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ACPC
African Climate Policy Centre

United Nations Economic Commission for Africa
African Climate Policy Centre

Working Paper 11

Critical Issues in Bioenergy: Exploring the Opportunities, Constraints and Trade-Offs

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CRITICAL ISSUES IN BIOENERGY FOR AFRICA: EXPLORING THE OPPORTUNITIES, CONSTRAINTS AND TRADE-OFFS

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LIST OF ACRONYMS

ABPP	Africa Biogas Partnership Forum
ABREF	Africa Biofuels and Renewable Energy Fund
AEEP	Africa-EU Energy Partnership (AEEP)
AF	Adaptation Fund
AfDB	African Development Bank
AFPRO	Action for Food Production
AU	African Union
CAADP	The Comprehensive Africa Agriculture Development Programme
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CECAFA	Clean Energy Access & Climate Adaptation Facility for Africa
CEIF	Clean Energy Investment Framework
CEMAC	Economic Community for Central African States
CERs	Certified Emission Reductions
CFS	Committee on World Food Security
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CTF	Clean Technology Fund
DARE	The Nigerian Developmental Association for Renewable Energies
EAC	East African Community
EBA	Everything But Arms Initiative
EBID	ECOWAS Bank for Investment and Development
ECOWAS	Economic Community of West African States
EIB	European Investment Bank
EJ	Exa Joules
EJ/yr	Exa Joules per year
ENTRP	The Environment and Natural Resources Thematic Programme
EU	European Union
EUEI	EU Energy Initiative
FDI `	Foreign Direct Investment
GBEP	Global Bioenergy Partnership
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse gas
GIZ	Gesellschaft für Internationale Zusammenarbeit
GTZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HFO	Heavy Fuel Oil
HIVOS	The Humanist Institute for Development Cooperation
I-ALC	AfDB Agency Lines of Credit
ICRISAT	The International Crops Research Institute for the Semi-Arid Tropics
IEA	International Energy Agency
IFAD	International Fund for Agricultural Development
IISD	International Institute for Sustainable Development
I-LOC	AfDB Infrastructure Lines of Credit
IPCC	Intergovernmental Panel on Climate Change
FAO	Food and Agriculture Organisation of the United Nations
IRENA	International Renewable Energy Agency
IUCN	International Union for Conservation of Nature

LFG	Landfill Gas
LHL e.V.	Lernen-Helfen-Leben e.V.
LPG	Liquefied Petroleum Gas
LUC	Land Use Change
NGO	Non-Governmental Organisation
OECD	Organisation for Economic Co-operation and Development
PDF	Partnership Dialogue Facility
RE	Renewable Energy
RMCs	Regional Member Countries
REEEP	Renewable Energy and Energy Efficiency Partnership
SACCOs	Savings and Credit Cooperatives
SADC	Southern African Development Community
SCF	Strategic Climate Fund
SNV	The Netherlands Development Organisation
SVO	Straight Vegetable Oil
UN-Energy	United Nations Energy Knowledge Network
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	US Agency for International Development
VRA	Volta River Authority
WHO	The World Health Organisation
WRA	Weed Risk Assessment (Australia)
WTO	World Trade Organisation

ABSTRACT

Energy is a critical input to advancing social and economic development. No country has made significant strides without massive increases in energy use, which partly explains the strong correlation between higher human development index and higher energy consumption. About 2.7 billion people in the world rely on biomass for their energy needs and 1.3 billion people still lack access to electricity, clearly indicating energy infrastructures and services in many countries are failing to meet the needs of the poor. In the absence of a major shift in policy directions and technical interventions, the future appears even bleaker as the world faces a combination of rapidly increasing population, growing energy demand, volatile oil prices and an urgent need to reduce greenhouse gases (GHGs). This contradictory scenario points to the fact that the current mode of energy–society relations is facing challenges that requires a re-think in the way energy is accessed, distributed and utilised. In this regard, bioenergy is an essential option for a wide-range of applications. In the same way that bioenergy played a key role in human progress at key junctures in human history, modern use of bioenergy resources can provide some of the solutions to the energy security and climate change challenges of the future. This is especially true in the case of Africa where traditional bioenergy, derived from poor quality sources and used inefficiently, is the dominant fuel source, amounting to about 50% of the primary energy supply in the continent. Transitioning from traditional bioenergy use towards modern and sustainable use of bioenergy resources brings significant potential for expanding the production of heat, electricity and fuels for transport. This paper outlines some of the technical, institutional and political considerations in the formulation of better and meaningful bioenergy strategies for serving Africa's social and economic development agenda.

1. INTRODUCTION

For millennia, human societies have converted the bioenergy of plants and animals to provide light, heat and motive power. Today, bioenergy is the largest single source of renewable energy with a share of over 10% of global primary energy use (REN21, 2011). The proportion of bioenergy in some developing countries can exceed 90% of their primary energy supply (IEA, 2011a). Hence, bioenergy is an essential energy option for a wide-range of applications and will remain an important source of energy in most developing countries for the foreseeable future. However, the current utilisation of bioenergy in the continent is unsustainable and inefficient. About 65% of the African population rely on traditional biomass for cooking, most of them in rural areas (IEA, 2010b). Coupled with the efficiency levels of just 10 – 20% (Bailis, 2005) in burning biomass, bioenergy utilisation in the continent has exacerbated environmental impacts such as deforestation, in addition to health problems and mortality from indoor air pollution due to the use of this resource for cooking.

However, there are huge prospects in deploying modern and more efficient biomass fuels in the continent. Bioenergy has the highest potential expansion among renewable energy technologies, mainly because the technology is mature and is a relatively easy substitute to fossil fuels. Modern and more efficient biomass technologies such as biogas and improved cooking stoves could be used to substitute traditional cooking stoves in the household sector. Biogas could also be used for power generation and transport. Bioenergy in the form of bio-ethanol and biodiesel could also serve as substitutes for petroleum products in the transport sector.

The potential for bioenergy production in Africa is high and bioenergy holds promises for contributing to the energy needs of the continent. However, there is a lack of information and limited knowledge on the achievements made in harnessing bioenergy in Africa, the constraints and opportunities as well as future prospects for its development in Africa. Currently, there are many initiatives aimed at renewable energy development in the continent including bioenergy development (IISD, 2011). For example, international and regional institutions such as the International Renewable Energy Agency (IRENA), the Africa-EU Energy Partnership (AEEP), the US Agency for International Development (USAID), the African Union (AU), the Southern African Development Community (SADC), and the Economic Community of West African States (ECOWAS) all have initiatives aimed at fostering the development of renewable energy in the continent through measures such as accelerating renewable energy use, market development, capacity building, financing and fostering policies (IISD, 2011).

This paper makes its contribution in addressing the gaps in bioenergy development in the continent with the aim to provide decision makers an overview of the critical issues that need to be considered. This paper also reviews some of the existing projects and programmes that foster modern bioenergy development in the continent with the aim of identifying the factors for success and failure, the opportunities, constraints and prospects for the future of bioenergy development in Africa. The paper has five main sections. Section 2 provides a brief overview of some bioenergy technologies and resources. Sections 3 and 4 explore the potential opportunities and the trade-offs in bioenergy development in Africa. The policy, institutional and financial challenges of integrating bioenergy into the current and future energy mix in the continent are discussed in Section 5 while the conclusions are provided in Section 6.

2. REVIEW OF SOME BIOENERGY TECHNOLOGIES AND RESOURCES

Bioenergy sits at the crossroads of three of the world's greatest challenges – climate change, energy security, and poverty reduction. Energy demand is expected to increase considerably in the coming years due to population growth and economic development. The largest increases in energy demand are expected to take place in developing countries, although their per capita energy consumption will remain below those in the developed countries where population growth is relatively low and some degree of decoupling between GDP growth and energy consumption has taken place. This demand for increasing energy consumption to power development comes at a time when the world is facing the challenge of climate change, which requires a significant reduction in greenhouse gas (GHG) emissions to help stabilise the climate system. This picture is further complicated by the fact that over 1.3 billion people lack access to electricity (587 million in Africa), and about 2.7 billion rely on traditional biomass fuels to meet their basic energy needs (657 million in Africa) (IEA, 2011b), and are therefore excluded from the benefits modern energy can bring to improving livelihoods and economic opportunities.

The FAO (2004) defines "bioenergy" as all types of energy derived from biofuels, which are fuels derived from matter of a biological origin, or biomass. FAO (2004) categorises biofuels according to the source of biomass used in production (e.g. forest, agriculture or municipal) and the state of the product. Thus, biofuels comprise woodfuels, agrofuels and municipal by-products and each of these groups is divided into solid, liquid and gaseous forms of fuels that can be used for heat or power generation. Further classification can be made in terms of traditional and modern bioenergy sources.

Traditional bioenergy refers to bioenergy in the form of firewood, charcoal, crop residues and animal dung, and has been used as a source of energy throughout human history for cooking and heating. Traditional use of biomass continues to be an important source of energy in many parts of the world, and represents the largest contribution to the energy supply of many rural communities across the developing world. However, these resources are often used inefficiently and under poorly ventilated spaces to cook food. Indoor air pollution is at present responsible for 2.7% of the total burden of disease (WHO, 2009).

Modern bioenergy refers to biomass (or bioresources) converted to higher value and more efficient energy carriers such as biogas, ethanol and biodiesel. Bioenergy in these forms is becoming increasingly important to countries as a low-carbon, distributed, renewable component of their national energy mix. In some regions such as the European Union and parts of the United States, future technologies are emerging to make bioenergy use even more efficient and cleaner, thereby providing for greater GHG reductions. Stationary and transport applications represent two of the most important applications of modern bioenergy.

In *stationary applications*, biomass is used for production of heat and electricity including combined heat and power (CHP), also known as cogeneration, and mainly used for industrial processes and households (Onovwiona and Ugursal, 2006). This can take various forms. One way is to utilise biomass resources through combustion to generate energy in the form of electricity and heat. Some of the biomass sources include residues from agro-industries, wood wastes from forestry and industry, animal manure, post-harvest crop waste, grasses (miscanthus and switchgrass), and municipal solid wastes. Cogeneration can also take the form of creating biogas through anaerobic digestion of food or animal waste by bacteria, in an oxygen-starved environment to produce biogas that contains a high volume of methane and carbon dioxide (CO_2). The methane-rich biogas is combusted and used for heating or for electricity generation in a modified internal combustion engine.

