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Commercialisation of biofuel industry in Africa: A review

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Abstract

Diversification of energy sources, agricultural activities and a higher percentage of locally produced energy are goals that can be satisfied by biofuels. Biofuels such as biogas, biodiesel, and bioethanol may be easier to commercialise than other alternative fuels, considering performance, infrastructure and other factors. Lack of a good understanding and application of key concepts of cost estimation—a key to successful project which impacts both the project profitability and influences the technical solutions—is a foremost barrier to its commercialisation in Africa, despite the availability of biomass resources. A plethora of other generic technological and non-technological constrictions has been identified to also hinder biofuels adoption and development. Understanding the economics of biofuel industry is, therefore, crucial in realising eventual commercialisation. This article provides knowledge-based review for expansion (commercialisation) of biomass-derived fuel (biofuel) through improved understanding of its economics in Africa. In addition, recommendations to overcome the technological and non-technological hurdles to market penetration of biofuels are discussed.

Keywords: Biofuel; Renewable energy; Sustainable; Cost estimation; Commercialisation

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Contents

1. Introduction

Energy plays a critical role in the development process, first as a domestic necessity but also as a factor of production whose cost directly affects price of other goods and services [1]. It affects all aspects of development—social, economic, and environmental—including livelihoods, access to water, agricultural productivity, health, population levels, education, and gender-related issues. Access to energy has been described as a key factor in industrial development and in providing vital services that improve the quality of life, the engine of economic progress [2].

Ensuring the provision of adequate, affordable, efficient and reliable high-quality energy services with minimum adverse effect on the environment for a sustained period is not only pivotal for development, but crucial for African countries in which most are struggling to meet present energy demands. Further, the continent needs such energy services to be in the position to improve its overall net productivity and become a major player in global technological and economic progress. It needs to increase from 10% to 35% or more, access to reliable and affordable commercial energy supply by Africa's population in 20 years [3]. As contained in the New Partnership for African Development (NEPAD) objectives on energy, African countries need to improve the reliability as well as lower the cost of energy supply to productive activities in order to enable economic growth of 6% per annum and to reverse environmental degradation and health impacts that are associated with the use of traditional fuels in rural areas [4,5]. The Millennium Development Goals (MDGs) especially MDG 1, reducing by half the percentage of people living in poverty by 2015 cannot be met without major improvement in the quality and magnitude of energy services in developing countries. A typical report that underscores how energy can be used to eradicate extreme poverty is the United Nation Development Programme in Mali, which initiated the spread of biogas units in peri-urban areas around the city of Bamako through the development of a locally adapted prototype [6]. Wider use of these biogas units would help reduce the demand for firewood in peri-urban areas and would supply high-quality fertilizer for local farming efforts. This initiative will also help in achieving MGD 4–7, reduce child mortality, improve maternal health, combat diseases and ensure environmental sustainability.

Africa is endowed with significant quantities of both fossil and renewable energy (RE) resources. Any strategy to develop these energy resources must be extremely mindful of both the environmental pollution problems (through carbon monoxide, ozone forming hydrocarbons, hazardous particulates, acid rain-causing sulphur dioxide etc.), and the threat of "climate change" associated with the use of fossil fuels, the latter as a result of the accumulation of certain greenhouse gases (GHGs) in the atmosphere (mainly carbon dioxide, methane and nitrous oxide that trap heat in the lower atmosphere and lead to global warming). As adopted by the third conference of parties (COP3) in Kyoto, Japan, attempts have been made to agree to legally binding obligations on most developed countries to reduce their GHG emissions by an average of 5.2% below 1990 levels by 2008–12 [4]. These attempts are resulting in the development of financing mechanisms such as the Clean Development Mechanism (CDM) that may be able to leverage significant resources for the development of RE resources on the African continent.

It is also noteworthy that there is an uneven distribution of the fossil energy resources on the African continent, which is reflected in the energy production/consumption patterns. This poor distribution of fossil fuel resources makes over 70% of countries on the continent dependent on imported energy resources, which again supports the development of abundant RE resources. Africa has significant renewable sources that can, at a minimum, be harnessed for satisfying certain niches in the energy sector. It has been estimated by Marrison and Larson that planting 10% of the total land in Africa that is not forest, not wilderness and not cropland with biomass energy crops would produce 18 exajoules (EJ) of bioenergy [7]. The development of renewable technologies and in particular bioenergy production (conversion of biomass) will help reduce the dependence on non-RE resources as well as minimise the social impacts and environmental degradation problems associated with fossil fuel.

Biomass-derived fuels share many of the same characteristics as their fossil fuel counterparts [8–10]. Once formed, they can be substituted in whole or in part for petroleum-derived products. With the petroleum age nearing its end, biomass fuel relevant to African economy that can at least partly close the prospective gap which is opening between globally rising energy demand and the uncertain expansion of energy supply are gasohol—a mixture of 10% ethanol in gasoline, biogas—produced by means of anaerobic digestion of plant and animal waste to yield methane, and biodiesel (fatty alkyl esters)—a cleaner-burning diesel replacement fuel made from natural renewable sources such as new and used vegetable oil by cracking the triglyceride molecule.

Biofuels, which are realistic contenders as a major low-carbon fuel source for the future present many opportunities. Multi-benefits analysis by the World Bank [11], shows that a biofuels industry in Africa, based on biomass feedstocks, would have substantial environmental, economic, employment and wider social benefits on a national scale—especially for rural and regional sections of Africa among which are:

- Source of foreign exchange saving activity especially for oil-deprived countries (development and use of locally-produced renewable fuel, and reduction of demand for imported petroleum), for example Zimbabwe is embarking on a national biodiesel programme which if properly implemented could contribute to 10% of her fossil diesel consumption per year equivalent to 300,000 l/day.

- Boosting of local agriculture productions and additional markets and revenue to farmers; leading consequently to the increase of rural folks purchasing powers and quality of life. By way of example, an on-going ethanol project in Jigawa state, Nigeria is expected to provide up to US $4 billion investment facility to blend premium motor spirit (PMS) with ethanol and help cushion fuel price as well as generate up to 7000 jobs [12].
- Beneficial environmental impact through the usage of organic municipal solid waste materials to generating a higher value end-product. The prototype carbon fund (PCF)-supported landfill gas to energy project located in the semi-arid interior of South Africa could reduce emissions related to coal-fired power production which include sulphur oxide, nitrogen oxide and particulates by displacing electricity from the grid.
- Reduced level of carbon dioxide emitted by motor engines and then preservation of the quality of the atmosphere.

