reports to identify commitments made by a number of West African countries and by the Economic community of West African States to the development of bioenergy sector, especially the production of liquid biofuels. The study also reviewed various liquid biofuels production initiatives in the region with the aim of articulating the driving motivations behind the investments and various sources of support received. The levels of success of the initiatives, encountered development challenges as well as other limiting factors were also evaluated. Steps were then taken to articulate what can be done to remove the obstacles to the development of bioenergy in the region. Various models of possible pathways to boost liquid biofuels production in the region were then developed and analyzed before drawing conclusion on sustainable approach to boosting liquid biofuels in West Africa.

RESULTS AND DISCUSSION

This section provides the outcomes of our review on global trends in the production of liquid biofuels. We also provided a summary of liquid biofuel production policies of a number of countries in the region and of ECOWAS. Furthermore, we articulated various liquid biofuel production initiatives in the region. We also discussed various challenges of producing liquid biofuels from lignocellulosic biomass, and concerns raised regarding potential environmental and socio-economic impacts of bioenergy development in West Africa. We then presented a model of possible pathways to boosting liquid biofuels and the requisite enabling infrastructure in a way that the problems are appropriately addressed. Finally, we analyzed the potential impacts of implementing the framework in achieving some sustainable development goals in West Africa.

Liquid biofuels production methods

Bioethanol, biodiesel and bio-oil are the three liquid biofuels of interests. Methods of processing lignocellulosic biomass to liquid biofuels can be divided into two categories, namely: biochemical processes and thermochemical processes. Biochemical methods are used for the production of biogas, bioethanol and biodiesel from lignocellulosic biomass while thermochemical methods are used to convert biomass to bio-oil. Enzymatic fermentation method is the most commonly used biochemical method. Biochemical methods generally consist of three main steps, namely: pre-treatment, enzymatic pyrolysis and fermentation. Torrefaction, thermal liquefaction, pyrolysis and gasification are the common thermochemical methods. Bio-oils are the most preferred pyrolysis fuel types for transportation purpose while biochar and flue gases are pyrolysis by-products produced along with bio-oil. Bio-oils are in most cases unsuitable for direct use, they often require refining and further processing steps just like in petroleum refineries. There has been a lot of scholarly works on the liquid biofuels, biomass feedstocks and the bioprocessing methods. This review is focused on boosting liquid biofuels, readers are directed to the following literatures for further details on biofuels production methods: Balat et al., 2009; Zhang et al., 2010; Panwara et al., 2012; Yılmaz & Selim, 2013; Kumar et al., 2015, and Kan et al., 2016.

Global trends in the production of liquid biofuels

The production and use of liquid biofuels is growing globally. According to WBA (2019), 'In 2017, 138 billion litres of biofuels were produced including bioethanol, biodiesel, HVO (Hydrogenated Vegetable Oil) etc'. It accounts for about 3% of the transport sector energy use in 2017. IRENA (2020), projected that liquid biofuels in the form of ethanol and biodiesel could account for 10% of transport sector energy use by 2030. The reason for the growth is due to the many advantages of biofuels as carbon neutral alternatives to fossil fuels, its renewability, and its promotion of rural development (von Maltitz et al., 2009; Ghobadian, 2012; Oyedepo et al., 2019). The global change from fossil fuels to biofuels is led by the EU with its legislative support which required member countries to ensure the blend of conventional fossil fuels with a certain percentage of bioethanol. Many countries, including the US, Brazil, China and India have since followed suite (Ghobadian, 2012; IEA, 2019a). Global production of biofuels in 2018 was 154 billion litres. Total biofuel output is forecast to increase 25% by 2024. According to the report, China is set to have the largest biofuel production growth of any country while the United States and Brazil still provide two-thirds of total biofuel production in 2024. However, biofuel production in the United States and EU member states is not on track to meet the projected 2030 demand (IEA, 2019a and 2019b; Nyström, 2019).