In *transport applications*, liquid biofuels, such as ethanol and biodiesel have attracted the greatest policy attention in recent years, owing to the growing demand from the transport sector and increasing world oil prices, hence positioning biofuels firmly in the energy security discourse in many oil-importing countries. Part of the attraction in these energy sources is the fact that liquid biofuels require little or no changes to today's vehicles and infrastructure and have strong potential as near-term alternative fuels. Brazil has the most advanced biofuels programme, which began in 1975 in the aftermath of the first oil-crisis. The programme has evolved over the past 30 years into a major industry which has successfully mobilised agriculture, industry, and transport sectors, supported by a strong R&D into a viable programme of action. The current Brazilian policy requires a 20-25% blend of ethanol and 3% blend of biodiesel in all motor fuels (Bekunda et al., 2009), which is the main driver of the biofuels programme in the country. A number of African countries such as Kenya, South Africa, Ethiopia and Zambia have started to blend biofuels into their national fuel mix and diesel fuels as part of their national energy and transport policy, which are beginning to bring together domestic actors from agriculture and industry sectors.

Thus through engaging in various initiatives and introducing bioenergy-friendly policies, African countries aim among others to increase their energy security. This next section assesses some bioenergy technologies and resources as they relate to heat and power, transport and domestic (traditional) applications.

2.1 Biomass combustion technologies for heat and power

Biomass combustion for heat and electricity is a well-established commercial technology (see Figure 1). It is simply thermal processing, or burning of biomass, which in the simplest form involves the burning of biomass in a combustion chamber of a furnace. Following this basic principle, biomass-derived electricity is produced using a steam cycle process, in which biomass is burned in a boiler to produce high-pressure steam that drives a turbine to produce electricity. Commercial and industrial combustion plants can burn a wide range of biomass ranging from wood pellets, wood chips, wood residues, briquettes, straw bales and other agricultural residues to municipal solid wastes. Biomass can also be burned with coal in a boiler of a conventional power plant, and is viewed as a cost-efficient way of incorporating renewable technology into conventional power production because much of the existing power plant infrastructure can be used without major modifications (FAO, 2007).

Hao et al. (2008) reported that the efficiencies of all electricity-generating technologies are lower than 50%, and biomass combustion facilities have an even lower conversion efficiency of 17-25%. Cogeneration is thus widely recognised as the solution to making system-wide efficiency gains, potentially increasing the efficiency of energy conversion of power generating plants to almost 85% (FAO, UNEP, and UN-Energy, 2011). Currently, USA, Canada, Japan and Europe are increasingly establishing and promoting the application of cogeneration both in the industrial and residential sectors. About 30% of total electricity production in Denmark, the Netherlands and Finland is cogenerated (Purohita and Michaelowa, 2007). Despite the obvious advantages of cogeneration, the system remains untapped in Africa perhaps because of lack of heat demand in households due to the hot weather and the low level of industrial development across the continent. However, few African countries have started applying cogeneration in their industrial sector. For example, Mauritius meets 40% its electricity needs from cogeneration (Palanichamy et al., 2004). Following the success of cogeneration in Mauritius, an initiative co-implemented by UNEP and AfDB aimed at promoting cogeneration in Africa was launched in 2007 to run for six years (UNEP, 2011). The initiative is being implemented in the agro-industrial sector in seven Eastern and Southern African countries (Kenya, Ethiopia, Malawi, Sudan, Uganda, Tanzania and Swaziland) using bagasse.

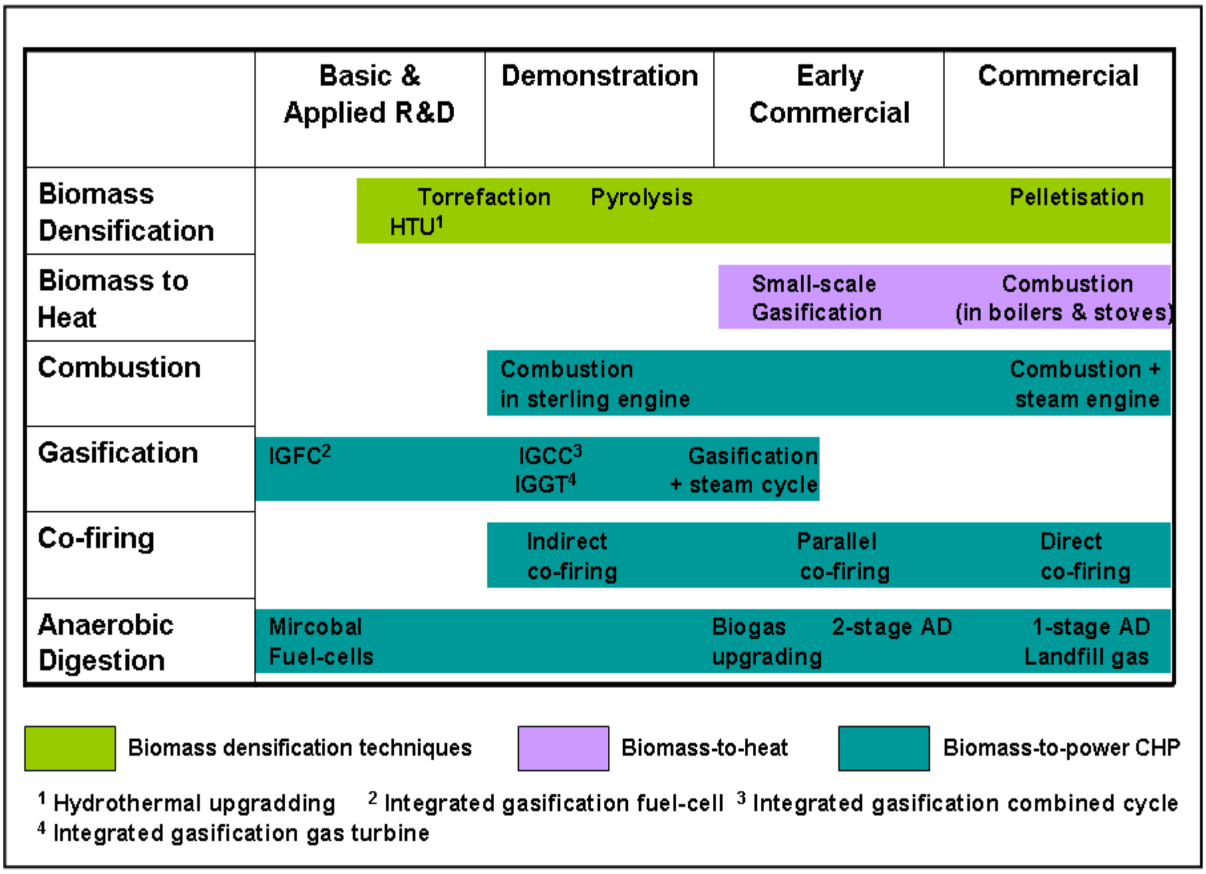

Figure 1: Development status of bioenergy to heat and power technologies
Source: IEA (2009)

2.2 Biogas technologies for heat and power

Biogas technologies are increasingly being used for power generation as well. Some of the promising technologies are reviewed below.

2.2.1 Anaerobic digestion

Anaerobic digestion is the bio-chemical process by means of bacterial breakdown of organic materials in oxygen-free conditions. This biochemical process produces a gas, known as biogas, mainly composed of a methane-rich gas and CO_2, which can be burnt for the generation of electricity and heat (Schulz et al., 2007). Feedstocks for biogas include sewage sludge, cattle dung and manure, chicken droppings, kitchen waste, food processing factory wastes, human excreta as well as biomass crops (Arthur et al., 2011).

Anaerobic digestion also occurs naturally underground in landfills and produces landfill gases (LFG) which can be collected for use in energy applications. Typically, landfill gases contain 50-60% methane (CH_4) and 30-40% CO_2 both of which are GHGs that contribute to global warming (Shin et al., 2005). The recovery of LFG for generation of electricity has been practiced since the 1980s to solve both environmental pollution and energy shortage problems. The US has the most LFG recovery plants followed by Germany and The United Kingdom (Hao et al., 2008). Recently, landfill electricity generation projects have been funded under the Clean Development Mechanism (CDM) of the Kyoto Protocol. However, out of the 130 landfill CDM projects worldwide, only 10 registered projects exist in Africa (UNEP, 2009) with another eight at the validation stage. However, the CDM methodologies are very conservative and tend to under-calculate Certified Emission Reductions (CERs) which may put marginal projects at risk (Couth et al., 2011), and may explain why there are only few projects in Africa despite the existence of large number of municipal landfills.

China, India, Nepal, Thailand, Germany, United States and Denmark have a long experience in the development of biogas programmes and projects (Salomon and Lora, 2009). However, the experience in developing countries has been largely limited to small-scale applications of anaerobic digestion in rural areas for cooking and running gas generators. Martin et al. (2009) report that over 560 biogas processors mostly based on livestock wastes and seedcakes provide fuel for clean-burning cooking stoves in Tanzania. Currently, there are roughly 1000 biogas plants installed in Tanzania by organizations such as Kakute Ltd., Karatu Development Association, the Danish Environment and Development Organization (Eco-Net) and other organisations. Many projects are promoting biogas plants in Africa, especially in the context of climate protection (See Boxes 1 and 2). Box 2 also shows the active involvement of the private sector and the NGOs in the domestic bioenergy sector, and exemplifies the potential in south-south partnerships.

Box 1: Biogas development in Africa

Biogas development is spreading fast across Africa. The Netherlands government is funding €30 million, one third of the total programme costs of the Africa Biogas Partnership Programme (ABPP), a partnership programme between HIVOS (the Humanist Institute for Development Cooperation) of Tanzania and the Netherlands Development Organisation SNV in supporting national programmes on domestic biogas in six African countries. The programme aims to construct "70,000 biogas plants in Ethiopia, Kenya, Tanzania, Uganda, Senegal and Burkina Faso providing about half a million people access to a sustainable source of energy by the year 2013" (SNV undated).