In a recent public symposium organised by United Nations Foundation (2006), it was noted that biofuels could also provide opportunities for poverty reduction and for satisfying the energy needs in rural and remote region, help generate employment and local economic development opportunities; it helps curb global warming and contributes to the protection of human health from air pollution; and, it enhances energy security [13].

This paper analyses the energy geography in Africa, the economics of a biofuel process industry in Africa, and limitations to biofuel commercialisation and conclude by suggesting future courses of action to take to speed up biofuels commercialisation. It is believed that this paper will be of benefit to the energy policy makers (planners) and entrepreneurs not only on the continent but also in other developing countries.

2. Energy overview in Africa

Africa is the second largest continent after Asia making up only 10% of the world's population, equivalent to about 80% of India's population. It has a total surface area of 30.3 million km^2, including several islands, and an estimated total population of 888 million [14]. Its population density in some regions is rather low. This is due in part to the Sahara Desert, which occupies one-fourth of Africa's landmass and is not suitable for habitation. In 1999, the population of sub-saharan Africa was estimated to be 642 million, over 80% of the African continent. Poverty in Africa is mainly rural. Africa is not only the poorest region in the world; it was the only major developing region with negative growth in income per capita during 1980–2000 [15]. According to the World Development Indicators of 2006, the growth rate of Sub-Saharan Africa (4.8%) improved drastically in 2004 to exceed the global growth rate (4.1%) of that year. However, this improvement does not detract from the fact that Africa remains the poorest continent in the world with one-third of the population starving [16]. The continent remains fragile with perpetual poverty due to several factors. Among the factors identified include deterioration of ecosystems with 25% of dry lands in Africa carrying degraded soils; 10% of soils in the humid parts of Africa being susceptible to deterioration; and the fast-growing human population. Other factors are poor political and economic management that increases poverty and have resulted in precarious political and economic environments. There is a direct correlation between the poor and the use of traditional biomass where a large proportion of people who live on less than $2 a day use traditional biomass as energy source (Fig. 1).

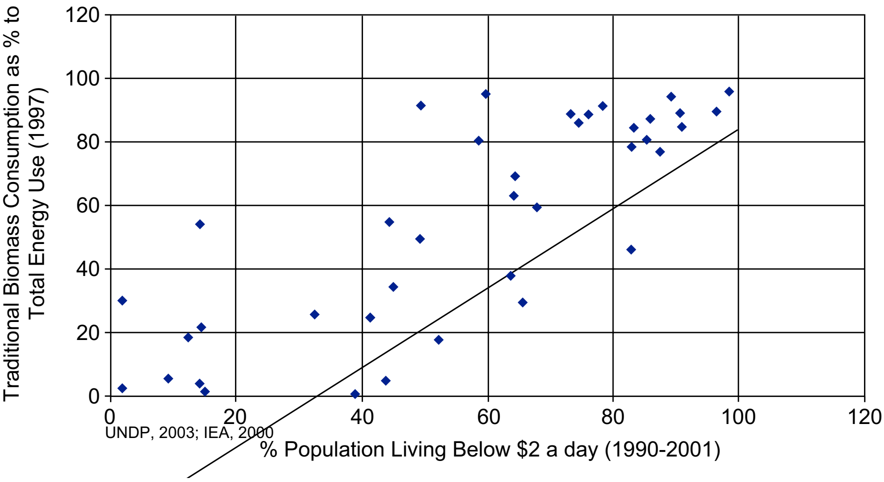
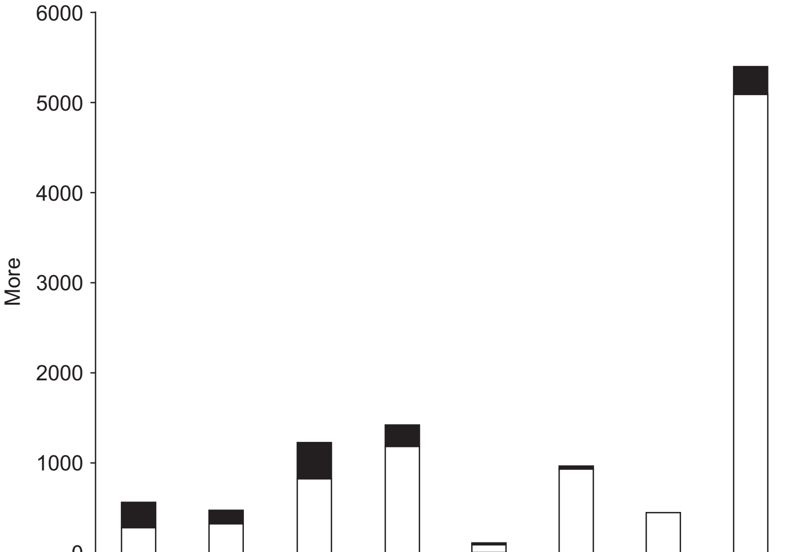


Fig. 1. The link between poverty and traditional energy use [17].



	Africa	Latin America	Asia	China	Non-OCED Europe	Former USSR	Middle East	OECD
■ share of renewables in total energy supply	279	135	400	243	10	27	3	305
□ Total primary energy supply	559	464	1224	1426	103	962	446	5395

Fig. 2. Renewables share of total energy supply [14].

Africa is an unexploited resource for biofuels development. Although the majority of African nations rely on biomass as a main energy resource, it is inefficiently used and to the detriment of a households' well being. Fig. 2 shows the share of renewables in the total primary energy supply (Africa renewables share is 50.1% in 2003). Tropical sub-Saharan African population is expected to serve as a prerequisite that will underpin the growth of

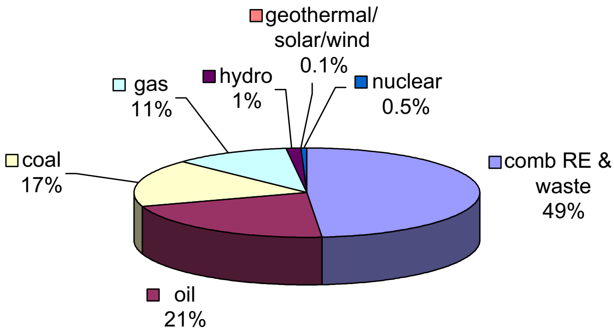


Fig. 3. Share of total primary energy supply in Africa in 2001 [15].

the continent's economy in rural areas. The high poverty level in Africa is revealed in the consumption model of modern energy. Per capita consumption of modern energy in African continent is very low when compared to other continent. Out of the total primary energy supply of 514 Mtoe in the continent in 2001, 48.7% which is largely in traditional form is combined renewable and waste [18].

