



Recent Advances in Renewable Energy: Research, Applications and Policy Initiatives

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Review Article

Received 14th September 2011
Accepted 26th November 2011
Online Ready 29th January 2012

ABSTRACT

Aims: Researches into a host of energy deployment options and creative policy initiatives continue in respect of renewable energy and this paper highlights some of the recent advances observed. It investigates the potentials of some second generation biofuels such as manure, tuber peels and other by-products of agriculture in providing biogas, bioethanol and biodiesel, and those of hydro power, solar energy and wind energy and also identifies workable options which can help in meeting energy demand particularly in the developing world.

Study design: Desk study with a focus on literature.

Observations: The European Union has manifested the most ambitious goal thus far in respect of the development of renewable energy sources and application by adopting a binding target of 20% renewable energy in final energy consumption by 2020. A pathway has also been outlined towards a 100% renewable energy supply system by 2050 for electricity, heating, cooling and transport for the European Union. Some developing countries are developing similar policies while many others do not yet have clear-cut plans to integrate renewable energy into their overall energy scenarios.

Conclusion: Biomass holds significant potential in mitigating deficiencies in energy supply in developing countries. Furthermore small hydro projects rather than giant projects hold better promise for meeting the energy needs of African and other developing economies. Enforcement of certain crucial policies in respect of renewable energy development and application as observed in Israel and India should be emulated by other developing countries in view of the impending demise of fossil fuel energy sources. Also, country-level partnerships in respect of energy exploitation, delivery and application; particularly in the areas of development of enabling policies, technology deployment, human resources provision and concessionary financial assistance are recommended.

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Keywords: Renewable energy policies; biofuels; hydropower; solar energy; wind energy.

1. INTRODUCTION

The global energy demand is anticipated to grow at a huge rate in the next 30 years. The International Energy Agency, IEA (2006) predicted that the world's energy needs will be almost 60% higher in 2030 than they are now. Two-thirds of this increase will arise in China, India and other rapidly developing economies, and these will account for almost half the energy consumption by 2030. Even as at present, there are significant deficits in energy supply in many countries, an example of which is Nigeria where the present demand hovers around 10,000 MW and the supply is just about a quarter of that figure. Still Nigeria aims at generating 20,000 MW by 2014. Sharp increases in world energy demand will necessitate important investments to enhance generating capacity and build new grid infrastructure. According to the International Energy Agency, the global power sector will need to build some 4,800 GW of new capacity between now and 2030. Security of supply, environmental concerns and the need for long-term, stable energy prices are all issues which could be alleviated through greater deployment of renewable energy technologies (IEA, 2010a). Given this situation, research needs to continue into a host of energy sourcing options and policy initiatives. This paper highlights some of the recent advances in this broad field with a focus on the renewable energy aspects.

2. BIOFUELS

2.1 End of the Road for Fossil Fuels?

Scientific interest and research into renewable energy technologies are still relevant, especially in view of the often very high costs of fossil fuels worldwide. Another reason for their relevance is the fact that the rampant use of firewood for domestic and industrial heating in low income countries invariably necessitates the destruction of forests and this is harmful to the environment. Also, it had been pointed out that the use of firewood, kerosene and charcoal in households had adverse effects on human health (Adelekan and Adelekan, 2004). Furthermore, using waste biomass to produce energy can reduce the use of fossil fuels, reduce greenhouse gas emissions and reduce pollution and waste management problems (Marshall, 2007; Inderwildi and King, 2009). Overall, these reasons are compatible with the aims and objectives of the Kyoto Protocol which are tailored towards the reduction of greenhouse gases. According to IEA (2010a) bioenergy currently provides 10% of global primary energy supply, 1.3% of electricity production, and 1.5% of transport fuels. A variety of conversion technologies are available, and a range of feedstocks can be used namely wastes, agricultural and forestry residues, and crops grown specifically for energy purposes. Driven by increasing concern over energy security and greenhouse gas mitigation, the global demand for liquid biofuels more than tripled between 2000 and 2007. Production costs are uncertain and vary with the feedstock available, but are currently estimated to be USD 0.80–1.00 per litre of gasoline equivalent. Most biofuels are currently produced from first generation feedstocks (food crops). These sources are generally limited in their ability to achieve oil product substitution, climate change mitigation, and economic growth. Their sustainable production is under review because of undue competition for scarce land and water resources. These factors have led to increasing interest in second-generation biofuels and these are produced from non-food biomass such as wood chips, switch grass, manure,

tuber peels, and other residual non-food parts of food crops. Some of the latest reported research findings regarding these second generation biofuels are highlighted later in this paper.

2.2 The European Renewable Energy Goal

The most ambitious goal thus far in respect of the development and exploitation of renewable energy sources appear to be that articulated by the European Renewable Energy Council. According to European Renewable Energy Council EREC (2010) in March 2007, the Heads of States and Governments of the 27 EU Member States adopted a binding target of 20% renewable energy in final energy consumption by 2020. Combined with the commitment to improve energy efficiency by 20% until 2020 and to reduce greenhouse gas emissions by 20% (or respectively 30% in case of a new international climate agreement) against the 1990 level, Europe's political leaders paved the way for a more sustainable energy future for the European Union and for the next generations. EREC (2010) stated that in January 2008, the European Commission proposed a new Directive on the promotion of the use of Renewable Energy Sources (RES). It set binding 2020 targets for all 27 Member States along with a clear trajectory to follow in order to enable the EU to reach a share of 20% energy from renewable sources (compared to 8.5% in 2005) and a 10% share of RES in the transport sector. Moreover, the directive improved the legislative framework for grid and administrative procedures, created cooperation mechanisms, required the use of minimum levels of RES in buildings, set provisions for the mutual recognition of certification for installers and established sustainability criteria for biofuels and other bioliquids. After reaching a broad agreement on the proposal, the new RES Directive was adopted by the European Parliament in December 2008, by the Council in April 2009, and finally published in the Official Journal of the European Union in June 2009. EREC works closely with the European Institutions, with Member States as well as with national renewable energy associations to facilitate a smooth implementation of the RES Directive. In order to reach the binding overall target of at least 20% renewable energy by 2020 as outlined in the RES Directive, the development of all existing renewable energy sources as well as a balanced deployment in the heating and cooling, electricity and transport sectors is needed.