For Tanzania, SNV estimates that the technical potential for domestic biogas is around 165,000 households with Kilimanjaro, Mbeya, Iringa and Ruvuma area holding the most potential. However, the relative high initial investment to build a biogas plant is a challenge. According to SNV (undated), the turnkey cost for a 6m^3 digester can be as high as US$1,000. To stimulate demand, the project team provides financial incentives such as investment subsidies and special biogas loans in cooperation with Equity Bank in Kenya which provides credit to the participating farmers for biogas production. The Kenya programme has thus constructed over 600 digesters in 2010.

Source: SNV (undated) SNV Tanzania. Tanzania Domestic Biogas Programme

Grid-connected large-scale biogas programmes are uncommon in developing countries. Few countries like Tanzania follow an integrated program approach through large-scale biogas production from organic wastes, to produce grid-connected electricity and organic fertilizers (Mbuligwe and Kassenga, 2004). Limitations in biogas technology such as the slow and unstable process have been addressed, thereby improving the overall efficiency (Rao et al., 2011). Several pre-treatment methods such as chemical, biological and thermal have also been successfully tested to improve the anaerobic digestion of waste (Ma et al., 2011).

Box 2: CDM and other climate-funding approved biogas plants in Africa
In partnership with Atmosfair (2010), the Kenyan organisation Sustainable Energy Strategies (SES) and the Indian NGO Action for Food Production (AFPRO) are building and installing biogas plants. The small-scale project activity aims to construct up to 13,000 domestic biogas digesters of 2m^3 and 3m^3 capacities each for individual households owning at least 2 zero-grazing cows in Nairobi River Basin/Kiambu District. The biogas units are fed with cow dung to produce renewable biogas for cooking and heating water. The project started in June 2010 with a pilot phase in which 20 biogas units are constructed and tested for 6 months. Following up this pilot phase, the CDM project activity commenced in 2011 aiming to construct 1,000 biogas units in 12 months and thereafter 6,000 biogas units annually. AFPRO trains the local masons so they can build the biogas plants independently. The biogas digester type Deenbandhu model 2000 is approved and has further been developed by AFPRO since the 1970s. In a six month pilot phase in the context of a CDM-JI initiative funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, about 20 Biogas plants have been introduced. Atmosfair intends to register the project as a UN-climate protection project and to build up to 5,000 biogas plants. In total 13,000 biogas units shall be constructed within three years. Carbon revenues will be the only source of subsidy financing. The biogas digesters are saving greenhouse gas emissions by replacing non-renewable biomass (mainly fuel wood and charcoal), as well as fossil fuels (mainly Kerosene and LPG) used currently by the households in Kiambu District with renewable biogas. A 2m^3 biodigester avoids 3 tCO_2e annually (in tonnes of CO_2-equivalent). The digesting process will generate fertile slurry as a by-product, which can be used as manure for local agriculture (e.g. vegetable farming) and/or as regular income earning activity. Beneficiaries will be mainly dairy farmers with zero grazing cows and members of rural dairy SACCOs (Savings and Credit Cooperatives). Atmosfair (undated) also has a similar project running in Burkina Faso but it uses crop residues to feed biomass gasifier plants, thereby saving 5,000 tonnnes of CO_2 per year and replacing the hitherto used diesel generators. The biomass gasifier plants have an installed capacity of 1.5-2 MW in the rural communities of Pô and Garango and will save between 5,000 and 7,500 tonnes of CO_2 annually. Since 2009 the Operational Team of the community provides green power from local biomass residues for the hospital and the administration building, thereby cutting procurement costs for the supplier, and creating an additional income for many people in the area (through sale of crop residues to the plants). The project is part of the International Climate Initiative and is funded by the Federal Ministry for the Environment (BMU).
Sources: Atmosfair GmbH (2008)

Algae is another source of feedstock for biogas which has several advantages over other types of energy crops because it is capable of doubling its biomass within 24 hours and the land area needed to produce it can be non-fertile, hence no competition for land with food crops (Zamalloa et al., 2011). Overall, biogas technology is not as widespread as in some other regions.

2.2.2 Gasification and pyrolysis

Gasification is a thermo-chemical process in which fossil fuels or biomass is converted into several combustible gases or synthesis gas for electricity and chemicals production (Gomez-Barea and Leckner, 2010). The significance of gasification technology stems from the fact that it can make use of advanced turbine designs and heat-recovery steam generators to achieve high energy efficiency. Siemons (2001) suggested that for developing countries, biomass gasification, as opposed to fossil fuel gasification, is advantageous because biomass can be produced locally and therefore cheaper and more accessible than fossil fuels. Hence, there is growing interest in the biomass gasification technology in Africa although only very few countries have so far taken the initiative to apply the technology. The most successful pilot project of biomass gasification aimed at economic empowerment of rural communities is in Eastern Cape, South Africa (Mamphweli and Meyer, 2009). The project involved the installation of a 300 Nm^3/h biomass gasifier in the Melani village that uses sawmill waste to generate low-cost electricity to drive community economic development initiatives in the village, including poultry farming, manufacturing of windows and door frames and sewing of clothing. However, despite abundant biomass resources, the application of biomass gasification also remains low in Africa.

Pyrolysis is essentially biomass gasification under conditions of complete absence of oxygen that produces a liquid bio-oil, a mixture of gas (syngas) and charcoal (biochar). A considerable amount of research has gone into pyrolysis in the past decade in a number of countries. However, as illustrated in Figure 1, pyrolysis technologies are still at the demonstration stage with only a few successful demonstration sites existing in Finland and Canada.

2.3 Liquid Biofuels and Biogas for Transport

Biofuel applications in the transport sector comprise a variety of liquid and gaseous fuels. Biofuels in transport can either be blended with fossil fuels, such as ethanol blended with gasoline or biodiesel with diesel fuel; or the fuels can be used directly in dedicated (modified) engines. In the transport sector, liquid or gaseous biofuels are currently the only mature renewable alternative to fossil fuels that is readily available and can be used without replacement of the vehicle fleet (FAO, UNEP, and UN-Energy, 2011). Although there is a growing interest in using biogas for transport, and there are some successful models (e.g. in Sweden), this section will limit its focus to liquid biofuels for transport.

2.3.1 Bioethanol

Bioethanol fuel is mainly produced by the fermentation of sugar and starch crops in which a catalyst is used to convert the sugars into alcohol. A wide range of common sugar crops such as sugar cane, sugar beet and sweet sorghum, containing a large proportion of simple sugars are used as feedstock for producing bioethanol. Other feedstocks include starch crops such as corn, wheat and cassava. According to Goldemberg (2008), ethanol has a higher octane rating than gasoline, which improves engine performance, but a lower energy content, which results in less distance travelled per unit of fuel. Currently, the United States is the largest producer of bioethanol with corn as its primary feedstock, followed by Brazil that uses sugar cane as its principal bioethanol feedstock. Various other countries have also entered the market, mainly in Asia.

Production costs vary significantly depending on the feedstock used and the size of the processing plant with larger plants offering economy of scale comparative advantage over smaller plants. The IEA (2009) indicates that ethanol can be produced from Brazilian sugarcane at less than US$0.30 per litre, which is significantly lower than ethanol production from corn in the US at about US$0.75 per litre, and US$0.87 per litre for bioethanol from wheat in the UK. The same study highlights that feedstock costs account for about half of the cost of ethanol from sugarcane. Biofuel producers in the African region are unlikely to be as low-cost as Brazilian producers of ethanol or Southeast Asian producers of biodiesel on large-scale projects. However, the opportunity to address energy security concerns through biofuels now exists.

For large-scale ethanol production, sugarcane and molasses (a by-product of sugar production) seem the most viable option. Donald (2011) argues that even though biofuel production costs in Africa is “unlikely to be as low-cost as Brazilian producers of ethanol or Southeast Asian producers of biodiesel on large-scale projects”, ethanol produced from molasses has low opportunity costs and is the lowest-cost biofuel in Africa: the low demand for molasses in many African countries and the high costs of exporting it make the prices to remain low at US$20 per tonne. Donald (2011) estimates that ethanol can be produced at a low cost of US$0.20 per litre or less (about half the price of imported gasoline).

2.3.2 Biodiesel

Biodiesel is produced from animal fats or vegetable oils through esterification process using feedstock such as rapeseed, soybeans, palm oil, jatropha, and sunflower. Outgrower schemes and sustainable farming are becoming drivers for biofuel business in Tanzania as many farms are growing *jatropha curcas* as cash crops for biofuel development projects (Martin et al., 2009). Smallholder farmers can produce jatropha seeds and process them into Jatropha oils for domestic lighting. They can also supply large-scale companies' biomass crops for bioenergy production.

Biodiesel can be blended with fossil-based diesel fuel or burned in its pure form in compression ignition engines. Although biodiesel contains 88-95% as much energy as fossil diesel, biodiesel improves the lubricity of diesel and raises the cetane value, thereby making the fuel economy of both generally comparable (FAO, 2007).

As in the case of bioethanol, production costs of biodiesel is highly dependent on the feedstock used and scale of the plant. The majority of plants installed are larger plants, some exceeding 200 million litres per year. Production costs range roughly from US$0.50/l to US$1.60/l, depending on whether waste feedstock or vegetable oil is used (IEA, 2009). Production costs are dominated by feedstock cost in the case of vegetable oils, and so improvements at the farm level are important entry points for reducing the cost of biodiesel fuels.

2.4 Domestic Energy Applications

Bioenergy for domestic applications can be in form of biomass, ethanol, biodiesel, gel fuels or biogas. Traditional biomass fuels such as charcoal, fuel wood, manure, and crop residues is the main source of energy for domestic use in Africa, for cooking, lighting and in some places for heating.

Improving household energy services across Africa can provide various socio-economic and environmental co-benefits. These include reduced deforestation and GHG emissions, reduced dependence on fossil fuels, low cost energy, improved sanitation, reduced indoor pollution, time saving for women and children, rural employment creation, bio-slurry fertiliser, reduced pressure on rangelands and general promotion of rural development (SNV undated; GTZ 2009). Box 3 provides an example of a CDM approved energy efficient fuel wood stove in which the health benefits associated with improved cookstove programmes, especially for women can also reduce greenhouse gas emissions.