The low levels of modern (commercial) energy consumption prevalent in Africa apart from the heavy usage of traditional (non-commercial) fuels-primarily biomass as indicated in Fig. 3 is also due to massively underdeveloped energy resources, poorly developed commercial energy infrastructure, widespread and severe poverty which makes it impossible for people to pay for conventional energy resources and landlocked status of some African countries (there are 15 landlocked countries in Africa) which makes the cost of importing commercial energy more expensive [19].

The energy resources distribution in Africa shows that every sub-region of Africa except East Africa is a net exporter of energy, at the same time importing petroleum products at the cost that is crippling the economy. North Africa is by far the largest, with significant oil and gas exports going to Europe and other markets. West Africa's exports are almost exclusively oil, and from one country—Nigeria. Southern Africa's net energy exports are oil (from Angola) and coal (99% of Africa's coal output) mainly from South Africa. Central Africa is an oil-exporting region due to Cameroon, Congo and Gabon. East Africa is a tiny net energy importer (mainly oil). In 1997, only five countries (South Africa, Egypt, Algeria, Nigeria, and Libya) accounted for 78% (8.9 quads) of all energy consumption, and 84% (22 quads) of all energy production in Africa (Table 1).

Africa suffers from two sets of problems: dependence on export products that are of declining importance in world trade and the loss of market share for primary exports. This underlines the need for energy diversification, in which biofuel can play a vital role. RE technologies (RETs) offer developing countries some prospect of self-reliant energy supplies at national and local levels, with potential economic, ecological, social, and security benefits [21].

3. Biofuel process industry and economics in Africa

The inexhaustible nature of biofuel as energy source is an important asset for their future potential from the security standpoint. Biofuels, as the name implies, are fuels

Table 1
African countries which import and export energy [20]

Major energy exporter[a]	Net energy exporter	Importers[b]
Nigeria	Angola	Benin
Algeria	Cameroon	Eritrea
Libya	Congo	Ethiopia
South Africa	Democratic Republic of Congo	Ghana
Egypt	Cote d' Ivoire	Kenya
Gabon	Gabon	Morocco
Congo	Sudan	Mozambique
		Namibia
		Senegal
		Tanzania
		Togo
		Zambia
		Zimbabwe

[a]Major energy exports are in excess of 0.5 quads.
[b]Most of the African countries imports are very small (less than 0.3 quads).

(solid, liquid and gas) derived from biomass, a renewable resource that can potentially be harvested sustainably. Biofuels are made from biomass through biochemical (fermentation of sugar to alcohol, and anaerobic digestion or fermentation) or thermochemical processes (gasification, pyrolysis, liquefaction). The growing seriousness of the global energy problem and associated environmental pollution are substantially increasing the importance of the development and commercialisation of biofuel industry in Africa. The production and commercialisation of biofuels in Africa could provide an opportunity to diversify energy and agricultural activity, reduce dependence on fossil fuels (mainly oil) and contribute to economic growth in a sustainable manner. Several studies have reported significant decline in the unit cost of RET over the past two decades. Further reduction in cost can be expected with technical progress and market growth [22]. Whilst the topic of ''bioenergy'' has received significant public and legislative attention in several developed countries such as Germany, Canada, USA and New Zealand and developing countries like Brazil and India, relatively little effort has gone into promoting modern bioenergy in African countries, despite the estimated large resource base in many of them [7]. For example, in South America, Brazil's sugarcane-based ethanol industry now produces about 160,000 barrels (1072 GJ) of oil-equivalent a day, assisting the country in achieving self-sufficiency in oil [23]. Also, in Sweden, bioenergy has grown into the second largest source of energy, contributing to reducing emissions of carbon dioxide and improving energy supply security. The use in 2003 alone was 378 PJ (105 TWh), or 42 GJ/capita [8]. There is lack of coherent biofuel strategy in Africa despite the increase in the price of conventional fuel on a daily basis, and their rising demand mainly due to psychological fear of geopolitical uncertainties compared to the dwindling convertible currency earning and rising evidence of climate change (2006 has been declared by the United Nations as International year of desserts and desertification).

There are very few operational commercial biofuel systems in Africa as that of small-scale systems. Existing bioethanol plants are concentrated mostly in the Southern African Development Community (SADC)-the southern tip of the continent such as South Africa, Malawi, Swaziland, Mauritius, and Zimbabwe. Other commercial ethanol producing countries are Ethiopia and Kenya. By way of example, ethanol programmes that produce a blend of ethanol and gasoline (gasohol) for use in existing fleets of motor vehicles have been implemented in Malawi, Zimbabwe and Kenya. There are strong indications that Nigerian cars may start running with a combination of petrol and 10% ethanol by the end of this year, signalling a breakthrough in efforts to find alternative fuel sources [24]. Available evidence indicates that these programmes have registered important economic benefits. In the case of Zimbabwe ethanol plant (Triangle Ethanol Plant), 60% of the whole plant is locally produced. The building was erected by local workers trained specifically for the job. It is estimated to be the lowest capital cost (the plant was designed to produce 120,000 liters ethanol per day with a capital cost of $6.4 million at 1980 prices) per litre for any ethanol plant at that time. However, in 1994–95, Triangle refinery decided to stop production of ethanol in favour of rectified spirit (an industrial alcohol used widely in printing solvent and capable of being refined to portable alcohol) which is exported to European destinations, and the blending of ethanol with petrol in Zimbabwe stopped at that time. This is attributed mainly to reduced government support [25].

Small-scale biogas plants are located all over the continent but very few of them are operational. It is estimated that only 25% of 300 units installed between 1980 and 1990 in Kenya are operational today. The high failure rate can be traced to the following main reasons [26]:

- Poor design and construction of digesters, wrong operation and lack of maintenance by users.
- Poor dissemination strategy by the promoters.
- Lack of project monitoring and follow-up by promoters.
- Poor ownership responsibility by users.
- Failure by government to support biogas technology through a focused energy policy.