According to estimates of the European renewable energy industry around 40% of electricity demand will be generated with renewable energy sources by 2020 (EREC, 2010). Furthermore, the new Renewable Energy Directive will undoubtedly stimulate the renewable energy heating and cooling market, according to EREC's projections, up to 25% of heating and cooling consumption can come from renewable energy by 2020. Moreover, the RES Directive provides a strong incentive to significantly reduce oil dependence in the transport sector over the coming years by setting a minimum target of 10% renewable energy in transport. The RES Directive set an important framework for the future growth of the renewable energy industry and paved the way for a stable investment climate, thereby not only increasing the security of Europe's energy supply, contributing to abating climate change, but also providing high-quality jobs and sustainable economic recovery. EREC published its 'RE-thinking 2050-A 100% renewable energy vision for the European Union' report in April 2010. 'RE-thinking 2050' outlines a pathway towards a 100% renewable energy supply system by 2050 for electricity, heating and cooling as well as transport for the European Union, examining the effects on Europe's energy supply system, on CO₂ emissions as well as outlining economic and social benefits of such a fundamental change towards a sustainable energy system. Similar policies are also being established in other regions. For instance in 2009, India announced a national biofuel policy with a mandate to achieve 20% blend of bioethanol and biodiesel by 2017 (Das and Priese, 2011).

3. ETHANOL

3.1 What is Ethanol?

Ethanol fuel is ethanol (ethyl alcohol), the same type of alcohol found in alcoholic beverages. It can be used as fuel, mainly as a biofuel alternative to gasoline, and is widely used by flex-fuel light vehicles in Brazil, and as oxygenate to gasoline in the United States. Together, both countries were responsible for 89% of the world's ethanol production in 2008 (Licht, 2009). In several countries, ethanol is increasingly being blended as gasohol or used as oxygenate in gasoline. This is because it is easy to manufacture and process and can be made from common crops such as sugar and maize. As noted by Blume (2007), the following are the key reasons for which ethanol is attractive as a substitute to gasoline: Ethanol is 98% pollution free; biodegradable; renewable; there is no carbon left when ethanol burns in cars; ethanol does not cause climate change; and all the by-products in the production of ethanol are edible and nontoxic, providing a very good source for animal feedstock. However, the present potential of biofuels to enhance energy security is limited. Globally, the huge volume of biofuels required to substitute for fossil fuels is beyond the present overall capacity of global agriculture. For example in the year 2006/2007, the United States used 20 percent of its maize harvest for ethanol production, which replaced only three percent of its petrol consumption (World Bank, 2008). The possibility of more significant displacement of fossil fuels should be possible with second and third generation biofuels.

Renewable technologies rely principally on plant and animal materials as their feedstock, of which the most dominant among the plant materials are the energy crops. An energy crop is a plant grown at a low cost and low maintenance harvest used to make biofuels, or directly exploited for its energy content. Conventional energy crops include Barbados nut (*Jatropha curcas*), sunflower (*Helianthus annuus*), sugarcane (*Saccharum officinarum*), soybean (*Glycine max*), and maize (*Zea mays*). In the present times, peels and other by-products of previously neglected crops such as cassava (*Manihot* species), sweet potato (*Ipomoea batatas*), cocoyam (*Colocasia* species), yam (*Dioscorea* species) and others are being investigated for their energy generation abilities. Cassava is yet to gain global recognition as an energy crop, although its importance in this regard is known in several places. Adelekan (2011) compared the ethanol fuel productivity of some selected varieties of tropical crops namely cassava, cocoyam, maize and sorghum and concluded that the ethanol derived from them is of very good quality and has the same properties as standard ethanol. The paper reported ethanol production rates of 145, 139, 346 and 135 l/tonne for cassava, cocoyam, dent maize and sweet sorghum respectively. Research reported by Adelekan (2012) and Adelekan (2010) pointed at the capability of cassava crop as a potent source of ethanol and methane and its potential to gain a recognizable presence in global energy economics. The papers investigated the biofuel productivity of this important tropical crop as regards ethanol and methane and provided production figures for these biofuels derivable from global production of cassava. They noted further that finding such an important use for cassava crop would help to reduce the current almost total reliance on wood and expensive fossil fuels as industrial energy sources in tropical countries and help to enhance energy security in those regions. Cassava (*Manihot esculenta* Cranz) is a very important crop grown for food and industrial purposes in several parts of the tropics. Nigeria, with a 2006 production of 49 million tonnes of cassava is the largest producer of the crop in the world (NPC, 2008). Other countries which grow significant quantities of the crop include Brazil, Congo Democratic Republic, Thailand, Ghana and Indonesia. A handful of others also grow the crop but at much lower production quantities. The present annual global production of the crop is

estimated at about 160 million tonnes. The study reported by Adelekan (2010) was a laboratory experiment which correlated volumes and masses of ethanol produced to the masses of cassava tubers (variety TMS 30555) samples used. It derived quantitative relationships to relate the masses of cassava used to the masses and volumes of ethanol produced. These were used to relate known production values of cassava from tropical countries to ethanol that can be potentially produced. This study found that a total of 6.77 million tonnes or 1338.77 million gallons of ethanol are available from total cassava production from tropical countries. The study recommended the production and use of ethanol from cassava crop in the cassava-growing tropical countries of the world.

Udeye et al., (2009) reported the design and installation of a continuous ethanol distillation unit based on the *Heterogeneous azeotropic* approach using *n*-heptane as the entrainer. This technique entailed the dehydration of ethanol, by which, technically, bioethanol could be produced. An ethanol distillation unit was designed, using mainly stainless steel. Bubble caps were constructed for a column which consisted of 11 stages of bubble caps. The decanter design was used for organic reflux. A reboiler with an electric heater was used in the dehydrating column. The prototype design restricted the feed flow rates to 0.2 kg mol/h of ethanol 95.0 mol%, using the mixed reflux between *n*-heptane and ethanol during distillation process. The experimental product gave an approximate maximum of 99.2 mol% of absolute ethanol. The design was based on a 95% ethanol liquid feed.

3.2 The Case of Nigeria and Other Developing Countries

The Nigerian experience as regards to the adoption and use of ethanol in local energy supply is also of interest. In August 2005, under the directive of the then President of the Federal Republic of Nigeria, Chief Olusegun O. Obasanjo, the Nigerian National Petroleum Corporation (NNPC) inaugurated its Renewable Energy Department (RED). This department was given the mandate to develop the biofuels industry in Nigeria. In essence, the Nigerian biofuels program sought to produce ethanol and diesel using agricultural base materials. As observed by Odusote (2008), this program aimed at establishing a synergistic connection between the energy and agricultural sectors. The aim was rightly placed because up till that time, the level of performance of the energy sector of the country had been very poor. The country's renewable energy program was set up as a catalyst to improve performance in these sectors. Although it had been planned to produce ethanol and diesel under this program, efforts so far made have concentrated on the production of ethanol (to achieve a first blending phase of 90% petrol with 10% ethanol), making the initiative known presently as the Nigerian E-10 Policy.

Parawira (2010) observed that biofuel production could potentially position developing nations to become net exporters of fuel which could greatly advance their objectives of economic independence. The paper noted further that many international corporations in Scandinavia, China, and Europe are purchasing tracts of land in developing countries (especially African countries) in an attempt to capitalize on this growth industry. New uses are being found for biofuel continually and this creates an impetus to strengthen efforts to produce them.