Box 3: A CDM approved energy efficient fuel wood stove

Energy efficient fuel wood stove is fast spreading in Africa to address the scarcity of fuelwood, reduce GHG emissions and health risk exposures on women. The Nigerian Developmental Association for Renewable Energies (DARE), the German organisation Lernen-Helfen-Leben e.V. (LHL e.V.) (both Non-Governmental Organisations) and the German carbon offset organisation, Atmosfair GmbH are running a CDM approved project on efficient fuel wood stoves (Atmosfair GmbH, 2008).

The project activity aims to disseminate up to 12,500 efficient fuel wood stoves (that saves up to 80% of fuel wood) and heat retaining polypropylene boxes (hereafter referred to as the SAVE80 system) in different states located in the Guinea Savannah Zone of Nigeria, at subsidised prices. Users are households who previously used inefficient, traditional fireplaces. The proposed small-scale CDM project activity is among the first in Nigeria and the first one applying small-scale methodology AMS[1] II.G (for details on AMS II.G, see UNFCCC (2010)). Atmosfair funds and pre-finances the project activity. In a form of technology transfer, the stove (SAVE80) components are fabricated in Germany and assembled by locals previously trained by DARE. By reducing greenhouse gas emissions stemming from the use of non-renewable biomass, the CDM funding is used to subsidise the sales of the SAVE80 system to households. About 30,000 tonnes of CO_2 are saved per year, averaged over a 10-year period. Similar projects funded by Atmosfair through various funding are on-going in Lesotho (financed by the Deutsche Post DHL Programme GOGREEN), Rwanda and Cameroun (both in the validation phase).

Sources: Atmosfair GmbH (2008)

The use of liquid biofuels at the household level, such as ethanol, biodiesel, straight vegetable oil (SVO) as well as biogas is spreading. One often cited example is the programme initiated by the Mali Folkecenter Nyetaa that helped communities to meet their energy needs by establishing local biofuel systems. The second stage of the project involved planting 1,000 hectares of jatropha to provide electricity for 10,000 rural inhabitants whereby villagers provide communal lands for jatropha in exchange for improved access to energy (Cotula et al., 2008).

Another domestic bioenergy source is gel fuel, which comprises ethanol, organic pulp and water and can be used as an alternative to paraffin, liquefied petroleum gas (LPG). However, Lloyd and Visagie (2007) compared gel fuels with alternative cooking fuels (paraffin, liquefied petroleum gas) and found that the gel fuels emitted high levels of unburned hydrocarbons, produced much less energy than the alternative fuels so that three times more gel fuel than the mass of alternative fuels was required to cook a standard meal. Hence gel fuels are not economically competitive against the alternatives of paraffin or LPG. The variance in the performance of the various gel products led the authors to recommend the establishment of a standard for gel fuels.

3. POTENTIAL OPPORTUNITIES FOR DEVELOPING BIOENERGY IN AFRICAN COUNTRIES

3.1 Bioenergy Feedstock

The use of modern bioenergy in Africa has generally been limited to few industries where residues are available such as timber sawmills and sugar factories. However, there is vast opportunity for modern bioenergy in Africa due to high productivity of biomass (Duku et al., 2011). African countries are five times more productive, in terms of photosynthesis efficiency, than temperate countries (Johnson and Matiska, 2006), with Sub-Saharan Africa having the greatest bioenergy potential among all world regions (Faaij and Domac, 2006). This is due to large areas of suitable cropland and pasture land as well as favourable climatic condition for biomass production and low cost of labour (Johnson and Matiska, 2006).

In addition to wood and agricultural waste, agricultural crops such as sugar cane, maize, sorghum, and cassava also form potential bioenergy feedstocks. Bio-ethanol has been produced from sugarcane on industrial scale in Malawi and from cassava in Benin (Wicke et al., 2011). Experience from Brazil shows that ethanol in Brazil can be produced at an equivalent of US$30-35 per barrel of oil and is thus competitive with fossil fuels (Donald, 2011), and this experience from Brazil offers some valuable lessons for African countries as they develop their bioenergy programmes. Recently, non-edible oils such as jatropha oil have

[1] Approved Methodology for Small-scale CDM project activities

been found to be promising feedstocks to produce biodiesel in Africa. Jatropha can grow under a wide variety of climatic and land conditions (Achten et al., 2008). Although many countries grow jatropha, only Togo, Mozambique, Ghana and Niger have large jatropha farms. The jatropha electrification project in Mali is one successful example on the use of jatropha (Wicke et al., 2011). However, not all countries see jatropha as a promising fuel for their energy sector, as recent studies show that among all, biofuel from Jatropha takes time to produce, may jeopardise food production and lead to contested outcomes (Hunsberger, 2010). For example, South Africa has placed jatropha on the list of invasive species (Amigun et al., 2011).

3.2 Potential Market for Bioenergy

Many countries in sub-Saharan Africa are characterised by severe poverty, low levels of investment and poor infrastructure. Under such circumstances, modern bioenergy may seem to have a low priority. However, modern bioenergy projects are being implemented as part of a sustainable development strategy by some African countries because of its varied benefits which include improved health, reduced GHG emissions, creation of rural livelihoods, foreign exchange earnings and reduced dependence on imported energy. The opportunities for new export markets in the emerging global trade in biomass and bioenergy products have also become attractive to many African countries as these can, to a certain extent, satisfy their needs for high investment and hard currency earnings. The global bioenergy market is expected to reach to a size of 400 EJ over this century and the value of this market at US$4/GJ is estimated to be over US$ 1.6 trillion per year (Junginger et al., 2006). This will create important opportunities for regions including Africa (Faaij and Domac, 2006; Verdonk et al., 2007).

The potential for GHG emission reductions from the use of modern bioenergy can be significant for Africa because credits can be earned under the CDM. Hence, the market potential for bioenergy is vast in Africa. When considered in the broader context of regional economic integration such as the East African Community (EAC), Southern African Development Community (SADC), the Economic Community for Central African States (CEMAC) and Economic Community of West African States (ECOWAS), the potential of modern bioenergy becomes more attractive since different countries in each region can mutually benefit from pooling their resources and jointly utilising their comparative advantages in global markets as suggested by Johnson and Matiska (2006).

3.3 Agricultural Requirements, Land Required and Suitable Crops

In discussing the agricultural requirements for bioenergy crops, a distinction needs to be made between bioenergy crops that are also food crops, such as wheat, maize, sugar, sweet sorghum, sunflower, soybeans and other bioenergy crops not used for food consumption, such as Jatropha or Croton. The agricultural conditions for growing the food-bioenergy crops are widely accessible. For those non-food bioenergy crops there is a need to conduct detailed research of their agronomy. *Jatropha curcas*, *Croton megalocarpus*, *Ricinus communis* (Castor) seeds are potential oilseed crops for biofuel production. While Jatropha is not indigenous to Africa, Croton and Castor are indigenous African plants that also grow in the wild. Few empirical data exist on the agricultural requirements of these plants, although there is some evidence to show that jatropha is a resilient plant that can grow under conditions of low precipitation (as low as 300 mm), albeit with low yields of seeds (GTZ, 2009).

Croton and Castor also require good management. For all three crops, little information exists on the optimal conditions for obtaining high yields. The three crops are also affected by various pests and diseases hence they require good management, water and fertilizer. GTZ (2009) finds that Jatropha is not economically viable for smallholder farming whether grown as a monoculture or intercrop plant due to its very low yields and uneconomical costs of production. The GTZ (2009) thus recommended ceasing from promoting Jatropha as a bioenergy feedstock among smallholder farmers for any plantation other than as a fence. Considering the limited information on the optimal agronomic and economic conditions for managing these crops, it is necessary that empirical studies are conducted to determine their optimal agronomic conditions and management for the various African contexts.

In contrast, sugarcane production is well known in Africa, and the technology for producing ethanol from sugarcane and molasses has been refined in Brazil over the past 30 years and can be readily adapted to Africa (Donald, 2011). African countries should thus study the Brazil case.

Land requirement for bioenergy production depends on the scale of production and land quality. Bioenergy crops can be grown and processed at different scales from the small-scale at household level to the large-scale at plantation level. Some parts of Africa are perceived to have land available for bioenergy feedstocks, due to favourable environmental conditions and low population density (Batidzirai et al., 2006). Abandoned agricultural land, non-productive land or land that would become free through improved efficiency of agricultural production, are options often mentioned. For example, Smeets et al. (2004) expect that with improvements in agricultural productivity of up to 8 times, about 700 million hectares (Mha) of land in Sub-Saharan Africa could be used to grow bioenergy feedstocks with annual yields of up to 317 EJ. Hoogwijk (2004) also sees Africa's abandoned agricultural and non-productive land to hold the potential of producing up to 134 EJ/yr for Africa. However, what is often referred to as unoccupied land turns out to be used by the local community such as the case of the Tana delta in Kenya. In terms of land size, bioenergy feedstocks can be grown as hedges, as intercrop in small-scale farms and as dedicated plantations. Land is key to agricultural production in Africa and to the livelihoods of its dominant smallholder farmers. To ensure that bioenergy development does not constrain access to land, many African countries need to reform their land laws and to build in checks and balances to ensure that local communities and indigenous peoples are not dispossessed of their land by large-scale plantations for bioenergy crops. African governments should build on the Committee on World Food Security (CFS) *Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests* (FAO, 2011) and enact laws that curb speculative acquisitions of agricultural land and to ensure that land leases are transparent and equitable. In terms of land quality, bioenergy feedstocks also need land of good quality to produce high yields (GTZ, 2009) in contrast to the widespread belief that Jatropha, for example, can survive on marginal land and still deliver good yields. Biomass suitability for bioenergy depends on various factors – in general the fit of the crop characteristics to the ecological, economic and social context – and this must be clarified before a feedstock is chosen.