The growth of large-scale anaerobic digestion (biogas) technology in the region is still at embryonic stage, but the potential is promising. The Kigali Institute of Science, Technology and Management (KIST) has developed and installed large-scale biogas (830 m^3 system in 2003 and 1430 m^3 system in 2005) plants in prisons in Rwanda to treat toilet wastes and generate biogas for cooking. A recent initiative to tap energy from waste land fills was the US $2.5 million Global Environment Facility (GEF)-financed project in Dar-es-salaam, Tanzania which was expected to utilise an estimated 23,000 m^3 of methane generated by the process of anaerobic digestion. It was estimated that large-scale replication of the pilot GEF Tanzania biogas project could result in the generation of electricity equivalent to over 10% of the Tanzania's total electricity-generating capacity. This promising initiative was, however, ended prematurely primarily due to problems of cost escalation which were partially linked to technology selection problems. The project also faced significant institutional constraints [22]. It is pertinent to note that most of the biogas plants in Africa are set up not only for the purpose of producing energy (cooking and lightning, fuel replacement, shaft power) but also as environmental pollution abatement system. Some of these are located in South Africa, Rwanda, Kenya, Tanzania, Burundi and Ghana.

Biodiesel technology can be regarded as an emergent technology in Africa. To date, no commercial biodiesel plant has been built in Africa. In Ghana, a biodiesel plant by

Anuannom Industrial Projects Limited (1.2 million-dollar factory, 360,000 ton production/annum), which has been under construction since 2003 would have been the first commercial biodiesel plant in Africa, but the construction was stalled probably due to lack of capital base to complete the construction and dispute [27,28]. There are very few small-scale biodiesel plants in Africa. Biodiesel SA in South Africa created by Daryl Melrose produces biodiesel from used vegetable oil. Efforts are in place to establish one in the nearest future. Presently, most countries in Africa are busy cultivating *Jatropha curcas* (physic nut), a drought-resistant and frost hardy plant. The seed of *J. curcas* contain high percentages (30–35%) of oil, which can be extracted for further processing.

There has been a tremendous increase in biofuel technology development and commercialisation in other continents. One of the reasons for this is sustained government support (in France, tax exceptions for biofuels is 0.35 EUR/l for biodiesel and 0.50 EUR/l for bioethanol and America has bioethanol subsidies of US $0.51/gal) [29]. For example, American output of maize-based ethanol is rising by 30% a year; Brazil, long the world leader in bioethanol production, is pushing ahead as fast as the sugar crop from which ethanol is made will allow; China, though late to start investing into bioenergy technology, has already built the world's biggest ethanol plant (The Jilin Tianhe Ethanol Distillery has an initial capacity of 600,000 ton a year—2.5 million liters per day and potential final capacity can be raised to 800,000 ton/year) [30]; Germany, the big producer of biodiesel, is raising output 40–50% a year while France aims to triple output of the two fuels (bioethanol and biodiesel) together by 2007; Britain, taking a backward stance has already embarked on investment into biodiesel industry. Also after a long research on biofuels, a Canadian firm has plans for a full-scale ethanol plant that will replace today's grain or sugar feedstock with straw. China, India, and Nepal have extensively utilised biogas as a source of energy and as liquid fertilizer for soil enhancement since the 1950s [31].

The main contentious problems of biofuel commercialisation in Africa relate to economics and political will. The economics of biofuel production and consumption will depend on a number of factors specific to the local situation. These factors include (a) the cost of biomass materials, which varies among countries, depending on land availability, agricultural productivity, labour costs, etc.; (b) biofuel production costs, which depend on the plant location, size and technology, all of which vary a great deal among countries; (c) the cost of corresponding fossil fuel (e.g., gasoline, diesel) in individual countries, which depends on fluctuating petroleum prices and domestic refining characteristics; and (d) the strategic benefit of substituting imported petroleum with domestic resources. The economics of biofuel production and use, therefore, will depend upon the specific country and project situation [32]. The variation of cost with location is referred to as location factor or index. Location does not only affect the cost of construction plant directly but also indirectly. In considering the cost of constructing a plant in other locations, the effects of perceived, real and to-be investigated factors like different laws, often a different language, the political and social environment, the industrial capability which is a function of availability of bulk materials, construction labour and productivity, cultural and institutional factors, the financial resourcefulness and economic situation in the location needs to be investigated. The effects of these several factors on cost will be very different in a developed country where the existing cost estimation models are concentrated, as compared with a developing country, such as countries in Africa. For biofuels projects to be developed and commercialised in the various African countries, it will thus be important that an indigenous theory of cost prediction, central to economic feasibility studies, be developed. It appears that there is no such theory, and not even a good collection of relevant data.

Economic competitiveness against mainly fossil fuel is a very common argument against RE. The cost of producing very low CO_2 biofuels such as cellulosic ethanol and methyl ester (biodiesel) are still higher than the cost of gasoline and conventional diesel. The gap is expected to narrow with the current hike in the price of oil. The costs could also probably decline in the future, especially if new processes being developed for producing cellulosic ethanol are successful, and subsidies as well as tax exemptions, which are currently applied in Europe and USA are used [31].

For many products and services, unit costs decreases with increasing experience. This effect is often referred to as learning by doing, progress curve, experience curve or learning curve. The learning curves are empirical and represent graphically how market experience reduces prices for various technologies and how these reductions influence the dynamic competition among technologies. Until several commercial-scale production facilities are built and more real-world experience is gained, the production costs of these fuels may not change significantly.

In nearly all production operations, some change in cost structure occurs as plant size is changed. Thus the theory of economy of scale presupposes that there exists an optimum size plant for most production operations [33]. Economies of scale and technological advancement can lead to increased competitiveness of these renewable alternatives, thereby reducing the gap with conventional fossil fuel. One of the most important examples is the one provided by Brazilian Alcohol Program (PROALCOOL), established in 1975 with the aim of reducing oil imports by producing ethanol from sugarcane. The programme has positive environmental, economic and social aspects and has become the most important biomass energy programme in the world. The Brazil ethanol production cost is now competitive from close to US $100 a barrel at the initial stage of the programme in 1980. This increase is measured in terms of progress ratio (PR) of the technology, which is the variation of prices according to cumulative sales. Thus, an efficient technology penetration is one that achieved low PRs. In US dollars, sugarcane ethanol produced in Brazil has shown PR of 93% (1980–85) and 71% (1985–2002) [34].