4. BIODIESEL

EEA (2006) pointed out that by 2020, the equivalent of 19 million tonnes of oil will be available from biomass, of which 46% will be from biowastes mainly municipal solid wastes,

agricultural residues, farm waste and other biodegradable waste streams. There are two common strategies of producing liquid and gaseous agrofuels. One is to grow crops high in sugar (sugar cane, sugar beet, and sweet sorghum) or starch (maize, cassava, yam), and then make use of yeast fermentation to produce ethyl alcohol (ethanol) (ICRISAT, 2009). The second is to grow plants that contain high amounts of vegetable oil, such as oil palm, groundnut, soybean, castor oil, algae, *Jatropha*, or *Pongamia pinnata*. When these oils are heated, their viscosity is reduced, and they can be burned directly in a diesel engine, or they can be chemically processed to produce fuels such as biodiesel. The chemistry of the process basically involves the fermentation of sugars into ethyl alcohol, carbon dioxide and the production of heat as shown in the equation $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + \text{heat}$. IEA (2010a) noted the higher efficiencies of commercialized technologies such as biodiesel, sugar/starch ethanol, and biomethane and opined that they are the result of improvements in large-scale plants. In addition, efficiency improvement potentials are higher for second-generation biofuel technologies such as cellulose ethanol, P-Series fuels, synthetic bio FT diesel, and DME.

The *Jatropha* industry is in its very early stages, covering a global area estimated at some 900,000 ha. More than 85 percent of *Jatropha* plantings are in Asia, chiefly Myanmar, India, China and Indonesia. Africa accounts for around 12 percent or approximately 120,000 ha, mostly in Madagascar and Zambia, but also in Tanzania and Mozambique. The West African nations of Mali, Ghana and Senegal have also established lofty production targets for *Jatropha* notably; to cultivate 320,000 ha of *Jatropha curcas* in Senegal by 2012 and 1 million ha in Ghana in the medium term. Latin America has approximately 20,000 ha of *Jatropha*, mostly in Brazil. The area planted with *Jatropha* was projected to grow to 4.72 million ha by 2010 and 12.8 million ha by 2015. By then, Indonesia is expected to be the largest producer in Asia with 5.2 million ha, Ghana and Madagascar together will have the largest area in Africa with 1.1 million ha, and Brazil is projected to be the largest producer in Latin America with 1.3 million ha (OECD, 2008).

5. BIOGAS

Many developing nations meet significant amounts of their energy needs through biogas particularly in the rural areas. The biogas support program in Nepal installed over 150,000 biogas plants in the rural areas (AEPNNEPAL, 2009) while the biogas program in Vietnam led to the installation of more than 20,000 plants throughout the country (SNV, 2009). Also, in Rwanda, the Kigali Institute of Science and Technology developed and installed several large-scale biogas plants at prisons to treat sewage and provide biogas for cooking (KIST, 2009). Even in developed countries, significant potential for biogas use still exists. For example in the United Kingdom, biogas is estimated to have the potential to replace about 17% of vehicle fuel (Claverton Energy Conference, 2008). In the case of Nigeria the potential for biogas production from farm wastes is immense. For instance, reported values of animal waste production range from 144 million tones/year (Energy Commission of Nigeria, 1997) to 285.1 million tones/year and this is potentially available for the production of biogas (Adelekan, 2002).

Several researchers have recently reported improvements in biofuel production from various agricultural materials including biogas from mixtures of cassava peels and livestock wastes (Adelekan and Bamgboye, 2009a), biogas from pretreated water hyacinth (Ofuefule et al., 2009), methanol from cow dung (Ajayi, 2009) fuel from indigenous biomass wastes (Saptoadi et al., 2009), ethanol from non-edible plant parts (Inderwildi and King, 2009), as well as biogas from various livestock wastes (Adelekan and Bamgboye, 2009b). It has been

discovered that, under aerobic conditions, living plants also produce methane which is significantly larger in volume than that produced by dead plants. Although this does not increase global warming because of the carbon cycle (Keppler et al., 2006), it is not readily recoverable for economic purposes. However, the methane which is recoverable for the direct production of energy is from dead plants and other dead biomass under anaerobic conditions.

Adelekan and Bamgboye (2009a) investigated biogas productivity of cassava peels (a huge volume waste product of limited use) mixed with poultry, piggery and cattle waste types in ratios 1:1, 2:1, 3:1 and 4:1 by mass, using 12 Nos. 220l batch type anaerobic digesters in a 3 x 4 factorial experiment using a retention period of 30 days and within the mesophilic temperature range. Biogas yield was significantly ($P \leq 0.05$) influenced by the different mixing ratios of livestock waste with cassava peels. The cumulative average biogas yield from digested cassava peels was 0.6 l/kg-TS. The average cumulative biogas yield increased to 13.7, 12.3, 10.4 and 9.0 l/kg-TS respectively for 1:1, 2:1, 3:1 and 4:1 mixing ratios when cassava peel was mixed with poultry waste. On mixing with piggery waste, the average cumulative biogas yield increased to 35.0, 26.5, 17.1 and 9.3 l/kg-TS respectively for 1:1, 2:1, 3:1 and 4:1 mixing ratios. In the case of mixing with cattle waste, the average cumulative biogas yield increased to 21.3, 19.5, 15.8 and 11.2 l/kg-TS respectively for 1:1, 2:1, 3:1 and 4:1 mixing ratios. Results showed that for all livestock waste types, mixing with peels in the ratio 1:1 by mass produced the highest biogas volumes, and was highest in piggery waste.

Ofuefule et al., (2009) reported a comparative study of the effect of different pre-treatment methods on the biogas yield from Water Hyacinth (WH). The WH charged into metallic prototype digesters of 121 L capacity were pre-treated as: dried and chopped alone (WH-A), dried and treated with KOH (WH-T), dried and combined with cow dung (WH-C), while the fresh water Hyacinth (WH-F) served as control. They were all subjected to anaerobic digestion to produce biogas for a 32 day retention period within a mesophilic temperature range of 25 to 36 °C. The results of the study showed highest cumulative biogas yield from the WH-C with yield of 356.3 L/Total mass of slurry (TMS) while the WH-T had the shortest onset of gas flammability of 6 days. The mean biogas yield of the fresh Water Hyacinth (WH-F) was 8.48 ± 3.77 L/TMS. When the water Hyacinth was dried and chopped alone (WH-A), dried and treated with KOH (50% w/v) (WH-T) and dried and combined with cow dung (WH-C), the mean biogas yield increased to 9.75 ± 3.40 L/TMS, 9.51 ± 5.01 L/TMS and $11.88 \pm$ L/TMS respectively. Flammable biogas was produced by the WH-F from the 10th day of the digestion period whereas the WH-A, WH-T and WH-C commenced flammable gas production from the 9th, 6th and 11th day respectively. Gas analysis from WH-F shows Methane (65.0%), CO₂ (34.94%). WH-A contained Methane (60.0%), CO₂ (39.94%). WH-T contained Methane (71.0%), CO₂ (28.94%), while WH-C had Methane (64.0%) and CO₂ (35.94%). The other gases were found in the same levels and in trace amounts in all the systems. The overall results showed that treating water Hyacinth with KOH did not have a significant improvement on the biogas yield. It also indicated that water Hyacinth is a very good biogas producer and the yield can be improved by drying and combining it with cow dung.