3.4 Trade Financing and Investments

According to IEA (2010), the global use of biofuels, especially transport fuels derived from biomass feedstock is expected to continue to rise rapidly until 2035 due to rising oil prices and government support. As the current cost of producing biofuels is often higher than that of imported fuel oil, strong government incentives are often needed to make biofuels competitive with oil-based fuels (IEA, 2010). Although IEA (2010) projects *"global government support to biofuels to increase to about US$45 billion per year between 2010* *and 2020, and to US$65 billion per year between 2021 and 2035"*, "*the United States, Brazil and the European Union are expected to remain the world's largest producers and consumers of biofuels*".

Government policy action and how it affects technology, the price of energy services and end-user behaviour is therefore critical for world energy (IEA, 2010). Bioenergy development requires substantial upfront investments which makes it difficult for the private sector. According to Hazell (2006), such investments yield little initial returns until adequate scales of production and demand are achieved to reduce the unit costs. It is therefore necessary to also invest in the value chain ranging from producers to consumers (farmers, processors, traders and consumers). In light of these production limitations, government actions such as in policies or subsidies are seen as necessary to achieving a critical market size (Hazell, 2006). While this is already occurring in Europe (e.g. EU requirement that diesel contains at least 2% biodiesel or the policy support in Brazil in the mid-70's for ethanol production), many countries in Africa are still to follow suit (Hazell, 2006). Some African countries such as Malawi, South Africa and Mozambique have a biofuel consumption mandate. They also incentivise biofuel production through fuel tax exemption, government support to research and production in government-owned facilities. Malawi trade policy makes provisions for regulating price and tax incentives (Donald, 2011). However, how these national policies interact with national food production and access to land need careful consideration.

Financial incentives for production and consumption can trigger a faster growth and uptake of certain energy sources as has been shown for Senegal and Mali (Denton, 2004), but can also distort biofuel markets (Donald, 2011). These incentives for example, in the form of special trading arrangements and preferred markets (e.g. EU sugar protocol, EU Special Preferential Sugar; EU EBA - Everything but Arms Initiative; US Quota), can distort prices such as for sugar. Although the EU and USA have long subsidised their producers, they have also given African countries preferential access to their markets although recent trade agreements and reforms have to comply with the WTO regulations and are thus gradually reducing and removing such supports (Johnson and Matsika, 2006). They have thus created export opportunities for most African countries. However, if other bioenergy producers such as Brazil, Indonesia, Malaysia, and South Africa were granted preferential access, it would erode the trade advantage currently available to African producers (Donald, 2011).

The excellent growing conditions for sugar cane and efficient milling operations in the SADC region make sugar production cost-effective while the positive international market conditions (preferential access) make ethanol production in the region potentially viable (Johnson and Matsika, 2006). The increasing global demand for biofuels, in particular ethanol thus provides opportunities for African exporters because neither the EU nor USA can meet their consumption mandates solely from domestic production (Donald, 2011). In contrast, biodiesel exports offer a lesser opportunity for African producers because the EU and U.S. import duties are lower and the duty-free access for African producers offers lesser advantage over low-cost Southeast Asian producers (Donald, 2011).

Johnson and Matsika (2006) highlight that import tariffs as well as standards in some OECD as well as SADC countries could affect the trade in bioethanol. However, to promote bioethanol trade, the scale of ethanol production in the southern Africa region need to be significantly increased to meet economies of scale as the current factory sizes are too small to result in a large enough market for export to be competitive (Johnson and Matsika 2006). The authors find the process of regional economic integration in SADC to be both a facilitator and a beneficiary of expanded bioethanol production. Such processes need to be accompanied by improving logistics, expanding the distribution capacity and transportation infrastructure in the region as many ports in the region are small and the extent and quality of road networks are limited. Removing import tariffs, signing long-term contracts, and linking up to international markets are important requirements for bioethanol trade development in the region (Johnson and Matsika, 2006).

The projected growth in demand for transport fuels by more than 5% per year in Sub-Saharan African countries during 2005 – 2020, will also provide opportunities for domestic use of biofuels. In Malawi, for example, ethanol produced from molasses is used as a substitute for imported gasoline since the early 1980s (Donald, 2011).

As African agriculture is dominated by smallholder farmers, they can be integrated into bioenergy feedstock production as outgrowers, for example in the production of sugarcane for ethanol production. Although large-scale biodiesel production in Africa has lesser comparative advantage, smallholder farmers could still produce biodiesel for domestic markets.

The scale of bioenergy production has different implications due to poor infrastructure, weak national agricultural research systems, high import costs on equipment and inputs, and an often unfavourable business environment (Donald, 2011). Hence small-scale production of jatropha oil for local use from existing farmstead hedges and wild trees may not require a biofuel policy. The case is however different for large-scale feedstock and biofuel production – issues about access to land and water need to be regulated, concerns about food production need to be addressed and enabling frameworks for such large-scale enterprises to cope with the limited infrastructural development in Africa also need to be addressed by policy. Donald (2011) recommends a phased approach to biofuel development that allows for flexible development of policy support, institutional capacity, and regulatory requirements for each phase.

The international community, multilateral organisations, and donors are already supporting the development of a biofuel industry in Africa by providing financial support, policy guidance, and capacity building (e.g. the Netherlands Development Organisation SNV or the German GIZ) as well as promoting smallholder participation. Various national and international research organisations are also into biofuels crop research as well as agricultural research in general (cf. Donald, 2011).

Various firms in Africa are investing in bioenergy development and are already producing and selling biofuels: For example, *D1 Oils plc (D1), a U.K. share company produces jatropha oil for export and domestic use in Malawi and Zambia* (Donald, 2011); Diligent Tanzania Ltd. (Diligent), a privately held Dutch company has been producing jatropha oil in Tanzania since 2005 while SEKAB, a Swedish company is planning to produce ethanol from sugarcane grown on leased land and from outgrowers in Mozambique and Tanzania (for details see Donald, 2011).

3.5 Rural Development

As bioenergy development has to be aligned with development, integrated approaches that incorporate bioenergy production with rural development also exist such as illustrated in Box

4. Various GEF small grants programme support biofuel production such as supporting farmers or local populations to grow Jatropha. Through this, the local actors derive various benefits such as training and capacity building in biofuel production, participation in innovative financial mechanisms; increased income through sale of Jatropha seeds and cuttings as well as developing other livelihoods such as beekeeping and selling of honey (GEF Small Grants Programme, 2006a).

Box 4: Integrated approaches to bioenergy production
In Tanzania, such an integrated project has provided income generating opportunities for poor women farmers through the sale of Jatropha seeds; fostered capacity building and entrepreneurial skills, for example to women farmers to make soaps and candles, and for producing biodiesel (GEF Small Grants Programme, 2006b). In Ghana, the GEF small grants programme (2006c) is financing the Tema Cooperative Sunflowers Association, a non-governmental Organisation, to integrate biofuel production into sustainable land management. The project developed and implemented a multi-integrated model for the cultivation of sunflower on degraded community lands, processing of sunflower feedstock into biodiesel, using the biodiesel to power farm tractors and machines and using the cake from the sunflower oil to feed livestock and poultry and fertilize the degraded lands. The project has improved the capacities of 50 rural farmers in Gomoa Adzentem and its surrounding villages to integrate renewable energy production into sustainable land management by investing in sunflower production, apiculture and food crop production. In Ghana, the GEF Small Grants Programme (2006c) improved the capacities of farmer groups to incorporate the cultivation of biofuel plants under improved agro-forestry farming systems to restore 1,000 ha of degraded lands, established own local enterprises and operating biofuel processing plants to process crude sunflower and jatropha oil into biodiesel. The project produced about 1,000 tonnes of sunflower feedstock during a one year period which has been processed into biodiesel that met all the environmental specifications of the Ghana Standard Board and the Volta River Authority (VRA). The project has also produced 120 litres of organic honey from the sunflower farms and bottled them for sale. According to GEF 2006c, "the project has developed partnership with the research and academic institutions as well as private sector partnership. For example, The Kwame Nkrumah University of Science and Technology and the University of Ghana, Legon provide the relevant technical backstopping. The Stanbic Bank, Accra is providing the financial support for the expansion of the cultivation of the sunflower feedstock in Brong Ahafo Region. The VRA also expressed interest in purchasing 1.6 million tonnes of sunflower biodiesel annually to feed its thermal plant in Aboadze". Within two years of operation 200 tonnes of CO_2e was avoided by using biodiesel instead of fossil oil in farming in the project area. About 50-60 bags of fertilizer, which would have been used in farming was substituted with sunflower cake residue. Despite challenges faced in terms of insufficient awareness by local inhabitants on the project gains, and hindrances to commercialising biodiesel, major benefits include reduced land degradation, avoidance of the use of chemical fertilizers and conservation of biological diversity in the coastal savannah areas of Ghana. Other benefits include the restoration of long-term productivity of the land, reduced deforestation and bush burning, and a 40% reduction in wildfires. The incorporation of apiculture in food crop production contributed to food security and increased income. The project's environmental, social and economic sustainability is reflected by its continuing functioning after the end of SGP-GEF funding period. Consequently, the Ghana Ministry of Energy is encouraging investments in renewable energy as part of the national energy mix policy. Similar projects have been financed in Cameroon and Kenya with satisfactory results (GEF Small Grants Programme, 2006e and 2006f).
Sources: GEF Small Grants Programme (2006 b,2006c, 2006d, and 2006e)

3.6 Mitigation Opportunities

Bioenergy has a significant GHG mitigation potential, provided that the resources are developed sustainably and that efficient bioenergy systems are used. Certain current systems and key future options including perennial cropping systems, use of biomass residues and wastes, and advanced conversion systems are able to deliver 80-90% emission reductions compared to the fossil energy baseline. However, land conversion and forest management that lead to a loss of carbon stocks in addition to indirect land use change (LUC) effects can lessen, and in some cases more than neutralise, the net positive GHG mitigation impacts (IPCC, 2011). Impacts of climate change through temperature increase, rainfall patterns change and increased frequency of extreme events will influence and interact with biomass resource potential. This interaction is still poorly understood, but it is likely to exhibit strong regional differences. Climate change impacts on biomass feedstock production exist but if global temperature rise is limited to less than 2^{o}C compared with pre-industrial record, it may pose few constraints. Combining adaptation measures with biomass resource production can offer more sustainable opportunities for bioenergy and perennial cropping systems (IPCC, 2011). Mitigation under bioenergy include options such as fuel switching from diesel/HFO to biodiesel, and fuel switching from coal to biomass (in the form of either pellets or biomass loose), as well as electricity generation from liquid and solid municipal waste (i.e. bio-methanation and landfill), etc.