Nguyen and Prince [35] also consider ways to reduce the cost of ethanol for bioethanol plant (in Australia) by optimising plant capacity. They derive a simple model of general applicability by balancing crop transport costs (which increase with plant size) against the production costs, which decrease as economic of scale. The relationship is generally applicable to all bioenergy conversion plant in general, which requires biomass to be transported from surrounding area. At the optimum, the cost of transporting crop, per unit quantity of fuel, must be a predictable proportion of the unit cost of production, generally in the range of 0.4–0.6. The ratio allows an easy check as to whether a design or operating plant is near the optimum size, and if not what action would improve the economy of the operation. This relation can also be used to predict the consequences of cost changes.

By way of example, in a relatively recent study of biofuel production in Africa [36], which investigated "economics of small-scale ethanol production from breadfruit and cassava flours via plant enzyme and acid hydrolysis" the working capital required for the plant process was estimated with the method reported by Lyda (1972) while the estimation of equipment running costs was based on the method of Degamo et al. (1979) in which case it was assumed that maintenance and repairs costs would increase by a uniform amount (G) and would constitute an arithmetic series. However, the estimation methods used were obsolete and disparate due to difference in location.

Economics of two types of biofuels namely biodiesel and biogas which are among a wide range of sustainable rural energy options will be discussed.

3.1. Biodiesel economics

The technology of converting vegetable oils and animal fats into biodiesel has been extensively studied [37–39]. Biodiesel can be made from two different chemical processes. The most commonly used and most economical process is called the base-catalysed esterification of the fat with methanol typically referred to as the “methyl ester process”. Base esterification is preferred because the reaction is quick and thorough, it occurs at lower temperature and pressure resulting in lower capital and operating cost [40]. This process creates four main products namely: methyl ester (biodiesel), glycerin, feed quality fat and methanol that is recycled back through the system. Most, if not all, existing commercial biodiesel plants use the methyl ester process.

Biodiesel can also be produced using ethanol, oil feedstock, and a catalyst to make an “ethyl biodiesel”. The benefits sometimes alluded to ethyl biodiesel include the following: the process does not require an alkali reagent such as sodium hydroxide (NaOH) and also the reaction process is a one step reaction that takes place at ambient temperature (without additional heat). Its drawbacks include sensitivity to water, which can result to quality problem in handling and the relatively high production cost per unit [41,42]. The quality problem and the higher operating costs could make it difficult to compete effectively with the more established methyl biodiesel production process.

A major technological issue in the biodiesel production is the question of whether to construct a batch or a continuous plant. Most plants currently in operation are batch plants and produce discrete “runs” of product. These plants in general vent unused methanol into the air and do not recapture unused catalysts resulting in high operating cost of the plant and serious environmental issue from the disposal of polluted water. Processing in discrete runs can at times create quality and homogeny problems in the final biodiesel product. However, batch operations have the benefit of being feasible on a small scale and also it is an established design. The former benefit of biodiesel will find a better application in the rural areas in Africa due to the financial base from local investors.

Continuous flow plants are not nearly as common as the batch counterpart. It has been studied to have several important operating cost advantages over the batch process. It is possible to reuse excess NaOH that has not become part of the biodiesel and reuse catalysts, which are lost in batch processes. The major obstacle to continuous flow operation appears to be the higher initial investment required. This is due to the fact that continuous flow generally requires a larger scale plant; thus the initial capital outlay to build a continuous flow plant is generally higher. Another issue is the availability of feedstock, which adds to the high initial costs. Price of crops as well as the season of the year will affect the overall cost of the biodiesel. This can be a major problem for a small start-group especially in the developing country Africa where the financial institutions lack understanding of the RE projects and their potential benefits. Also, there are high risks, difficult to be accurately assessed, associated with technological immaturity and unpredictable government energy policies; thus, for the smaller start group, it can be excessively difficult to find financing for a larger biodiesel plant size.

When evaluating technology and process alternatives, it is important to consider not only the capital costs of the initial investments but the operating costs of running the plant. More attentions tend to be focused on the capital expenditure required to build the plant. This is reasonable since it is the first barrier that must be overcome in establishing a biodiesel production plant. However, the long run success of the plant is frequently more dependent on the daily operating performance than on the amount of the initial capital outlay invested. Low quality, inconsistent in the product quality, poor product yield or high operating costs resulting from the day-to-day running cost of the plant can cause low efficiency or total failure of the venture.

The economics analysis of a soybean methyl ester project indicate that the cost could be broken into the following categories: raw material cost, capital cost and operating cost. The single most important factor influencing the economic viability of biodiesel is the feedstock cost. The average cost of raw material for biodiesel plant ranges between 60% and 75% of the total biodiesel production cost [43]. Therefore, economics of biodiesel production should be centred on its working capital.

Investment in plant and equipment (capital cost), while extremely important in establishing biodiesel production capabilities, is much less important than feedstock costs in the final net price of biodiesel. Therefore, the cost of producing feedstock has been the major obstacle to economic feasibility of biodiesel. There is no single cost for biodiesel production, but rather a wide range of costs depending largely on the source of feedstock used and to a lesser extent on the co-product credits for the high protein meal and glycerin.

It is observed that biodiesel production facilities are relatively insensitive to economies of scale normally enjoyed by larger plants. This is due to the fact that scale-dependent variables such as labour only constitute a small portion of operating cost [44]. Economics of biodiesel production will also depend greatly on localised variable (site specific). Locations that offer low utility rate (e.g. electricity), existing facilities, and close proximity to large oil seed acreage (farm) would be a good location.

We have investigated the sensitivity of the Nguyen and Prince model (Nguyen and Prince, 2004) outcomes viz throughput tonnage and biodiesel cost to a wide range (250%) in variables such as the capital cost capacity factor, labour costs, depreciation factor, transport cost and seed cost. It was revealed that finding the optimum (least cost) plant capacity is an important element in planning for the establishment of a biodiesel-processing plant as the result showed that the optimal plant size can vary widely in the range (500–5000 kg/h) for the plant sizes explored. Also the results obtained in the study generally show a near flat profile around the optimum plant size (biodiesel cost vs. plant capacity) which indicates that smaller than optimum plant observed for each of the variations in the parameters can be built with only minor cost penalty [45].