Uzodinma and Ofoefule (2009) investigated the production of biogas from equal blending of field grass (F-G) with some animal wastes which include cow dung (G-C), poultry dung (G-P), swine dung (G-S) and rabbit dung (G-R). The wastes were fed into prototype metallic biodigesters of 50 L working volume on a batch basis for 30 days. They were operated at ambient temperature range of 26 to 32.8 °C and prevailing atmospheric pressure conditions.

Digester performance indicated that mean flammable biogas yield from the grass alone system was 2.46 ± 2.28 L/total mass of slurry while the grass blended with rabbit dung, cow dung, swine dung and poultry dung gave average yield of 7.73 ± 2.86 , 7.53 ± 3.84 , 5.66 ± 3.77 and 5.07 ± 3.45 L/total mass of slurry of gas, respectively. The flash point of each of the systems took place at different times. The field grass alone became flammable after 21 days. The grass-swine (G-S) blend started producing flammable biogas on the 10th day, grass-cow (GC) and grass-poultry (G-P) blends after seven (7) days whereas grass-rabbit (G-R) blend sparked on the 6th day of the digestion period. The gross results showed fastest onset of gas flammability from the G-R followed by the G-C blends, while the highest average volume of gas production from G-R blend was 3 times higher than that of F-G alone. Overall, the results indicated that the biogas yield and onset of gas flammability of field grass can be significantly enhanced when combined with rabbit and cow dung.

Adelekan and Bamgboye (2009b) investigated the effect of mixing ratio of slurry on biogas productivity of wastes from poultry birds, pigs and cattle. The investigation was carried out using 9 Nos. 220-litre batch type anaerobic digesters designed to remove CO_2 , H_2S and other soluble gasses from the system. Freshly voided poultry, piggery, and cattle wastes were collected from livestock farms at the Institute of Agricultural Research and Training (IAR&T), Moor Plantation, Ibadan, Nigeria. After being totally freed of foreign matter, the samples were well stirred and digested in a 3x3 factorial experiment using a retention period of 30 days and within the mesophilic temperature range. The waste: water mixing ratios of slurry used were 1:1, 2:1 and 3:1 by mass. Three replicates were used for each ratio. Two hundred gram samples of each animal waste type were obtained before and after experimentation and analysed for chemical constitution. All the readings of the biogas yield were analysed using the Duncan Multiple Range Test (DMRT). Biogas yield was significantly ($p < 0.05$) influenced by the various factors of animal waste ($F = 86.40$, $P < 0.05$), different water mixing rates ($F = 212.76$, $P < 0.05$) and the interactions of both factors ($F = 45.91$, $P < 0.05$). Therefore, biogas yield was influenced by variations in the mixing ratios as well as the waste types used. The 1:1 mixing ratio of slurry resulted in biogas productions of 20.8, 28.1, and 15.6 l/kgTS for poultry, piggery and cattle wastes respectively. The 2:1 ratio resulted in 40.3, 61.2 and 35.0 l/kgTS while the 3:1 ratio produced 131.9, 117.0 and 29.8 l/kgTS of biogas respectively. Therefore an increasing trend was observed in biogas production as mixing ratio changed from 1:1 to 3:1. For cattle waste however, production decreased from ratio 2:1 to ratio 3:1. The N, P, K values were highest for poultry waste (3.6, 2.1, and 1.4% respectively) and least for cattle waste (2.2, 0.6, 0.5% respectively). Organic carbon was highest for cattle waste (53.9%) and least for poultry waste (38.9%). Reduction in C/N ratio for each experiment ranged from 1.1 to 1.9%. This study found that for poultry and piggery wastes, slurries mixed in ratios 3:1 waste: water produced more biogas than those of 2:1 and 1:1 ratios. For cattle waste, the 2:1 mixing ratio produced the most biogas. This paper therefore recommended a livestock wastes: water mixing ratio of 3:1 for poultry and piggery slurries, and 2:1 for cattle slurry for maximum biogas production from methane-generating systems, given 30% TS content.

Bolarinwa and Ugoji (2010) studied biogas production by anaerobic microbial digestion of starchy wastes of *Dioscorea rotundata* (yam) and *Manihot esculenta* (cassava) aided by abattoir liquid effluent using a laboratory digester. The volume of the gas produced at 12h intervals by feedstock varied for the 72h of study. The cassava substrate mixture produced the highest daily average volume of gas (397ml), mixture of cassava and effluent 310.4ml; mixture of cassava, yam and effluent 259ml; mixture of cassava and yam produced 243.6ml; yam 238ml; mixture of yam and effluent 169.4ml while abattoir effluent produced the lowest volume of gas (144.4ml). The average pH of digester varied between 5.6 and 6.7 while the

temperature varied between 32.3°C and 33.3°C. The microbial load of digester samples was determined at 12h-intervals. Two groups of bacteria were isolated. Acid-formers isolated included *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Bacillus subtilis*, *Escherichia coli*, *Serratia liquefaciens*, *Micrococcus pyogenes* and *Streptococcus pyogenes* while the methane-formers were *Methanobacterium* sp. and *Methanococcus* sp. This study concluded that spoiled yam and cassava, which are otherwise of no apparent use, could provide a cheap source of renewable energy for domestic use.

Adeyosoye et al., (2010) studied biogas yield of peels of sweet potato (SPP) and wild cocoyam (WCP). Buffered and sieved goat's rumen liquor was added to 200 mg of dried and milled SPP and WCP in 100 ml syringes supplied with CO₂ under anaerobic condition and incubated for 24 h. Total biogas produced was measured at 3 h intervals till the 24th h when the fermentation was terminated. The inoculum was also incubated separately. All treatments were replicated three times and readings were taken in duplicates. The proximate composition of SPP and WCP were similar except for the higher EE content (12%) of SPP. The SPP and WCP used contained 26.81 and 26.97% DM, 3.06 and 3.83% CP, and 78.94 and 79.17% carbohydrate respectively. Both samples had the same crude fibre (7.00%) content. Total biogas produced from SPP, WCP and the inoculum varied from 13.0, 11.0 and 5.0 ml respectively at the 3rd h through 66.5, 61.5 and 18.0 ml at the 18th h to 77.5, 72.0 and 30.0 ml at the 24th h respectively. The differences in biogas production across the treatments were significant ($p < 0.05$). There were no significant differences ($p > 0.05$) in the volumes of methane produced from SPP (42.5 ml) and WCP (39.5 ml) which were significantly ($p < 0.05$) higher than 20.0 ml produced by the inoculum. The study pointed out that peels of sweet potato and cocoyam wastes that can produce significant quantities of biogas for domestic applications. The foregoing studies confirm that ultimate methane yields from biomass are influenced principally by the biodegradability of the organic components. The more putrescible the biomass, the higher is the gas yield from the system (Wis, 2009).