Renewable Energy (RE) and in particular bioenergy is likely to play an important and increasing role in achieving ambitious climate mitigation targets. Although it is not possible to precisely link long-term climate goals and global RE deployment levels, RE deployment significantly increases in the scenarios with ambitious GHG concentration targets. Ambitious GHG concentration targets lead on average to higher RE deployment compared to baseline. However, for any given long-term GHG concentration goal, the scenarios exhibit a wide range of RE deployment levels. In 2008 total RE production stood at roughly 64 EJ/yr (12.9% of total primary energy supply) with about 40 EJ/yr of this being traditional biomass. In contrast, projected levels of RE deployment in 2050 are greater than 100 EJ/yr in most scenarios and reach 200 EJ/yr to 400 EJ/yr in many scenarios. Given that traditional biomass demand decreases in most scenarios, an increase of production level of RE (excluding traditional biomass) anywhere from roughly three-fold to twenty-fold is expected (IPCC, 2011).

In other words, it is likely that RE will have a significantly larger role in the global energy system in the future than today. Even without efforts to address climate change, RE can be expected to expand. Even in baseline scenarios with no assumed climate mitigation target, large RE deployments of more than 100 EJ/yr, in some cases even up to about 250 EJ/yr, by 2050 are projected. However, ambitious GHG concentration targets lead, on average, to higher RE deployment compared to baseline with about 400 EJ/yr by 2050 as the upper limit of RE deployment (IPCC, 2011).

In the majority of reviewed scenarios, RE makes a higher contribution to low-carbon energy supply by 2050 than the competing low-carbon supply options (e.g. nuclear energy and fossil CCS). Besides the aspect that all RE obtain a more important role in the scenarios over time, a general trend is that bioenergy (predominantly modern bioenergy), wind energy and solar energy are commonly characterised by the largest contributions to the energy system among RE technologies by 2050 (IPCC, 2011).

4. TRADE-OFFS IN BIOENERGY

4.1 Use of Agricultural and Forest Land

Despite its positive prospects, the growing global bioenergy market may have sustainability risks (Johnson and Matiska, 2006; Faaij and Domac, 2006; Verdonk et al., 2007). One of the concerns is the increased use of agricultural and forest land for the production of bioenergy crops. Large-scale, mono-crop plantations of bioenergy crops at the expense of natural forests are causing deforestation and destroying natural habitats and landscape. The general concern is that such vast areas of land would be difficult to find without interfering with food production and important ecosystems such as natural forests (Tirado et al., 2010). A common response to this concern is that degraded lands and wastelands, rather than agricultural lands or natural forests, could be used for energy plantations. In reality, however, this is not the case. There is also no reason to believe that this will happen under the current market dynamics. For example, more than 720,000 ha of mono-crop jatropha plantation established by 2008, is expected to expand to over 21 million ha in 2014; some of this has been established by converting ecologically stable Miombo woodlands in Africa (Romijn, 2011). Although degraded lands are less expensive than agricultural and forestry lands, yields tend to be so low that degraded lands become uninteresting. Hence, investors tend to establish energy plantations on fertile forestry and agricultural lands where it is most profitable to do so (Azar and Larson, 2000).

4.2 Foreign Direct Investments in Land

Land is at the centre of social, political and economic life in most African economies, which are heavily dependent on agriculture and natural resources. Most lands in Sub-Saharan Africa have, however, no legal documentation of ownership and most of them remain customary lands. Although land registration and title of ownership are needed for better natural resource management and investment on land, the system of land registration has not worked very well in many African countries (Toulmin, 2008). In the absence of such important instruments, African governments are increasingly attracting foreign direct investment (FDI) in land for biofuel production with the presumption that it can contribute towards agricultural modernisation and poverty reduction. The lands allocated to the biofuel companies are mostly customary lands generally signed off for around 99 years, for a minimum one time rent and this is causing the eviction of local people from their ancestral lands. In most cases, these lands are a subject of contestation between local people and government, for example, in Tanzania (Habib-Mintz, 2010). On one hand, Li and Liu (2005) asserted that FDI can have positive impacts on the host country's productivity and economic growth. On the other hand, Habib-Mintz (2010) argued that without strong regulatory frameworks for land, FDI in land could exacerbate poverty and food insecurity.

4.3 Impact on Food Production and Prices

Due to the recent nature of increases of biofuel production in Africa, few empirical bases exist for assessing its impacts on food production and prices. However, there are concerns that biofuel feedstock production could displace the production of food crops (for food and feed) in Africa. The ways through which biofuels production can negatively affect food production and prices can be summarised under competition for land and water and competition for crops as feedstocks.

Where land tenure is insecure, bioenergy production can lead to the marginalisation of the farmers and rural poor by limiting their access to land and water which they need for their livelihoods, thereby contributing to food insecurity. As African governments are concerned about their national food security and in the wake of the recent global increases in food crop prices, many of them attempt to restrict the production of biofuel feedstocks in order to improve national food security (Donald, 2011). Globally, biofuel production had a modest (3-

30%) contribution to the increase in commodity food prices observed up to mid-2008 (Mueller et al., 2011). While large-scale bioenergy feedstock production competes with other land uses, in particular food production, it is important that an integrative food policy approach is adopted that also incorporates the transfer of food from food surplus areas of a country to its food deficit areas. Such a policy move and improving post-harvest storage can improve food security and reduce the tensions between food and biofuel production.

On the other hand, the growth and development of modern large-scale biomass energy plantations could lead to increased incomes for participating smallholder farmers (e.g. sugar; Karekezi and Kithyoma, 2006). The authors suggest that developing countries with large populations reliant on agriculture should prioritise the effective use of existing agricultural wastes for energy generation, as this approach has the least adverse impact on the poor (Karekezi and Kithyoma, 2006). However, many bioenergy feedstocks are also staple food crops in Africa (e.g. cassava). Thus, Rosegrant et al. (2006) report that if cassava were to be extensively used as a feedstock for bioethanol, cassava prices would increase tremendously, adversely affecting the welfare of its major consumers, most of whom are in Sub-Saharan Africa. The authors find a food-versus-fuel trade-off likely, where innovations and technology investments are largely absent and where trade and subsidy policies are not successful. Therefore, if bioenergy continues to grow and is based on food crops, it could adversely affect food security by reducing the amount of cassava available for consumption. The case of Rwanda illustrated in Box 5 further elaborates the implications of bioenergy development on food security.

Box 5: The potential for liquid biofuel production in Rwanda and implications for food security

GIZ (2011) assessed the biomass potential of biofuels such as vegetable oils, biodiesel and bioethanol in Rwanda and finds that despite Rwandan Government initiatives, current farming systems in Rwanda lack the potential to profitably produce feedstock such as castor, jatropha, moringa and sunflowers for biofuel production. Only growing cassava and sugarcane for bioethanol production and eucalyptus plantations for woodfuel production were found profitable.

An analysis of potential land available for the cultivation of energy crops in Rwanda shows that in the short- to medium-term, there are also no agricultural areas available for bioenergy crop cultivation and this is even more so when future food demand is considered (GIZ, 2011). The authors found that a sharp increase in productivity of 5% annually would be necessary to achieve, in 2020, in order to have a surplus of agricultural products that could theoretically be used for biofuel production.

Like in many African countries where food security remains a challenge, biofuel production in Rwanda is expected to compete strongly for land with food crop production, grazing and wood fuel production (GIZ, 2011). Hence GIZ (2011) finds that under the current agricultural production context in Rwanda that "*only small-scale biomass production can be considered, in fences and hedges, alongside roads or in intercropping systems*" Jatropha was found less profitable than many food crops hence there is no potential for increased incomes should farmers shift from food production to jatropha production, especially on marginal lands (GIZ, 2011). These have implications for all dimensions of food security namely:

Availability: Biofuel production that requires considerable area of land will likely compete with land available for agriculture in Rwanda (GIZ 2011).

Access to food: GIZ (2011) suggests large-scale investments in land whether for bioenergy production or other uses other than food crop production in Rwanda would increase the risk of dispossession of farmers' land use rights. As there are limited employment and income opportunities outside agriculture, farmers cannot be adequately compensated. GIZ (2011) thus argues that the potential to raise farmers' incomes from jatropha production is very low as jatropha is currently less profitable than many food crops in Rwanda.

Use of food: With small-scale biomass production in fences and hedges, alongside roads or in intercropping systems, negative impacts on food availability and access can be avoided - in such a case, the bioenergy derived can improve use of food by providing households energy for cooking.

Stability: Stability of access and availability and use of food can be affected by many risks such as unforeseeable changes in climate and its impacts, extreme weather conditions, or a shift in the growing areas of certain crops. Hence investments in land for bioenergy production should not foreclose the use of such lands for food crop production should the current food producing lands become no longer viable due to climate variability and change.

Economic viability: There is potential for the rural population to earn additional income from planting jatropha as fences or alongside roads. GIZ (2011) finds that biofuel production in Rwanda "based on domestic biomass resources is currently not economically viable in view of the current fossil fuel prices (the cost of biofuel is between US$1.86 – US$2.05 per litre fos. eq.)" and even the "production costs for electricity generation using jatropha vegetable oil exceed the current electricity price (US$0.55 /kWhel)" It may therefore be necessary to cover the price difference between biofuel production costs and fossil fuel price, to make the product price competitive with that of fossil fuels.

Effects on water and environment*:* Biofuel production requires large quantities of water, in particular sugar mills and ethanol plants. Efficient water use and wastewater treatment are essential to reduce the negative effects on water quality and availability. Monoculture can have adverse impacts on local biodiversity. This is more likely to happen with palm oil and sugarcane plantations, whereas the cultivation of jatropha in integrated systems would probably not have such impacts. Improvements in air quality could be expected through the use of biofuels.