3.2. Biogas economics

Biogas which is produced by the anaerobic fermentation of organic material is distinct from other renewable energies like solar, wind, thermal and hydro sources because of its importance in controlling and collecting organic waste materials which, if untreated, could cause severe public-health and waste pollution problems, and at the same time producing fertiliser and water for use in agricultural irrigation. Unlike other forms of RE, biogas production systems are relatively simple and can operate at small and large scales in urban or very remote rural locations [46], and nor is it monopolistic. Biogas technology, therefore, contributes to control of environmental hazards (preventing air pollution; and mitigating GHG emissions) and recycling of nutrients whilst alleviating dependence on imported fuel. It also reduces the use of forest resources for household energy purpose and thus slows down deforestation, soil degradation and resulting natural catastrophes like flooding and desertification.

The economy of a biogas plant consists of large investments costs, some operation and maintenance costs, mostly free raw materials, e.g. animal dung, aquatic weeds, terrestrial plants, sewage sludge, industrial wastes, poultry litter etc., and income from sale of biogas or electricity and heat. Sometimes, other values can be added, e.g. for improved value of sludge as a fertilizer. The future cost of biomass energy, biogas inclusive, will not only depend on factors such as the extent of technological advances in biomass-energy conversion and feedstock productivity but also on the good understanding of the relation between capital costs and plant size which is an important determinant of the scale of a fixed-proportions enterprise [47,48]. In assessing the economic viability of biogas programmes one should distinguish four major areas of applications: individual household units, community plants, large-scale commercial animal-rearing operations, and industrial plants. In each of these cases, the financial feasibility of the facility depends largely on whether outputs in the form of gas and slurry can substitute for costly fuels, fertilizers or feeds which were previously purchased, while at the same time abating pollution. Economics of biogas technology rest on the following factors [49]: (a) the useful energy content of different fuels, e.g., dung, fuel-wood, kerosene and biogas; (b) the efficiencies with which these fuels are currently being used, or the possible equipment which could lead to higher efficiencies; (c) the NPK contents of different organic fertilizers, and the fertilizer-yield response under different agronomic conditions and crop rotations; and (d) behavioural aspects of the energy sources or organic fertilizers such as current use patterns etc.

Our own study of small and institutional scale biogas plants in Africa indicates diseconomies of scale with the cost capacity factor (n) of 1.20. The cost capacity factor obtained is notably greater than the conventionally used 0.6 factor rule [50]. The economics also showed that biogas technology economics is not affected by geographical limitation and location (costal and landlocked locations). This trend collaborates the fact that a biogas technology can be locally produced or built, and locally operated. The cost of the technology is, therefore, largely independent on exchange rate volatility or geographical location of the plant.

3.3. Fuel ethanol economics

The use of ethanol dated back to 100 years, but it was the oil shock of the 1970s and the push in the 1980s and 1990s for more environmentally acceptable fuel that has seen its rapid growth of production and consumptions in countries like Brazil, the USA and Europe. The recent interest in ethanol production in Africa is driven partly by the increase in oil price and its low convertible currency earnings. At present, the global ethanol production is over 40 billion accounting for less than 2% of the total petrol consumption. The International Energy Agency (IEA) predicts that ethanol alone has the potential to make up to 10% of world gasoline use by 2025 and 30% in 2050.

Ethanol is produced by both biological and physical process (fermentation of sugar with additional conversion step to fuel grade by distillation). It can be produced in two forms: hydrous (or hydrated) and anhydrous. Hydrous ethanol typically has purity of about 95% plus 5% water. This can be used as a pure form of fuel in specially modified vehicles. Anhydrous alcohol (water-free or "absolute") on the other hand is formed when the last traces of water are removed. Anhydrous ethanol requires a second stage process to produce high-purity ethanol for use in petrol blends; in effect, the 95% pure product is dehydrated using Azeotropic processes or a molecular sieve to remove the water, resulting in 99% pure alcohol. Ethanol can be produced from three main types of biomass raw materials: (a) sugar-bearing materials (such as sugarcane-juice, molasses, sorghum, wheat) which contain carbohydrates in sugar form; (b) starches (such as corn, cassava, potatoes) which contain carbohydrates in starch form; and (c) cellulose (such as wood and agricultural residue) whose carbohydrate form is more complex [32]. While all strategic factors such as economics and environment protection favour the use of ethanol as a fuel extender in place of fossil fuels, the major source of deterrence seems to emerge from the alcohol based chemical industry. African countries are amongst the few that have developed significant presence in alcohol-based chemical industry in the world.

It is difficult to provide generally information about ethanol fuel. This is because the production cost of ethanol and its economic value to the consumer and to the country depend on many tangible and intangible factors making the costs very site-specific and variable even from day to day. For example, production costs depend on the location, design and management of the installation, and on whether the facility is an autonomous distillery in a cane plantation dedicated to alcohol production, or a distillery annexed to a plantation primarily engaged in production of sugar for export [51].

There are different economic strategies for co-producing sugar and ethanol. The main choice is whether to produce in fixed or flexible quantities. Fixed quantities production generally means reserving all of the economically extractable sugars for sugar production and using "C" molasses or "final molasses" for ethanol production. C molasses is not valuable for sugar production because the sugar extraction has reached a point of diminishing returns. Such a strategy would be chosen when the market value of sugar is generally higher than that of ethanol in production-equivalent terms, and is expected to remain higher for the foreseeable future. Alternatively, sugar extraction can be halted after the first or second stages, resulting in "A" or "B" molasses, respectively. These molasses steam will have fermentable sugars that can still be economically extracted. However, the presence of additional fermentable sugar increases the efficiency of ethanol conversion. Consequently, if ethanol is expected to have a market value close to or greater than that of sugar, then it makes economic sense to prioritise ethanol production over some sugar production, by using molasses A or B as the ethanol feedstock. Distilleries can benefit from having the flexibility to switch these alternatives balances of molasses use [32].

While the economics for ethanol production is important, the real incentives for fuel ethanol production have been supported by the agricultural sector, national energy security, and environmental benefits. Economies of scale have been shown to exist in construction costs of ethanol plants. Gallagher et al. [48] suggested an estimated power factor of 0.86 for dry mill ethanol industry based in the USA. However, average capital costs for plants of a given size at a particular location is still highly variable due to costs associated with unique circumstances, such as utility access and environmental compliance. Since the production of fuel grade ethanol involves sophisticated and expensive process and equipment, economics of its operation should carefully be examined.