West Africa's biofuels production potentials

West Africa has a lot of potential for significant contribution to global biofuels production as it is bequeathed with abundant biofuels feedstocks, especially from lignocellulosic sources. Onuoha (2010), Ishola et al. (2013); Iye & Bilsborrow (2013); Simonyan & Fasina (2013), Ben-Iwo et al. (2016), Adewuyi (2020), and Gnansounou et al. (2020) provided extensive reviews of various types of biomass resources and biofuels production potentials in Nigeria. Baumert et al. (2018) and Bridge builders (2019) discussed the growing of Jatropha and its use for biofuel production systems of Burkina Faso. According to Dianka (2012), 'West African region has a large potential to become a leading producer of many types of biofuels given the availability of raw materials, climate conditions, land availability and production costs'. He further opined that 'the economical and political stability of the Union favour the development of a common biofuels market that can become a substantial exporter of biofuels to the EU'. Table 1 shows the projected biofuels production potentials from some West African countries. Simonyan and Fasina (2013) also stated that 'Nigeria is capable of producing 2.01 EJ (47.97 MTOE) of energy from the 168.49 million tonnes of agricultural residues and wastes that can potentially be generated in a year.' In another discuss, Onuoha (2010) indicated that Nigeria has the capacity to produce 61 million tonnes of animal waste per year; 83 million tonnes of crop residue per year, and 13,071,464 hectares of forest land to produce woody biomass. In another report, quoting Iwayemi (2008), Dunmade (2017) stated that Nigerian biomass endowment stands at 144 million tonnes per year, a large percentage of which can be harnessed for energy production. Tables 1a and 1b show the projected amount of residues for each crop from some West African countries by 2050.

Table 1a. Total amount of residues for each crop and country in 2050 (Gnansounou et al., 2020)

Countries	Residues in 2050 (tons year^{-1})			
	Banana	Cassava	Maize	Oil palm fruit
Benin	9,234	819,256	7,685.674	3,077.327
Burkina Faso	-	973	8,918.250	-
Cote d'Ivoire	129,339	501,689	3,715.272	10,684.203
Gambia	-	2,419	166,548	242,021
Ghana	33,892	3,119,461	11,614,328	11,937,521
Guinea	93,332	249,527	3,771,572	4,045,498
Liberia	56,800	117,975	-	1,102,467
Mali	104,809	10,079	9,656,257	-
Niger	-	30,143	60,527	-
Nigeria	-	9,918,856	65,349,629	30,153,631
Senegal	15,077	35,143	1,304,100	971,578
Sierra Leone	-	810,805	272,168	1,347,265
Togo	10,652	212,098	4,425,680	584,178
Total	453,135	15,828,423	116,940,006	64,145,689

Table 1b. Total amount of residues for each crop and country in 2050 (Gnansounou et al., 2020)

Countries	Residues in 2050 (tons year^{-1})				
	Rice	Cotton	Sorghum	Soybeans	Sugarcane
Benin	1,065,856	1,472,230	989,713	59,640	30,021
Burkina Faso	1,674,142	2,827,218	14,391,713	93,638	374,608
Cote d'Ivoire	902,837	1,387,922	366,398	3,412	1,620,026
Gambia	35,543	2,949	207,549	-	-
Ghana	348,962	74,947	2,208,393	-	121,572
Guinea	1,195,235	228,402	284,269	-	115,888
Liberia	167,959	-	-	11,262	119,738
Mali	1,874,119	2,628,206	9,565,583	13,338	295,313
Niger	11,585	48,853	9,418,996	-	106,378
Nigeria	3,061,685	1,631,367	45,238,144	2,448,622	1,544,025
Senegal	452,933	186,605	880,192	-	879,523
Sierra Leone	747,960	-	266,739	-	37,117
Togo	72,804	493,664	2,186,686	14,621	-
Total	11,611,622	10,982,362	86,004,374	2,644,424	5,244,209

Table 2 shows the projected amount of cellulose, hemicellusoe, and lignin that could be produced by each country by 2050 while Table 3 shows the West African biofuels production potentials and sources. Within the last two decades, oilpalm and jathropa have gained a lot of attention as energy crops of focus for biofuels production (Torrey, 2010). Looking at the foregoing data, it is clear that West African region has a great potential to make significant contribution to global liquid biofuels production.