Integrated farming systems could be one way to produce energy crops in Rwanda. The potential quantity of jatropha vegetable oil that could be cultivated in integrated farming systems is estimated at approximately 25,000 tonnes p.a. While the potential on marginal land cannot currently be empirically measured, assuming a 3% of marginal agricultural land yields about 6,000 tonnes of jatropha vegetable oil annually which is still low. Hence the current conditions in Rwanda do not allow for sustainable production of biofuels.

Sources: GIZ (2011)

As most African farmers are net food-deficit producers, diverting land and water away from food and feed production, agricultural expansion or shift to biofuel production will likely lead to trade-offs for such farmers (Hazell, 2006). As such, bioenergy development and its effects on poverty and food insecurity has to be carefully considered. Hazell (2006) suggests developing high energy yielding biomass crops that require lesser land and water thereby reducing the resource needs of bioenergy crops. This is yet to be achieved in Africa for example by supporting crop research to develop improved varieties of Jatropha.

Many crop by-products in Africa are used for other purposes such as for livestock feed, thatching houses or for soil protection. It might therefore be difficult to use by-products without trade-offs especially in the semi-arid areas. For African countries where net-deficit food production is a problem, a food-first approach should be followed. Such an approach focuses on agricultural production to first meet food and feed needs and can complement bioenergy production that uses agricultural wastes.

Developing and growing biomass in less-favoured areas may not be an option for many African countries that have a food production deficit as even in such countries prime agricultural land is already given to cash crop production (e.g. tea and coffee in Kenya) and the remaining marginal semi-arid lands used for food production are also marginal for certain biofuels feedstock (e.g. Jatropha). Environmental risks and benefits of using improved bioenergy feedstock (fast growing varieties) for second generation technologies that convert cellulose-rich biomass to bioenergy have to be carefully considered.

Investing in increasing the productivity of the food crops thereby freeing up additional land and water for the production of bioenergy crops (Donald, 2011) seems a viable strategy but will require increased investment in agriculture, which is still to make its mark in many African countries. Recent evidence shows that investments in agriculture in certain African countries need to be higher than the CAADP's recommended 10% to be able to take hold and lead to agricultural growth (Brüntrup, 2011).

4.4 Environmental Implications

Bioenergy has environmental benefits and risks depending on factors such as feedstock type, processing and interactions with the local community. Bioenergy might be a cost-effective substitute for oil but might lead to little reduction in GHG emissions due to the fossil energy used for its production and distribution.

Ethanol produced from sugarcane has favourable energy and carbon balances while biodiesel produced from oilseeds and ethanol produced from maize and sugar beets have less favourable energy and carbon balances (Hazell, 2006). Second-generation technologies based on cellulose-rich biomass are expected to be more energy efficient, but great scope remains for developing additional technologies that lead to larger carbon savings (Hazell, 2006).

Environmental risks posed by bioenergy feedstocks' production include nutrient mining and land degradation, mining of water resources (especially for those feedstocks that use much water), monoculture, harvesting methods that expose land to greater erosion, pollution from pesticides and fertilizers, and biodiversity loss (Hazell, 2006). While the EU Directive on the Promotion of the Use of Energy from Renewable Sources (Directive 2008/16, "Renewable Energy Directive") introduced sustainability criteria whereby feedstocks used to produce biofuels to meet the EU-mandated targets cannot come from land with high biodiversity value status as of January 1, 2008 (Donald, 2011), ensuring such standards in African countries is a challenge. However, bioenergy crops can also contribute to better environmental management if grown under the right conditions (Hazell, 2006). For example, Barrick Gold Mining Corporation and Export Trading Company Limited set up an 11 hectare jatropha plantation for biodiesel production on exhausted land damaged by their mining activities in Tanzania (Barrik, 2008 in Martin et al., 2009).

4.5 Gender Considerations

Like all development interventions, bioenergy development is gender sensitive and this should be reflected in such initiatives. Gender considerations are important for integrating the perspectives of women and men into bioenergy initiatives and ensuring that both equally benefit from the projects.

Gender roles and responsibilities shape energy consumption patterns and division of labour in households. Women in Africa constitute up to 80% of agricultural labour, and traditionally, it is the role of women and girls to fetch wood and water. Hence women should be adequately consulted in such issues. The UNDP and WHO (2009) estimate that indoor air pollution from the combustion of biomass and coal for cooking cause more than 2 million deaths yearly with over 400,000 deaths in Africa. Through their domestic roles, women are most affected in addition to children. Shifting from burning biomass to improved stoves or using biogas can significantly reduce the health impacts from burning these fuels. Improved energy efficiency also reduces the work burden of women and girls – Women used the saved time for other activities and girls have more time for their school work.

Gender barriers such as women's limited access to credit should be considered, for example in projects promoting improved cookstoves that require upfront investments. As women constitute the larger proportion of Africa's agricultural labour force, research on bioenergy crops and their agronomy should adequately incorporate women's perspectives and knowledge. However, gender indicators are not integrated into many bioenergy projects or explicitly focussed on. An exception is the GEF small grants programme whereby gender is explicitly focussed on. Gender analysis, sex-differentiated data, gender monitoring and gender auditing needs to be part of all bioenergy projects to ensure that men and women equally benefit from the projects.

4.6 Risk of Invasive Plant Species and Biodiversity

According to Gasparatos et al. (2011), habitat destruction for establishment of large-scale bioenergy crop plantations has become a threat to biodiversity. Faaij and Domac (2006), however, argued that perennial energy crops, which are the preferred bioenergy crops, have better biodiversity benefits than annual energy crops. They cited the experiences in Sweden and the UK, as examples, where the integration of willow production on the landscape level had positive biodiversity effects.

The selection criteria of taxa of all plant families as sources of feedstock for bioenergy are primarily based on their productivity and processing efficiency. Although these traits are desirable, assessment of the potential risk of these species of becoming invasive has been ignored (Gordon et al., 2011). Apart from habitat destruction, invasive species cause more biodiversity loss than any other factor (IUCN, 2009). Invasive species also cause substantial economic and ecological impacts in new habitats (IUCN, 2009). For example, it is estimated that invasive plants are costing the USA over US$34 billion annually in terms of damage and control efforts (Gordon et al., 2011). Gordon et al. (2011) reported that a system of evaluating the invasiveness of a species is, at present, in place and the threat could be prevented to some extent. For example, the Australian Weed Risk Assessment (WRA) system modified for the local environment is currently being used and the system has been successfully tested worldwide. Currently, however, there is lack of information on the application of this system in Africa.

4.7 Socio-economic Impacts

Bioenergy can contribute to development in several ways, the major one being economic growth through employment. It has also been claimed to have macroeconomic advantages: security of supply and an improved balance of trade (Faaij and Domac, 2006). In this respect, bioenergy can contribute to human well-being. However, several authors argued that the negative socio-economic impacts of bioenergy outweigh the economic benefits (Gasparatos et al., 2011; Yang et al., 2009; Faaij and Domac, 2006). According to Faaij and Domac (2006), child labour is involved in the production of biofuel in many developing countries and the remuneration received by local producers is insufficient. As already mentioned, most of the feedstocks for bioenergy are food crops. The recent increase in global food prices was believed to be partly caused by biofuel expansion, which reduced the availability of food supply at the international market and responsible, for example, about 40% of increase in the global price of maize, hence negatively affecting food security of millions of people (Tirado et al., 2010). Faaij and Domac (2007), however, argued that food security is not a problem but lack of purchasing power of the poor. According to them, production and access to food would not be affected by large energy plantations if proper management and policies are put in place. Ewing and Msangi (2009) also asserted that bioenergy development can generate income and provide welfare gains that can improve purchasing power of the poor and decrease their vulnerability to food and energy price shocks. Yet, bioenergy not only competes directly with food production but also indirectly with agricultural labour (Gasparatos et al., 2011). Arndt et al. (2011) found a negative impact of biofuel on food production in Mozambique when female labour is used intensively in biofuel production as women are drawn away from food production.

5. INTEGRATION OF BIOENERGY INTO PRESENT AND FUTURE ENERGY SYSTEMS

5.1 Policy, Financing and Implementation Requirements

5.1.1 Background

Due to the increased awareness of bioenergy technologies, and an appreciation of its importance in establishing a sustainable energy supply for the future, and the role it plays in climate change mitigation, there has been a significant body of legislation and policy published at the international level over in the recent past (Fehily, 2007). The recent volatility and high level of international oil and gas prices, however, are making biomass increasingly competitive as energy feedstock. At the same time, the indirect benefits of bioenergy, if properly internalised, can offset eventual price differences with fossil fuels (FAO, 2006). As discussed in the preceding sections, Africa has a vast potential of bioenergy resource which has remained under-utilised due to several factors, which include inability to effectively implement policies, lack of suitable policies, regulatory and institutional arrangements. In some instances there is lack of information and awareness on the benefits accruing from bioenergy resources. Other barriers that hinder deployment of bioenergy as part of current energy systems are social/cultural, technical, lack of planning frameworks and institutional coordination for RE policy, lack of coordination between national and local authorities regarding planning of RE deployment.

Full sustainable utilisation of bioenergy has also been hampered by financial factors such as non-recognition of external costs and risks associated with conventional energy systems. In addition, financial institutions in most countries in Africa have short-term lending portfolio that does not cover the amortisation period for RE technologies. Further, local financial institutions generally lack expertise in RE technologies leading to perceived high risks and reluctance to provide project finance. Other financial barriers include, weak institutional workable economic regulatory systems, inadequate institutional capacity to support RE technologies, and lack of information and awareness among financiers on RE investments portfolio.

5.1.2 Institutional and Regulatory Framework Considerations

Successful integration of bioenergy into modern present and future energy systems require due attention to establishing policy, institutional and regulatory framework. Adequate legislation need to be formulated that will enable competitive, sustainable bioenergy production. In determining the statutory requirements to govern the bioenergy industry, detailed consideration with regard to environmental, socio-economic, and technical aspects should be taken at every stage of bioenergy industry development which includes pre-development, facility operation, by-product management/utilisation, and decommissioning. Efforts should be made to harmonise existing disparate policies related to bioenergy, which includes agricultural, environmental, energy policy, forestry, water, etc so as to provide balanced conditions for sustainable production. Furthermore, the legislation should adequately address issues related to regulation of bioenergy production and consumption.