We have investigated the ethanol cost and optimum plant size for bioethanol plant located in Delta and Lagos state of Nigeria using three different types of cassava yield (10, 18 and 25 metric ton/ha). The study established that, both the yield of cassava per unit area and the location of the biomass have a significant impact on the ethanol cost and optimum plant size. The optimum plant size decreases as the agricultural yield of the cassava decreases (increased cost of cassava to meet the production target); 25 metric ton/ha gives the minimum cost of ethanol (112.44 naira/Kl) with optimum plant size (60,000 l/day). The implication is that for low agricultural productivity, it is better to build smaller distilleries. Of significance in this regard is the determination of optimum size of the plant, which will minimise the cost of production.

4. Barriers to biofuel commercialisation in Africa

For developed countries, RE sources primarily serve as a means to diversify the national energy supply and a means by which the concept of sustainable development can be implemented and GHG emissions can be reduced. However, for developing countries, renewables in general and biomass energy in particular play a very different role and is used in different ways. There is a great difference of background motives and a resulting performance gap between the South and the North in terms of harnessing RE products such as biodiesel. Therefore, it has become important to fill this gap with experiences gained in the developed world, but adapted to the needs of developing countries.

The fundamental problems to commercialisation of biomass-derived energy exist in both developed countries and developing countries. However, the magnitude and characteristics is more pronounced in developing countries. The multi-dimensional differences among regions and countries make the analysis of the magnitude of these hurdles more complex. Despite national differences, it is possible to generalise some barriers. The table below (Table 1) gives the schematic view of barriers to accelerated adoption and commercialisation of biofuel technology in Africa. A classification of developing countries is made in line with economic and technical development status in line with study carried out by Bhagavan [52].

Various generic barriers currently identified to hinder the adoption and commercialisation of biofuel technologies in Africa apart from the high cost of raw materials and other economics-related constrictions can be categorised as technological and non-technological (policy, legal, financial, institutional, cultural, social etc.) constraints. These barriers are in a way general for RE (Table 2).

- *Type A*: Technologically advanced developing countries, with well diversified and fairly comprehensive industrial, energy and R&D infrastructures e.g. South Africa.
- *Type B*: Technologically advancing developing countries, which are industrialising fairly fast, but are still quite limited in the diversification of their industrial, energy and R&D infrastructure e.g., Egypt, Morocco, Algeria.
- *Type C*: Slowly industrialising developing countries, with still very limited infrastructure in industry, energy and R&D, such as, Nigeria, Mauritius, Libya.
- *Type D*: Technologically least-developed countries: most sub-Saharan Africa countries, e.g., Ethiopia, Chad, Burundi, Mozambique, Ivory Coast, Niger, Dr Congo, Somalia, Mali, and Sudan.

Table 2
Schematic barriers assessment on a classified country basis (adapted from [52])

	Institutional/ policy hurdle	Technical hurdle	Economic hurdle	Financial hurdle	Information hurdle	Capacity hurdle
Type A	**	*	**	**	*	*
Type B	**	**	**	**	**	**
Type C	***	**	***	***	***	**
Type D	***	***	***	***	***	***

Low: *, Medium: **, High: ***.

4.1. Policy, institutional and legal hurdles

The commercialisation of biofuel systems requires adequate institutional support and corroboration. Lack of coordination among institutions involved in RE development and commercialisation (excessive bureaucratic bottleneck) such as government ministries of energy/science and technology, research institutes, and financial institutions, hinders efforts for the accelerated adoption of RETs. Ghana established the National Energy Board (NEB) in 1983 with one of its mandate to develop and demonstrate RE in the country. The NEB ceased to operate in 1991 and the RE activities were later taken on by the Energy Sector Development programme (ESDP) established in 1996. The ESDP closed down in 2002 and has in its place the DANIDA supported National Renewable Energy Strategy [18].

A major argument against RE in general and biofuel in particular is the large subsidies requirements. Subsidies conceal the commercial energy cost. This badly allocates scarce capital resulting to imbalanced competition between energy sources. Failure on the part of government to extend the subsidies enjoyed by the conventional energy to RE technology is also a hurdle that needs to be resolved. In addition, very few of the African countries have in place clear strategies and targets for RE development generally and specifically. The increase in biofuels utilisation and development in other continents over the past years is due to government policy decision. In North America, policies that help grain-based ethanol compete in the market were extended, and additional strategies to increase biodiesel utilisation are being considered. In 2002, German parliament decided to exempt all biofuels from gasoline tax until the end of 2009. In Europe, guidelines to incorporate certain level of alternative fuels into the existing motor fuel have been established and biofuels are expected to be the primary means of achieving these goals [53].

Many developing countries are characterised by a weak legal system, with problems ranging from lack of appropriate legislation, little respect for the judicial system to weak legal enforcement. Investors may be discouraged by difficulties in upholding and enforcing contracts. Lack of positive legislation that would encourage investors (especially the sugar companies) in Kenya to diversify into alcohol production is a typical example. However, due to the surging crude oil prices (from US $28 to US $62 over the past 14 months) key producers of sugar like Brazil and India have scaled back their sugar production in favour of ethanol, which uses the same raw material. The increase in Germany and Italy in biodiesel production from 450,000 and 210,000 ton in 2002, respectively to 1,088,000 and 419,000 ton is due to favourable legislation [53]. In some African countries, the hostile social climate and political instability prevent opportunities of international collaboration and support.

4.2. Financial limitation

The high initial cost of production of biofuels and inadequate financing arrangements for biofuel technology has been identified to be an important barrier to biomass energy commercialisation in most African countries. Existing capital markets do not favour small-scale investments as normally required for some biomass energy. This is, however, not peculiar only to African countries [54,55]. Some of the factors contributing to the formation of this barrier are:

- Lack of available credit facility with low interest rate.
- Bias against biomass energy and lack of adequate information of the potentials of biofuels project.
- The perceived risks of biomass energy projects also act as a major barrier to investments.
- Unfavourable government policies.