Table 2. Amount of cellulose, hemicellulose and lignin available in the selected WA area by 2050 considering that 50%residues were left on the field. Energy content in the selected biomass (Gnansounou et al., 2020)

Countries	Cellulose (tons year^{-1})	Hemicellulose (tons year^{-1})	Lignin (tons year^{-1})	Total Energy content (GJ year^{-1})
Benin	2,435,313	1,463,603	1,341,186	93,989,852
Burkina Faso	4,602,408	2,882,498	2,164,508	172,284,720
Cote d'Ivoire	3,259,012	1,997,339	1,904,670	126,688,100
Gambia	106,951	67,504	54,160	4,000,678
Ghana	4,899,719	3,009,908	2,692,610	190,514,168
Guinea	1,484,255	911,400	828,349	60,235,161
Liberia	260,013	160,925	153,594	10,195,012
Mali	3,593,196	2,223,739	1,742,045	135,486,934
Niger	1,671,345	1,104,608	660,506	60,474,290
Nigeria	25,635,444	16,035,878	12,817,400	981,005,286
Senegal	731,502	469,398	384,690	27,583,543
Sierra Leone	480,114	290,291	274,929	19,140,877
Togo	1,262,812	781,084	629,165	47,632,777

Table 3. West African biofuels production potentials and sources (Dianka, 2012)

Country	Biofuel type production potential and sources
Benin	20,000 m^3 year^{-1} ethanol based on cassava
Burkina Faso	20,000 m^3 year^{-1} ethanol based on sugarcane
Ivory Coast	19,000 m^3 year^{-1} ethanol based on molasses
Guinea-Bissau	~10,000 m^3 year^{-1} ethanol based on cashew tree apples
Mali	18,000 m^3 year^{-1} ethanol based on molasses
Niger	Biodiesel based on jatropha
Senegal	15,000 m^3 year^{-1} ethanol based on molasses
Togo	10,000 m^3 year^{-1} biodiesel based on jatropha
Total	Ethanol (93,000 m^3 year^{-1}) and biodiesel (20,000 m^3 year^{-1})

Status of liquid biofuels production in West Africa

ECOWAS and its member countries, with the support of their partners, have been working hard to boost the production of liquid biofuels as a component of its regional policy on renewable energy. ECOWAS Renewable Energy Policy (EREP) and ECOWAS Energy Efficiency Policy (EEEP) policies outline Renewable Energy and Energy Efficiency targets to be achieved by ECOWAS countries by 2030. Auth and Musolino (2014) stated that, 'he goals of the policies correspond precisely to the poles of the UN Secretary General's initiative on Sustainable Energy for All and have led to new developments in the renewable energy and energy efficiency sectors throughout the region'. FAO (2019) also hinted that 41 countries out of the 54 African countries mentioned in their policies that they will implement at least one modern bioenergy measure to mitigate their GHG emissions. Liquid biofuels and biogas are among the top five policies and measures that African countries are focusing on to combat GHG emissions (ECOWAS, 2013; Dunmade, 2017; IEA, 2019a and 2019b).

In West Africa, fourteen countries indicated the need to develop modern bioenergy to mitigate their GHG emissions. Focusing on Liquid biofuels, ECOWAS member countries adopted biofuel-blending targets of 5 percent for ethanol and biodiesel in 2013 and a Bioenergy Strategy in 2016. Majority of the ECOWAS countries are focusing on liquid biofuel production to be used for transport except Cabo Verde that wants to generate electricity from biodiesel in remote islands. Mali also intends to develop 4 MW through hybrid systems (solar and jatropha) for rural electrification while Niger focuses on the production of biofuel and biogas for cooking purposes (FAO, 2019). Nigeria is promoting a blending mandate of 10 percent ethanol with gasoline (E10) and 20 percent of biodiesel with diesel (B20). Similarly, Liberia hopes to reduce its emissions by 58 ktCO2e per year by blending its diesel fuel with 5 percent of biodiesel from palm oil. Furthermore, Burkina Faso is also promoting the creation of biofuel plants with a blending mandate of 10 percent ethanol and 5 percent biodiesel. Other West African countries like Togo, Gambia, Guinea and Sierra Leone are also advocating production of liquid biofuels from various feedstocks such as sugarcane, corn and rice husk (Abila, 2012; Jokiniemi & Ahokas, 2013; Popoola et al., 2015).