Adelekan et al., (2010) undertook a comparative study of the effects of undigested and anaerobically digested poultry manure and conventional inorganic fertilizer on the growth characteristics and yield of maize at Ibadan, Nigeria. The digested manure was a by-product of biogas production. The pot experiment consisted of sixty (60) nursery bags, set out in the greenhouse. The treatments, thoroughly mixed with soil, were: control (untreated soil), inorganic fertilizer, (NPK 20:10:10) applied at the 120 kgN/ha; air-dried undigested and anaerobically digested manure applied at 12.5 g/pot, or 25.0 g/pot or 37.5 g/pot, and or 50.0 g/pot. Plant height, stem girth, leaf area, number of leaves at 2, 4, 6 and 8 weeks after planting (WAP) and stover mass and grain yield were measured. Analysis of variance (ANOVA) at $P \leq 0.05$ was used to further determine the relationships among the factors investigated. Generally, results in respect of crops treated with digested manure, were quite comparable with those treated with undigested manure and inorganic fertilizer, right from 2WAP to 6WAP. Stover yield was increased to as much as 1.58, 1.65 and 2.07 times by inorganic fertilizer, digested and undigested manure, respectively while grain yields were increased by only 200% with inorganic fertilizer, but by up to 812 and 933% by digested and undigested manure, respectively. In conclusion, digested poultry manure enhanced the growth characteristics of the treated plants for the maize variety used. As observed, the order of grain yield was undigested manure > digested manure > inorganic fertilizer. This reinforces the joint utility of manure as substrate for biogas production and as a useful fertilizer. These second generation energy crops highlighted in this paper are bound to assume definitive importance in global energy economics in the very near future.

6. AN ENEMY OF AGRICULTURE?

Habibah (2009) noted that the demand for biofuels may create a huge demand for cereals, sugar and oilseeds which may result in an increase in food price, greater food insecurity and higher level of poverty. A negative impact on the environment resulting from deforestation, intensive tillage and cultivation practices may also occur. In other words, biofuel is competing for arable land that would have been used for growing food crops but is now being used to grow energy crops. The first-generation biofuels are those made from sugar, starch, vegetable oil, or animal fats using conventional technology (FAO, 2008). The basic feedstocks for the production of first generation biofuels are often seeds or grains such as wheat, which yields starch that is fermented into bioethanol, or sunflower seeds, which are pressed to yield vegetable oil that, can be converted into biodiesel. These feedstocks could instead enter the animal or human food chain, and with the rise of global population, their use in producing biofuels has been criticized for diverting food away from the human food chain, supposedly leading to food shortages and price increments. However, as pointed out by Adelekan (2010), what is sometimes overlooked is that the creation of a competing need most times motivates producers to raise production levels of the product in order to satisfy the higher demand. The other point is that competition necessitates the judicious absorption of any existing excess production as well as the plugging of avenues for wastes of all kinds. With the increased use of grain chaff and tuber peels for ethanol production, it is anticipated that increased efficiencies in production will be brought to bear on agriculture and these advantages will then be of benefit. In addition, any lingering fears of biofuels constituting an enemy of agriculture should disappear with time as more attention is being directed at the second generation biofuels which essentially are not food crops but biological materials such as wood chips, moss, weeds, residual non-food parts of food crops and so forth (IEA, 2010a).

7. SOLAR POWER

7.1 Importance of Solar Energy

The importance of solar energy is underscored by the fact that in one daylight hour, the amount of solar energy which reaches the earth is more than the total amount of energy used by everybody on earth in a 1-year period. Furthermore, within the period of one year, the earth receives about 178,000 terawatt (TW) of energy from the sun. Simply put, this is 15,000 times more than the energy consumption of the whole world today. 50% of this energy is absorbed by the earth and 30% is reflected back into space by the atmosphere. The hydrological cycle is powered by the remaining 20% and only 0.6% of this amount goes into photosynthesis. Photosynthesis is the basis of all life forms on earth and it created the reserves of fossil fuel. It is well-known that these reserves are exhaustible and the rather rapid decrease in the availability of fossil fuel resources shows that fossil fuel security becomes questionable today. Being faced with this problem, a complete change to renewable energy resources as a free, clean and silent energy supply should become unavoidable. This offers a great potential to reduce global warming and to stop the effects of climate change (Smith, 2007). The intensity of solar energy on a surface oriented perpendicular to the sun's rays above the earth's atmosphere (known as the solar constant) has been measured by satellite to be between 1,365 and 1,367 W/m² (NASA 2003). Depending on the conditions, the sunlight can reach a maximum of 1 kW (kilowatt) per square meter. Offiong (2003) reported that the average solar radiation received in Nigeria per day is as high as 20 MJ/m² depending on the time of the year and location. A more

recent study, Chiemeka and Chineke (2009) evaluated the global solar energy potential at Uturu (0.5.33°N and 06.03°E), a town in Nigeria. The temperature data were obtained from 1st to 30th November, 2007 using the maximum and minimum thermometers placed in the Stevenson screen at 1.5 m above ground level. The Hargreaves equation was used to evaluate the solar energy potential at Uturu. The mean solar power potential obtained for the period over Uturu was 2.45 ± 0.29 kWh m⁻² per day. A comparison of the mean global solar potential obtained at Uturu and that reported by Offiong (2003) showed that the insolation potential obtained at Uturu was 44.1% less. This difference may be attributed to the hilly nature of Uturu, coupled with the fact that the climate at Uturu varies significantly with the seasons of the year. The foregoing clearly shows that solar energy is a ready resource which Nigeria and by inference other tropical countries especially, can exploit for power generation.

7.2 Solar Applications

According to United States Department of Energy, USDOE (2006), solar energy can be converted to other more usable energy forms through a variety of demonstrated technologies that are divided into two categories: thermal and photonic. Solar thermal technologies first convert solar energy to heat, which can be used directly (such as heating water for residential or commercial use), stored in a thermal medium (such as heating water or dry rocks) for later use, or converted to mechanical and/or electrical energy by an appropriate device (such as a steam turbine). Solar photonic technologies directly absorb solar photons—particles of light that act as individual units of energy—without complete conversion to heat. The absorber then either converts the photon energy to electricity, as in a photovoltaic (PV cell), or stores it as chemical energy through a chemical reaction (as in photosynthesis or the dissociation of water into hydrogen and oxygen).