4.3. Technical/infrastructure hurdles

Within the category of technical barriers, different RETs present distinct barriers related to technical issues [54]. The supply of feedstock (feedstock currently used for commercial biofuel production is agricultural crops) is crucial to the success of biofuel industry. Obtaining agricultural yields predicted to produce a percentage of biofuels for transport in Africa will be problematic. By way of example, to supply 30% by volume of the petrol used in South Africa would require of the order of 5 million tons of maize. This is a large amount as it is only half the maximum available capacity [56]. Another factor is development of biofuel technology is likely to be based on the developed world for the foreseeable future. This is because only industrialised countries (including the BRIC countries—Brazil, Russia, India and China) have the technological base, the capital, infrastructure required to push large-scale new development in the energy sector [57]. This is probably due to lack of technical and marketing infrastructure for the effective unpacking and adaptation of available technologies and effective social marketing of the products. Low to lack of cooperation/partnership with international bodies such as Renewable Energy and Energy Efficient Partnership (REEEP), a public–private partnership launched by the UK along with other partners at the Johannesburg World Summit on Sustainable Development in August 2002. This partnership actively structures policy initiatives through concerted collaboration among its partners for clean energy markets and facilitates financing mechanisms for sustainable energy projects. An example of how the partnership will boost biofuel commercialisation is the recent grant of €70,000 gotten by the Nigerian National Petroleum Corporation (NNPC), from REEEP from Germany to support detailed feasibility study (research analysis on how to achieve improved target yield performance for cassava whose current national average of 15 ton/ha is considered marginal to feed the proposed ethanol plant in the country.) at different target locations [58]. Attempt to import the biofuel technology from the developed countries (technology transfer) to Africa will fail due to lack of proper understanding of peculiar African features (the technology being transferred is not appropriate to the local context and demands, or is not adapted to the local environment). On the positive side, the nascent biofuels industry should look at how the brewing and the sugar industry manage to do well in Africa. Inadequate maintenance and bad quality of products (lack of standardisation and quality control) is due to the fact that the technology and option are not suited to local African resources and need. Technical success of biofuel project will be a function of capacity/manpower availability to operate and carry out maintenance operation on the plant and of course spare part availability. This is obviously lacking in most African countries. It has been discovered that the capital cost of a plant varies significantly from place to place depending on the infrastructure already in place. The surrounding infrastructure will, therefore, influence the profitability of the project.

4.4. Information hurdles

Lack of awareness and limited information on the national RE resource base, their benefits both economically and environmentally is a barrier to the market penetration of RE in general and biofuels projects specifically in most African countries. The public is, therefore, not educated to influence the government to begin to take more decisive initiatives in enhancing the development, application, dissemination and diffusion of biomass energy resources and technologies in the national energy market. The fact that the stakeholders and the consumers are not sensitised to the potentials of biomass energy is another issue. This will probably affect the view of investing as risky.

Poor telecommunications infrastructure (especially poor internet access, and lack of adequate telephone access—this is changing with the advent of mobile telecoms) and high cost of services is also a source of barrier to biofuel commercialisation. Among the benefits of telecommunications for improving efficiency and productivity are the following:

- *Reduction of travel cost*: in many cases telecommunications can be substituted for travel, resulting in savings in personnel time and travel costs.
- *Energy savings*: telecommunications can be used to increase the efficiency of shipping so that trips are not wasted and consumption of fuel is minimised.
- *Decentralisation*: availability of telecommunications can help attract industries to rural areas, and allow decentralisation of economic activities away from major urban areas.

There is often no industrial association or other co-ordinating body that can help to develop networks of actors in the RE sector.

4.5. Capacity/manpower hurdles

The limited availability of correctly trained and skilled manpower is one of the most critical requirements to the development and market penetration of biofuels in Africa. This is largely due to the exodus of highly trained manpower from developing countries most especially Africa to industrialised nations. By a way of example, Africa as a whole counts only 20,000 scientists (3.6% of the world total) and its share in the world's scientific output has fallen from 0.5% to 0.3% as it continues to suffer the brain drain of scientists, engineers and technologists [59].

The increased number of this exodus attributed to the deteriorated political, economic, and social conditions in Africa reduces the availability of skilled manpower (human resources) which African countries need so badly for self-reliant and sustainable development. This has led to increased cost of doing business in Africa as expatriates to carry out installation, operation and maintenance of biofuel technology need to be imported.

5. Conclusion

Energy is a key factor in industrial development and in providing vital services that improve the quality of life. However, its production, use, and byproducts have resulted in major pressures on the environment, both from a resource use (depletion) and pollution point of view. The decoupling of inefficient, polluting fossil energy use from development represents a major challenge of sustainable development. The long-term aim is for development and prosperity to continue through gains in energy efficiency rather than increased consumption, supported by a transition towards the environmentally friendly use of renewable resources. On the other hand, limited access to energy is a serious constraint to development in the developing world, where the per capita use of energy is less than one-sixth that of the industrialised world.

Renewable energy technologies (RETs) and specifically biofuels offer developing countries some prospect of self-reliant energy supplies at national and local levels, with potential economic, ecological, social, and security benefits (biofuels are a component of the diversification for future energy demand). Achieving the widespread utilisation of biofuels can be realised through proper understanding of its economics. NEPAD and the African Union (AU) both have roles to play in developing rational energy policy and encouraging biofuel investment across the continent. Information exchange and experience sharing should be encouraged amongst institutions and practitioners that are engaged in the promotion of sustainable consumption and production. In this regards, the on-going African Roundtable on Sustainable Consumption and Production (ARSCP) sponsored by UNEP and UNIDO is a step in the right direction towards overcoming the commercialisation hurdles. Actions to globalise the production and utilisation of biofuel, including technology sharing between African countries and others should be encouraged. Brazil and the USA can contribute enormously to the commercialisation of bioethanol in Africa, whilst the EU has made significant advances in biodiesel, and India and China have much experience with biogas.

More robust tools are needed for estimating capital and operating costs of biomass to fuel conversion plant in African countries, concentrating on parameters such as plant size, type of feedstock, exchange rate, and other location-specific information, variables, to investigate the applicability of the techniques developed, specifically (to demonstrate how biofuel plant size optimisation will benefit from availability of better capital and operating cost-estimating techniques); to estimate the revenues that may be expected from avoided carbon emissions. The greater the uncertainties of project cost such as capital cost, the more cautious investors are likely to be. Hence the more accurate these factors are, the greater the likelihood of the more marginal projects proceeding, to the benefit of all concerned. There is thus a need to develop cost-estimating tools that can help:

- Generate baseline data for the technological and economic development of biofuel production and utilisation on the African continent. This will also expedite the environmental and economic benefits of renewable energy.

- Map out business opportunities for energy companies and entrepreneurs.
- Assist governments to reform and harmonise biomass-based energy regulations and legislation. For example, efforts are needed to promote a long-term perspective on the total energy system taking into consideration externalities, the depletion of fossil energy sources and the reduction of supply risks through the diversification of the primary energy supply bases.

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