Jathropa and oilpalm

Jathropa and oilpalm have received a lot of investment attention in the last two decades as energy crops with great potentials in many West African countries. There has also been a lot of discussions about the pros and cons regarding their cultivation and utilization as feedstocks for biofuel production. Jatropha is a hardy tree that thrives in hot, dry climates. A number of jathropa species are widely grown as an energy crop across West Africa especially in Burkina Faso, Ghana, Mali, Niger, and Nigeria. Jatropha curcas is particularly recommended for cultivation as energy crop. It does well in quite extreme conditions of semi-arid climate and marginal soil, however, to yield plenty of fruit for producing oil, it needs sufficient water, fertilizer and care (The Research Council of Norway, 2011). There are concerns that its intensive cultivation would lead to 'converting arable land' for the cultivation of energy crops and that could affect staple food production, lead to increased food prices and food insecurity. Anderson (2007) was of the opinion that jatropha is a crop that can be used for biofuels without causing the aforementioned problems because it is used by farmers as a border around their crops. She stated that its appalling scent and inedible seeds keep animals away from the food crops inside. In addition, the oil from jatropha seed can be easily refined into biodiesel. Anderson (2007) also opined that jatropha may have a future in sub-Saharan Africa once crop improvements have been devised and each country adapted modern management practices are established.

Oil palm (Elaeis guineensis) is another crop of importance that originated and widely grown in various parts of West Africa. It is a versatile crop in that all parts of the plant, 'from the roots to the flowers to the by-products, are used for food, traditional medicine, and for their important sociocultural value' (Yombouno, 2014). Nigeria is the largest producer of palm oil, with a global market share of 3%. It is followed by Cote d'Ivoire (Duku et al., 2011). The last two decades have witnessed rapid growth in commercial oilpalm plantations, many of which are supported by governments and by foreign investors. However, there are also some concerns regarding environmental and socioeconomic impacts of commercial oilpalm plantations. For example, Cernansky (2019) stated that there are concerns about impacts on local water supplies, wildlife populations, biodiversity, climate change as well as loss of farmlands by the locals to commercial oilpalm plantations. Additional impacts include communities displacement as well as their cultural/traditional institutions alterations. All stakeholders especially local communities involvement as participants in large scale oilpalm development would be necessary for its sustainable growth.

Major investors in West African energy crop cultivation and biofuels production

Although there are lots of enthusiasm regarding transition to the production and utilization of advanced liquid biofuels in West Africa but only limited number of the initiatives have been started. Those that were started are essentially focused on blending petroleum fuels with varying percentages of ethanol imported largely from Brazil. There are also some indigenous and foreign companies in West Africa that started commercial production of energy crops and/or biofuels production. Annuanom Industrial Project Limited, KITE-Ghana (Kumasi Institute of Technology, Energy, and Environment), the Gratis Foundation, New Energy-Ghana, and Biofuel Africa Ltd are some of the major players in Ghana with investment focus on jathropa (Antwi-Bediako, 2019). For example, Biofuel Africa Ltd. started its first working farm operation in Ghana in 2007. Its activities involve growing and selling jatropha fruits and seeds to production and sale of jatropha oil on a commercial scale (Torrey, 2010). There were also some government-private participation programmes aimed at fostering biofuels production. An example is the case of Nigerian National Petroleum Corporation's partnership with state governments and other industry partners (Dianca, 2012; Dunmade, 2018a). Tables 4 and 5 are Ghana based bioenergy/biofuels investment projects based jathropa and oilpalm serving as picturesque of the trends in West Africa. While there are robust bioenergy production policies by many West African countries, the majority of the initiatives focusing on local production of liquid biofuels are still on the drawing boards awaiting technical partnerships and funding. Although the delay in the take-off of these laudable projects are of concern, it however provides opportunities for proper learning from current producers. It should afford the ECOWAS countries ample time to learn, and develop/utilize lifecycle based liquid biofuel production facility design principles. Adopting sustainable design approach would not only result in minimum ecological footprint but also ensure economically sustainable and socially acceptable production systems (Cristobal-Sarramian & Atzmuller, 2018; Dafrallah, 2010; van Zyl, 2011; Popoola et al., 2015; Ndiaye, 2018; Dunmade, 2019; Nyström et al., 2019).