Aliyu and Jibril (2009) reported the design, construction and testing of an indirect passive solar dryer for cassava chips. The dryer was designed to accommodate a total quantity of 45 kg and was tested by carrying out three experiments with fresh cassava chips of approximate sizes of 2.5, 3.0 and 3.5 cm. The highest temperature recorded during the experiments was 60.5°C. The average result shows that the 3.0 cm chips inside the drying chamber were dried from 65% (87% dry basis) to 10% (11% db) moisture content in 4 days, while the samples outside the chamber (control) were dried to 11% (13% dry basis) in 6 days. This result showed that over thirty percent saving in drying time was achieved in the dryer compared to the open sun drying. The calculated drying efficiency and the Pick-up efficiency of the dryer were 31 and 58% respectively. The organoleptic quality test of the dried cassava chips showed that samples in the dryer retained their white colour, thus, indicating no mould growth. This further confirms the position that utility scale agro-based solar applications can find ready use in domestic settings.

A popular use of solar power is for domestic heating and cooling. Space heating and cooling are applied throughout the world. However it is gaining much more prominence in the Middle East and subtropical regions of the world. As noted by IEA (2010b), in 2007, world solar hot water and heating capacity totaled 147 GW (63% of which was in China). In the same year, 16 GW of capacity was added, 80% of which was in China. Another increasing use of solar energy is in the case of photovoltaic (PV) applications. Since 2000 cumulative installed photovoltaic (PV) capacity has increased by 40% per year (IEA, 2010c). This impressive market growth is the result of the continued policy support for PV in an increasing number of countries. In the next 10 years, PV is expected to achieve competitiveness with power grid retail prices in many regions. This will require a continued, strong and balanced policy effort

to allow for optimal technology progress, cost reduction and ramp-up of industrial manufacturing for mass deployment. PV also offers the ability to provide electricity to populations in remote locations, enhancing the quality of existing electricity supplies, and the quality of life (IEA, 2010c).

Sene et al., (2009) investigated the formation of $\text{CuIn}(\text{Se}, \text{S})_2$ films for application in photovoltaic devices by post-deposition treatments of electrodeposited pre-cursors. The polycrystalline CuInSe_2 (CIS) pre-cursor layers were prepared by the one-step electrodeposition (ED) method on molybdenum-coated soda lime (SL) glass substrates. Growth was performed from low concentration buffered baths containing CuSO_4 , $\text{In}_2(\text{SO}_4)_3$ and SeO_2 with Li_2SO_4 electrolyte. As deposited films were amorphous and required recrystallization by annealing in H_2Se or H_2S prior to device processing. Reaction in flowing H_2Se produced random oriented CuInSe_2 films which resulted in devices with low conversion efficiencies of only 3%. Annealing in flowing H_2S led to partial replacement of the selenium in the CuInSe_2 film with sulfur, determined by XRD and EDS to produce $\text{CuIn}(\text{Se}, \text{S})_2$ quaternary alloys. Devices processed from $\text{CuIn}(\text{Se}, \text{S})_2$ films showed improved J-V characteristic with conversion efficiencies of 6.4%.

7.3 The Case of Israel

The case of Israel regarding the development and application of solar power should point the way forward for many developing countries. Israel has formidable solar energy resources which range from 5.5 to 7.0kWh/m²/day depending on location within the country's borders and an average value of 5.48kWh/m²/day solar radiation on collector surface (NREL et al., 2006; Arava Institute, 2007). Despite this however, the situation for much of this decade is that Israel has been a heavy user of fossil fuels with its attendant risks to the environment. Electricity sourced from coal, oil (both imported) and natural gas accounted for 71.1, 17.5 and 11.4% respectively of total electricity generation (OECD/IEA, 2007). Hydropower understandably accounts for just 0.06% of the total since there is little known potential for this in that desert region. Other renewables also account for 0.02% of total electricity generation. In 2007, greenhouse gas emissions in Israel exceeded 80 million tons per year, with 60% of the emissions generated by the energy sector. The electricity sector alone was responsible for over 35 million tons of GHG emissions (Mor and Seroussi, 2007). Israel's overall CO₂ emissions annually amounted to 9.7 tons per person. Although this figure has declined by about 1% per year, Israel's population continues to increase by about 2% annually (higher than virtually any other developed country), and its total greenhouse gas emissions level has been increasing by about 1% annually since 1990. At current trends, annual CO₂ emissions will reach nearly 83 million tons by 2025 (Israel Central Bureau of Statistics, 2007). Therefore Israel faces significant challenges in lowering its CO₂ emissions, while meeting the energy needs of a growing population in a rapidly developing country. This situation has given sufficient cause for concern on the part of government especially, regarding the need to improve this situation.

Because of the foregoing, in 2002, the Government of Israel set a target of at least 2% of all electricity to be supplied by renewable energy by 2007; this target rises to 5% by 2016 (Mor and Seroussi, 2007). In April 2008, National Infrastructure Minister Binyamin Ben-Eliezer announced a commitment to increase the share of renewable energies to 15-20% of Israel's total energy use by 2020 (The Jerusalem Post, 2008; European Commission, 2008). According to Ministry of National Infrastructures (2008), a recent government resolution mandates a minimum quota of 10% for electricity from renewable energy resources by 2020.

This might be increased to 20%; presently only about 0.1% of electricity is generated from renewables. "A new Energy Masterplan is being drafted, which emphasizes the introduction of new energy sources and includes 2,000 MW of electricity from renewables by 2020 (1,000 MW from solar energy)." Reaching these targets required the construction of large solar PV and wind plants, as well as an integration of smaller systems. Israel pioneered the efforts to develop rooftop solar water heating, and as a result the country has the highest per capita solar water heater use rate in the world. While Israel had over 1.3 million solar water heaters producing the equivalent of over 4% of Israel's electricity consumption as a result of mandatory solar water heating installations (Mor and Seroussi, 2007), it had just less than 2 MW of photovoltaic installations by the end of 2007. This was expected to increase by 1 MW a year later (IEA, 2007). With a population of 7.28 million, Israel's PV generated power currently hovers around 0.25W/capita. This low value is bound to pick up judging by ongoing aggressive government encouragement. Besides solar power, Israel's renewable energy potential is limited. Biomass potential is about 8.6 thousands of tonnes of oil equivalent (Mtoe), primarily from municipal waste. Israel's wind potential is also rather low, with maximum capacity around 600 MW (or about 1.75 billion kWh), and faces the additional difficulties of location and grid interconnection (Mor and Seroussi, 2007). Therefore the emphasis for renewable energy in Israel is on solar energy. This emphasis followed from what was observable worldwide to the extent that the primary growth activity for renewables had been in the solar sector, and this has increased rapidly in recent years. In 2005, global solar power generation increased by 44%, and it was anticipated to increase six fold from then through 2010 (IEA, 2010a).