Table 4. Major investments in Jatropha curcas plantations in Ghana (Duku et al., 2011)

Name of institution/company	Land area under cultivation (ha)	Funding sources
B1 Ghana	700	Private investment
ADRA/UNDP	800	UNDP/GEP/ADRA
New Energy	6	Donor funding
Gbimisi Women Group	4	UNIPEM/UNDP-GEP
AngloGold Ashanti Ltd	20	Corporate Fund
Valley View University	4	University Funds
Total	1,534	

Table 5. Major investments in the oil palm industry in Ghana (Duku et al., 2011)

Company	Location
Benso Oil Palm Plantation (BOPP) Ltd.	Benso
Twifo Oil Palm Plantation (TOPP) Ltd.	Twifo Praso
Ghana Oil Palm Development Corporation Ltd (GOPDC); known as the Okumaning Oil Palm Plantation Development Programme	Akim Oda
National Oil Palm Plantation	New Juaben
Norpalm Ghana Ltd (formerly called Prestea Oil Palm Plantation)	Presten
National Oil Palm Plantation Ltd	Ayiem

Sustainable pathway to boosting liquid biofuels production and utilization in West Africa

It has been projected that Africa has the potential to be the world's largest bioenergy producer by 2050. It was estimated that the continent has the capacity to produce up to a quarter (317 EJ per annum) of the projected total world potential of 1272 EJ per annum (Auth & Musolino, 2014). However, production of advanced liquid biofuels in commercial quantities is still at the infancy stage in many West African countries (Adjovi, 2012; Afrane, 2012; Dunmade, 2020). There are therefore a number of things to be put in place in order to boost West African liquid biofuels production in a way that would enable it to occupy its rightful place in the world. There is a need to develop a program of identifying, selecting and focusing on massive production of a few number of high yield locally adaptable bioenergy crops that would serve as feedstock for the biofuels sub-sector (Dioha & Kumar, 2020). Although significant progress has been made in this regard, as one can see a rise in foreign investment in the production of biofuel crops like jatropha, cassava, oilpalm, cashew and sugarcane. However, jatropha is a bioenergy crop with future potential for liquid biofuel production because cassava and sugarcane are important staples in the sub-region. Another good step that has been taken in that direction is the enabling policies that have been put in place by many West African countries to enhance the optimum production and utilization of Jatropha for biofuel production in the sub-region. Further progress would include expanding the sources of feedstock for the industry. Among the areas that could be explored include putting policies and logistic infrastructure in place for the gathering and marketing of forest residues, sawmilling wastes, household and market organic wastes (Auth & Musolino, 2014; Oyedepo et al., 2019).

FAO (2019) reported that there is increasing liquid biofuel use in Western African countries like Nigeria and Ghana. The growing trend has been attributed to the adoption of two policies in the region, namely: the 5 percent biofuel-blending target for ethanol and biodiesel in 2013 and a bioenergy strategy in 2016. However the growing demand needs to be met with adequate supply of locally produced liquid biofuel. Hence the need to boost the local production as doing so would lead to the development of the local economy, increased rural jobs, improved public health and the overall improvement in standard of living of the citizens. In addition, boosting liquid biofuels production in West Africa would involve providing an enabling environment for steady growth in local demand as well as expansion to regional and international consumer market for the production outputs (Smeets et al., 2007; ECOWAS, 2013; Popoola et al., 2015; FAO, 2019). Fig. 2 illustrates a model pathway to boosting liquid biofuels production in West Africa. It shows the need for a participative approach, that involves all the stakeholders.