As noted by Mor and Seroussi (2007) Israel continues to develop leading-edge solar technology in companies such as Solel and Millennium Electric, and at university settings including the Blaustein Institute on the Sde Boker campus of Ben-Gurion University and the Weizmann Institute. At the universities and their research institutes, the main focus areas have been in materials studies, modeling solar devices and systems, energy conversion and storage, and concentrator photovoltaic. The most prominent developments at these centers have been the Weizmann Institute's solar tower for concentrating solar energy, and the solar dish facility at the Blaustein Institute. The Institute's main research emphasis has been on improving solar thermal and PV efficiency for commercial purposes while the Weizmann Institute in Rechovot has focused on solar technology as a base for other currently research-oriented processes such as hydrogen fuel storage and transportation. Within the corporate sector, companies such as Solel, Solar Power, and Millennium have made significant progress in solar thermal and PV development. DiSP has focused almost exclusively on developing concentrating PV systems for distributed power systems, with potential for providing both electricity and heat as a CHP unit (taking advantage of the fact that 70%-90% of solar energy in most units escapes as heat rather than producing electricity). Solar Power has developed PV for a variety of applications in communications, "self-reliant" communities such as moshavim, and agriculture, thereby exploiting PV's unique ability to meet load reliably at specific locations at lower cost than the incumbent utility. Solar Power has been planning PV expansion to larger areas, mainly Netanya-area industrial parks and facilities. Finally, Millennium Electric has used its PV/T solar cell array for monitoring traffic and billing on the Cross-Israel Highway toll road, on grid-connected school systems, and signage. IEC is working with Millennium on implementing a 29-home grid-connected "Solar Village" demonstration project in the Negev, to assess its impact on the local grid and the required interconnections and metering. Solel has set a goal of meeting 10% of Israel's electricity demand through its technology by 2020 (Solel, 2009).

In 2008, National Infrastructure Minister Binyamin Ben-Eliezer pledged to adopt a plan to build one new solar station per year for the next 20 years. Israel President Shimon Peres was reported to have stated thus; "I believe Israel should go from oil to solar energy. Oil is the greatest problem of all time-the great polluter and promoter of terror. We should get rid of it" (Businessweek, 2008).

8. HYDROPOWER

Currently hydropower produces almost 20% of the world's total power needs and is the world's most important source of renewable electrical energy. Hydropower constitutes over 50% of the electricity supply in at least 63 countries in the world (Gondwe, 2010). Norway offers a very good example of the success of hydropower. It is a country where for more than a century, hydropower resources had been harnessed and the country is practically 100% supplied with hydro-electricity from 850 hydropower plants, including half of the world's underground power plants. Thus for Norway, hydropower had been the foundation for the development of the nation's industry and hence economic prosperity (Hydropower Conference, 2010). Therefore, other countries of the world with unexploited hydropower resources have a lot to benefit from the Norwegian experience of social, environmental, technical and economic aspects of hydropower development. International Hydropower Association (2010) pointed out that hydropower continues to be a vital component of electricity supply systems and is considered to be the most significant short-to-medium term renewable resource, with the potential to increase its contribution by over 50% during the next half century. Most of this potential is in China, India, Turkey, Brazil and other Asian and South American countries, as well as West and Central Africa. Key barriers to future large-scale development of hydropower are the huge capital requirements, water resource user conflicts, and environmental and social challenges. However, hydropower developments not only provide a sustainable, abundant source of low cost electricity, they can also enhance potable and irrigation water supply and provide flood control. The world's second largest hydro power plant with a capacity of 12,600 MW has been built in Itaipu, Brazil. Immense economic, environmental and social costs involved in such a huge project as this make it difficult for them to receive ready approval on the part of government, the public, and other stakeholders particularly in the developing economies of the world. Advances in hydropower development in many regions, particularly in Africa should look in the direction of building small hydropower projects since pertinent economic, environmental and social issues appear more readily surmountable in this case. Yet still, African nations would still require concessionary financing to undertake small hydro projects. The International Hydropower Association (2010) is issuing Sustainability Guidelines. This new document is billed to include updated recommendations relevant to government decision makers, regulators and other project approval agencies, financial institutions and government aid agencies on the five key areas initially reported: energy policy framework; decision-making process; comparison of hydropower project alternatives; improving environmental management of hydropower plants; and sharing benefits with local communities.

According to ESHA (2005) although in Europe, the potential for large hydro development is practically exhausted, yet small hydro still has a huge and untapped potential principal of which are abandoned or outdated sites with low head, drinking water networks, wastewater projects, irrigation projects, which will allow European Union small-hydro industry to increase its activities. The paper stated further that small hydropower ought to be systemised as far as possible, so as to achieve an optimal set up on technical, environmental and economic points of view. Contrary to the generally accepted idea that small hydropower is an old form

of energy exploitation that has garnered such experience that it cannot be improved; small hydro still has a scope to evolve, especially in equipment and design practices. Therefore small hydro will benefit from continued research and development so as to be even more economically viable and more integrated to the environment. Small hydropower projects are needed to reach the environmentally safe targets on renewable energy and to contribute to climate change mitigation, security of supply and economic development most especially in the developing countries. With only 4.9% of the total hydropower potential in Africa, 12.2% in Asia and 19.8% in South America having been developed, as compared to 48.3% in Europe and 41.8% in North America, climate change was bound to have a considerable negative impact on hydropower development and operation, both for the present and for the future, on these continents (Gondwe, 2010). Challenges posed by climate change in terms of water availability will be more severe on huge hydro projects than smaller projects. This is another point in favour of preference for the smaller hydro projects over the much bigger ones.

The oceans contain a huge amount of energy which in theoretical terms can become significant in global energy economics. International Energy Agency (2010d) observed that changes in salinity, thermal gradients, tidal currents or ocean waves can be used to generate electricity using a range of different technologies currently under development. These could provide reliable, sustainable and cost-competitive energy. Capturing ocean energy could have substantial benefits. Potential Global Electricity Production (TWh/year) from the oceans have been estimated thus; Tidal current > 800 TWh/year; Salinity gradient, 2,000 TWh/year; Ocean wave, 8000 – 80,000 TWh/year; Thermal energy, 10,000 TWh/year. These potential figures compare to the total presently ascertained world electricity production from all sources of 17,450 TWh. The number of ocean energy technology concepts has increased to about 100 known devices. A small number of ocean energy developers have produced full-scale prototypes, and few have completed testing or published results. For all ocean power generation technologies, deployment will not be possible without the proper market policies and support mechanisms and these are presently lacking.

9. WIND POWER

9.1 A Revival of an Old Art

Countries around the world are turning increasingly to wind turbines for electricity generation. In 2008, wind energy generation capacity in 76 countries worldwide increased from 27,262 MW to 121,188 MW, totalling more than 1.5% of the global electricity consumption (IEA, 2010e). In Denmark the contribution of wind energy to total electricity supply reached 19% for the same year. In Portugal and Spain more than 11% of electricity demand is met by wind, nearly 9% in Ireland and more than 6% in Germany. Integrating electricity produced from wind into power networks can be challenging due to the variability of wind, the variability of the electricity already in the grid (load), and consumer demand. According to GWEC (2007), data on global installed capacity for wind power systems showed that Europe and North America had 65.4 and 17.6% respectively of global capacity. Asia and Pacific region had 14.4 and 1.3% respectively. Latin America and the Caribbean had 0.7% while Africa and the Middle East were responsible for only 0.6% of global wind power generating capacity. Hays and Attwood (2006) concluded that Asia is playing an increasingly important role in the global wind industry as the region prepared to invest over \$12 billion in wind power generation capacity in this latter half of this decade.

United States Department of Energy, USDOE (2009) reported its extensive program which has a goal to develop clean, domestic, innovative wind energy technologies that can compete with conventional fuel sources to help meet America's increasing energy needs while ensuring energy security and protecting the environment. The program enumerated key strategies to advance adoption of wind energy technology in the United States such as research and development partnerships with industry; research and development collaborations with foreign wind energy laboratories; enhanced research funding at the universities; mapping of wind resources; incentives for utilities to invest in wind energy development and deployment; certification and standards development; promotion of demand for wind energy domestically and abroad by raising awareness; collaborations with a variety of organizations to remove institutional and legal barriers; as well as coalitions with universities, industries, state and local governments to establish regionally based test facilities. The USDOE envisages a scenario in which wind power would provide 20 percent of United States electricity aggregate supply by 2030. Also, for the United States, USDOE/NREL (2009) reported remarkable decreases in cost of energy from wind and increases in cumulative installed wind energy power generation capacity over the period 1980-2007. By 2007, the United States had an installed capacity of 18,000 MW of power from wind sources and this was produced at a cost of 8 cents/KWhr. In 1980, the figures were 20 MW and 90 cents/KWhr respectively.

9.2 The Case of India

The installed capacity of power plants in India was 132 GW by the first quarter of 2007, of which were thermal (64.7%), hydro (26.2%), nuclear (3.1%) and new renewable (5.9%) (MOP, 2007); whereas, Chinese power capacity reached over 600 GW (People's Daily, 2007), showing India's backlog. Wind energy is an alternative clean energy source and growing at a rate of 28% in the last decade has been the world's fastest growing renewable energy source (GWEC, 2006). In India, wind power already occupies a prominent position with regard to installed capacity; reaching 7.1 GW by the first quarter of 2007 (INWEA, 2007). In 2006 alone, an aggregate capacity of 1.8 GW has been added (GWEC, 2007). Thus, India is the fourth largest wind market in the world. However, the total installed capacity of wind power projects still remains far below their potential (i.e.<15%). Nevertheless, success recorded thus far in India as regards wind power generation should be emulated by other developing economies since the advantages of zero pollution, reasonably lower costs compared to fossil-fueled power plants as well as rapid deployment of technology together with low maintenance costs are quite economical.

Purohit and Michaelowa (2007) reported on the state of wind energy development and application in India. The experience of India should point the way forward for many developing countries. So far, the cumulative installed capacity of wind power projects in India is far below their gross potential ($\leq 15\%$) despite very high level of policy support, tax benefits, long term financing schemes and so forth, for more than 10 years. One of the major barriers is the high costs of investments in these systems. The Clean Development Mechanism (CDM) of the Kyoto Protocol provides industrialized countries with an incentive to invest in emission reduction projects in developing countries to achieve a reduction in CO₂ emissions at lowest cost that also promotes sustainable development in the host country. Wind power projects could be of interest under the CDM because they directly displace greenhouse gas emissions while contributing to sustainable rural development, if developed correctly. Estimates indicated that there was a vast theoretical potential of CO₂ mitigation by the use of wind energy in India. The annual CER potential of wind power in India could theoretically reach 86 million tonnes. Under more realistic assumptions about diffusion of

wind power projects based on past experiences with the government-run programmes, annual CER volumes by 2012 could reach 41 to 67 million and 78 to 83 million by 2020. The projections based on the past diffusion trend indicate that in India, even with highly favorable assumptions, the dissemination of wind power projects is not likely to reach its maximum estimated potential in another 15 years. CDM could help to achieve the maximum utilization potential more rapidly as compared to the current diffusion trend if supportive policies are introduced. Purohit and Michaelowa (2007) pointed out that India will attain its cumulative wind power capacity of 45,000 MW by 2030.

One of the barriers to the large-scale dissemination of wind power projects in India is the high upfront cost of these systems. Other barriers to wind power projects are low plant load factors, unstable policies of the state governments and poor institutional framework. Indian Wind Energy Association (2007) found that the actual installations in 2006-07 could have been much more but many constraints such as the lack of power evacuation infrastructure, availability of sites, logistics and even shortage of wind turbine supply could have somewhat slowed down the process of wind farm capacity additions. There have also been regulatory issues in some states that needed to be resolved.

10. CONCLUSIONS

The solution to the problem of securing adequate energy supply lies in the integration of several options and technologies from diversified fields, viz: biomass, biogas, bioethanol, biodiesel, solar energy, wind energy, hydropower and other reasonably ecofriendly options. No particular option may be regarded as the panacea. Different countries and respective regions of the world would have to decide and choose on the combination of options which suit them the best giving cognizance to their resource base, technology level, and available manpower to operate the various systems. Economic, environmental and political considerations are also vitally important. For the tropical and agrarian countries, options should include the cultivation of cassava, cocoyam (often neglected but sturdy crops) and other second generation biofuels, as well as the use of livestock and other agro-wastes as sustainable sources in the production of ethanol fuel, biogas and other biofuels for the supply of energy. Other key options are solar power, wind power and hydro power. The experiences of Israel and India highlighted above should encourage the African and other tropical countries to pursue these options more aggressively. As noted by the International Energy Agency (2010a), ensuring energy security and addressing climate change cost-effectively are key global challenges. Finding solutions to the problems involved will require the participation of stakeholders worldwide by directing stronger efforts at renewable energy development and application. On a final note this paper recommends country-level partnerships particularly in the areas of development of enabling policies, technology deployment, human resources provision and concessionary financial assistance to the developing countries.

ACKNOWLEDGMENTS

The author is grateful to students and staff of the Federal College of Agriculture, Moor Plantation, Ibadan, Nigeria for their cooperation in the course of preparing this paper.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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