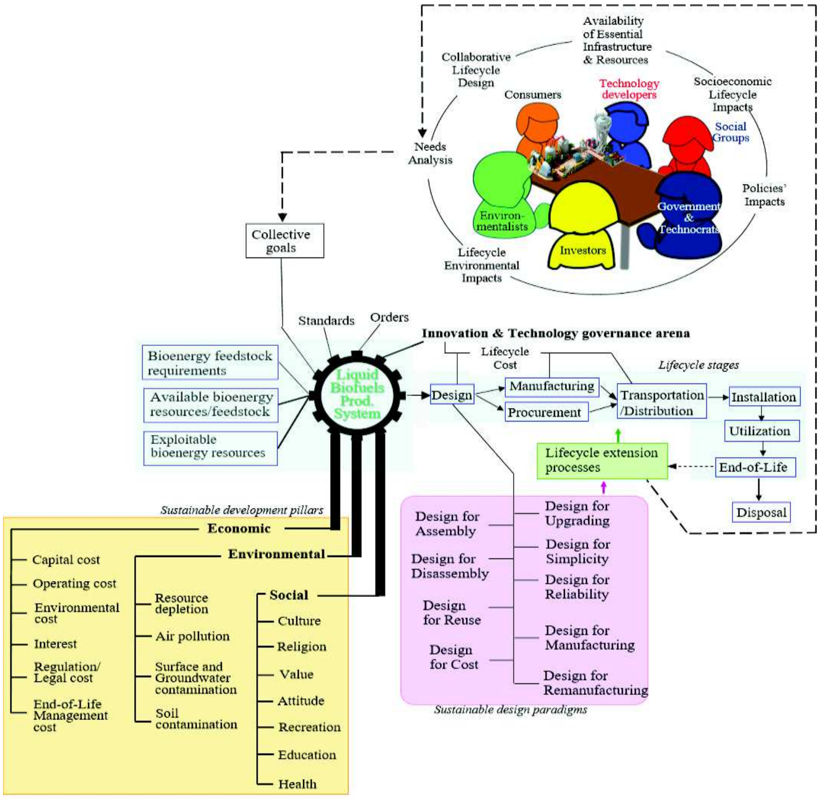

Figure 2. Diagrammatic illustration of a model sustainable pathway to boosting liquid biofuel production in West Africa.

It also shows the need to consider the availability of requisite infrastructure for stable and sustainable operation of biofuels production facilities on a long run (Dunmade, 2010 and 2020). Furthermore, the framework advocates the use of lifecycle engineering principles both in the facility design and management of the operations of such liquid biofuel production systems (Dunmade, 2012 and 2013a). It sees a necessity to ensure that available bioenergy resources match the requirements of the developed liquid biofuels production systems. In addition, it shows the need for progressive capacity building for the evolution/proliferation of local or hybrid liquid biofuel production technologies. Moreover, improved biofuel production would require tailoring the capacity to manageable scale at the beginning and making progressive production and market expansion as the technical-knowhow increases. Involvement of local communities and other stakeholders as participants, right from the beginning throughout the lifecycle of the project would be necessary for the success and continuous improvement/expansion of liquid biofuels production in the region (Dunmade, 2013b and 2018b).

Bioenergy development challenges and solutions

Although there are several benefits in producing liquid biofuels from second generation biomass, there are also many challenges to its implementation (FAO and

PISCES, 2009). Challenges to liquid biofuel production from lignocellulosic biomass can be divided into three major categories, namely: Feedstock, technology and policy issues.

According to Nigam & Singh (2011), 'production of second-generation biofuel requires most sophisticated processing production equipment, more investment per unit of production and larger-scale facilities to confine and curtail capital cost scale economies. To achieve the potential energy and economic outcome of second-generation biofuels, further research, development and application are required on feedstock production and conversion technologies'.

Furthermore, there are many concerns raised regarding potential environmental and socio-economic impacts of bioenergy development in West Africa (Dunmade, 2019). Issues raised regarding bioenergy production in Africa include the requirement of large expanse of land to grow energy crops on a commercial scale, loss of land rights of local communities, economic viability of large scale energy crops production, negative impacts on climate change, water pollution, soil erosion, deforestation, food security, human health and social conflicts, and loss of biodiversity (The Research Council of Norway, 2011; UNU-IAS, 2012; Kgathi et al., 2017). ECOWAS (2014) stated that 'collecting these resources also exposes women-mostly in rural areas-to the risk of injury, rape, or harassment, and limits the time available for education, commercial activities, or leisure.' The use of firewood for cooking also exposes women to 'household air pollution from indoor smoke, small particle pollution, carbon monoxide, and nitrogen oxides' (ECOWAS, 2014).

It is also argued that large scale energy crops production will deprive farmers the land to grow crops required for their subsistence, and that this could lead to food scarcity and food price hike (Anderson, 2007) Consequently, many people at the economic fringes may not be able to afford to buy nutritional food. Energy crops can thus worsen food insecurity in poor countries (Adjovi, 2012). Another concern is that large bioenergy development programs can lead to deforestation. It is also believed that it will worsen the current energy provision burden placed primarily on women, which is not only depriving them of engaging in gainful employment but also responsible for widespread respiratory diseases resulting from their cooking with charcoal and firewoods (Forest cover, 2019). All the aforementioned concerns are genuine and worth consideration in bioenergy development programs. However, those concerns can be addressed through adequate planning and supportive policies. For example, according to Simonyan & Fasina (2013), 'lignocellulosic feedstocks (such as trees, shrubs, grasses, agricultural and forest residues) are potentially more abundant and cheaper than feedstock from conventional agriculture because they can be produced with fewer resources and on marginal and poor lands. Also, agricultural and forest residues are currently available from current harvesting activities without the need for additional land cultivation'. They further stated that about 50% of the residue are burnt on cropland before the start of the next growing season.' Such burning of residue is not only a waste of resources but it also contributes to global warming, photochemical smog and associated health problems. Agrifood process residues, which are currently being sent to landfills, are also potential energy sources that can be harnessed to boost biofuels production in West Africa. The effort being made in Benin, Burkina Faso, Ivory Coast, Mali and Togo at promoting a community based intercropping of improved Jatropha seeds with food crops is helping to stop soil erosion, restoring degraded lands, and providing a significant increase and sustainability on food crops yields (Kotrba, 2013; Bridge builders, 2019). These goals will be easily realized under a more efficient plant breeding and improved agronomic management (Abila, 2014; Baumert et al., 2018). In addition, community scale bioenergy development programs involving the use of improved energy and food crops seedling, efficiently managed biofuel processing and marketing with adequate supportive governmental policies would eliminate or at least minimize most of the aforementioned concerns. Kgathi et al. (2017) buttressed this point by reporting 'positive environmental impacts such as high energy return on investment and high GHG savings when Jatropha is cultivated on abandoned agricultural fields in some parts of West Africa'.

Furthermore, community scale bioenergy programs would lead to increased women employment, improved social status/standard of living of rural dwellers, increase local government revenues, and general rural development. Moreover, it will reduce women's dependence on using firewood for cooking and thereby reduce the associated respiratory diseases. Anderson (2007) recommended slow implementation of jathropa as a biofuel to allow time for farmers to adapt to new modern farming practices/technology. Jatropha, according to Anderson (2007), would be an ideal supplement to small farmers' income since it doesn't require irrigation, requires very little fertilizer and very little care.

CONCLUSIONS

This paper presented the current trend in global liquid biofuels production, with a focus on the status of biofuels production in West African sub-region. A number of steps that need to be taken to boost liquid biofuel production in the region were then highlighted. Among the articulated points are the need to expand the current feedstock base, establishment of enabling environment for continuous improvement in consumer market demand, and steps to evolution and proliferation of locally owned advanced lignocellulosic biofuel production technologies. Taking these steps are expected not only to boost liquid biofuel production in the region, but it will foster continuous growth and encourage innovations in the sector. Potential impacts of implementing the framework is that it will ultimately lead to attainment of a number of sustainable development goals in the West African sub-region.

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