The bioenergy laws, specific regulations and norms should be revised accordingly to meet the current needs such as basic requirements that private investors must meet in order to qualify for economic and technical incentives from the government. The policy and legal framework should be such that it opens up substantial investment opportunities for bioenergy by providing solid, innovative and clear guidelines to all key stakeholders.

5.1.3 Policy and Implementation Considerations

A number of countries have wide ranging objectives for bioenergy development and the main drivers for bioenergy policies for most African countries include; (i) energy security, specifically reducing dependence on imported energy sources, (ii) economic growth, particularly improving rural economies and improving welfare of rural communities, (iii) taking advantage of available economic and international legal instruments, such as CDM (iv) support to agriculture and the agro-industry.

For Africa to sustainably develop its bioenergy potential and increase deployment of bioenergy technologies in the heat, electricity and transport sectors, a fully coordinated approach at national, regional and local level is required. This can only be achieved through formulation of sound integrated policies, and effective institutional, legal and regulatory frameworks in the respective countries that covers all aspects related to the industry such as biomass production, conversion technologies, environmental issues, biodiversity and socio-economic issues. The following are some of the policy and legislative aspects that may be considered to promote the integration of modern bioenergy technologies into present and future energy systems in Africa.

(i) Bioenergy targets

As part of accelerating the deployment of bioenergy into current energy systems in African countries, consideration could be given to target setting in the national development plans as regards meeting the energy needs in the transport, industry and electricity sectors. The target-setting may take the form of directives providing for mandatory use of bioenergy e.g. biofuels (Mabee et al., 2009).

(ii) Fiscal incentives and investment subsidies

This provides a means of supporting the deployment of bioenergy into current and future systems, through introduction of preferential policies, provision of subsidy support and monetary payments, exemption of consumption tax, value added tax, direct subsidies and low interest loans, and provision of investment support payments and other forms of funding. Tax exemptions can be provided for bioenergy, which can go a long way in barrier removal for bioenergy deployment as they act as a rebate for producers. Such kind of incentives could be provided to bioenergy companies and farmers producing bioenergy feedstocks (Mabee et al., 2009).

(iii) Market development

There is need to nurture and develop growing markets of bioenergy applications through initiatives such as creation of special funds for financing demonstration projects for new energy technologies

(iv) Environmental considerations

In developing the bioenergy industry, due consideration needs to be given to environmental management through instituting measures to ensure sustainable exploitation and development of bioenergy resources. Amongst other environmental tools and mechanisms to address environmental concerns are environmental impact assessments as is done in Kenya and the application of Life Cycle Assessments in the development of any bioenergy project.

(v) Research and Development

African governments need to consider active promotion and support through funding of research and development in bioenergy projects from both private and public initiatives.

5.2 Potential Funding Sources and Resource Mobilisation

Modern bioenergy has been developing rapidly in recent years and presents great opportunities for sustainable development and climate change mitigation. However, developing countries encounter difficulties in financing their bioenergy projects and programmes. Developing countries worldwide can access and apply for financial resources after fulfilling detailed project criteria from multilateral funds and partnerships, national initiatives, and foundations (GBEP, 2010).

These financing sources, instruments and mechanisms can be divided into three categories: *internal*, *external* and *innovative*. Internal sources are those mobilised within the country itself, and include both public (through the national budget) and private ones (through investments). Internal instruments and mechanisms include taxes, subsidies and other fiscal instruments. External sources include development aid and foreign direct investment (FDI). The term ‘innovative’ is used to describe financing sources, instruments and mechanisms that have not traditionally been deployed when mobilising financing. What is considered innovative will depend on the country-specific context.

5.2.1 National Initiatives

The funding sources under national initiatives (internal sources of funding) and instruments include: (i) national budgets and other public financial rearrangements; (ii) fiscal and policy instruments; (iii) municipal budgets and other arrangements; (iv) national funds (e.g. the national energy fund); and (v) private sector sources of funding. There is an increasing need to rely on internal sources, as external funds are not easily forthcoming and may be unpredictable. A good understanding of how the governments pursue bioenergy is therefore important for maximising the financial flows allocated to bioenergy. A country’s capacity to raise financial resources internally and the potential for improving the mobilisation of these resources are thus crucial for the successful integration of bioenergy into current and future energy systems.

5.2.2 Multilateral Funds/Partnerships

External sources of funding flows for bioenergy may include; bilateral donors, multilateral donors, private sources such as Foreign Direct Investment (FDI), expatriate funds, international NGOs and international philanthropic organisations. International and regional development banks are also another source of funding, in particular, the World Bank have been one of the main sources of funding for bioenergy and environmental initiatives. These identified funds have various funding mechanisms which include: co-financing, grant funding, technical assistance, end-user payment, equity, loan, ODA and lease financing. Table 5.1 provides a list of some external sources of funding for bioenergy projects.

5.2.3 Innovative Funding Sources

Mobilising funding for bioenergy using innovative sources involves non-traditional financial instruments and mechanisms of raising financing. Innovative instruments are additional and supplementary to traditional sources and instruments. Because innovative sources are additional to the traditional sources, they constitute a viable and reliable new supply of financial resource base, and in the process increase the amount of resources available while ensuring better predictability of financial flows into bioenergy programmes. In recent years, innovative financing instruments and mechanisms are increasingly being seen as a reliable and stable source of funding that is less likely to be susceptible or interrupted by changes in political dynamics or donor modalities.

The financing instruments under innovative financing include; (i) product charges - these could aim at discouraging use of a product and/or build into its price the indirect environmental costs associated with its use; (ii) user charges - these could aim at covering the cost of services associated with the treatment/disposal of the pollution resulting from product use or the management of a natural asset; (iii) taxes for natural resource management - these could aim at collecting economic rents from the extraction of non-renewable resources; and (iv) liability payments aimed at compensating for damages caused by a polluting activity. The mechanisms include: i) debt-for-nature swaps; ii) compensation for ecosystem service schemes; and iii) compensation for conservation scheme.

Table 1 Selected external sources of funding for bioenergy projects

	Potential sources of financing	Nature of donor contributions	Bioenergy activities supported	Financial instrument/delivery mechanism used	Geographical range
1	African Development Bank (AfDB) Agency Lines of Credit (I-ALC)	Multi-lateral (public)	Small-scale energy-sector operations	An arrangement between AfDB & client (project sponsor, national or regional government)	African Development Bank Regional Member Countries (RMCs)
2	AfDB Clean Energy Access & Climate Adaptation Facility for Africa (CECAFA)	Multi-lateral contributions & resources from World Bank Climate Investment Funds (CIF)	Renewable energy & energy efficiency, & Clean Development Mechanism (CDM) projects	As intermediary for channelling financing & technical resources from World Bank, Clean Technology Fund (WB CTF) & World Bank Strategic Climate Fund (WB SCF)	African Development Bank RMCs
3	AfDB Clean Energy Investment Framework (CEIF)	Multi-lateral resources	Access-to-all energy activities; Climate adaptation projects; Clean energy development activities; Use of biofuels (ethanol or biodiesel) in urban transport sector	Resources delivered as AfDB non-concessional Window for 15 middle-income country members; Funds delivered as non-guarantee financing for private projects in 53 regional member countries	AfDB Middle-income & "blend" Regional Member Countries (for public-financed projects); All AfDB (RMCs) (for well private-sponsored projects)
4	AfDB Infrastructure Lines of Credit (I-LOC)	Multi-lateral (public)	Small-scale energy operations, in particular decentralised rural & energy programs located in big city peripheries; Small-scale renewable energy development	An arrangement between AfDB & client (project sponsor, national or regional government)	African Development Bank RMCs
5	EBID: African Bio-Fuels and Renewable Energy Fund (ABREF)	Contributions from governments & voluntary contributions from private sector	Liquid biofuels and biomass energy projects which have an ability to generate CERs through the CDM of the Kyoto Protocol	Equity; Debt medium & long term; Mezzanine Finance; Leasing	All African countries. Though, in the first phase (2008) the emphasis was on ECOWAS countries

	Potential sources of financing	Nature of donor contributions	Bioenergy activities supported	Financial instrument/delivery mechanism used	Geographical range
6	Ecowas Bank for Investment & Development (ECOWAS – EBID)	ECOWAS regional member countries & non-regional members (States and legal entities)	Activities linked to bioenergy activities e.g. basic transport, energy & equipment; Rural development & the environment (agriculture, ecosystem protection, capacity building); Industry (agro business, technology transfer, technological innovation)	Grant loans; Guarantees for financing investment projects & programs; Technical assistance	West African countries (ECOWAS members)
7	EUEI -Intelligent Energy COOPENER	Financed by COOPENER (EUEI) and tenders	Biomass energy Biofuel production and use	Facilities and loans	Developing countries, in particular in sub-Saharan Africa, Latin America and Asia
8	EUEI - Partnership Dialogue Facility (PDF)	EU Member States and the European Commission.	Biomass energy Liquid biofuels	EUEI provides with facilities in the range of EUR 50,000 – EUR 200,000 for each single activity	Global. Developing countries, with special focus on Africa (Sub-Saharan African countries preferable)
9	European Investment Bank (EIB)	European Investment Bank	Switching fossil fuels, waste management, renewable energy (i.e. biomass) & biogas	Lends at close to the cost of borrowing; Lends on favourable terms to projects furthering EU policy objectives	Global
10	European Programme: Thematic Programme for Environment & Sustainable Management of Natural Resources Including Energy (ENRTP)	Multilateral (EU funds)	Sustainable production & consumption; Developing institutional support & technical assistance	Grants	Developing countries that are Parties to the Kyoto Protocol
11	GEF Trust Fund - Climate Change focal area	Global Environment Facility (GEF)	Renewable Energies; Energy Efficiency; Sustainable Transportation	GEF is the financial mechanism for both UN Convention on Biological Diversity & UNFCCC	Developing country parties to the UNFCCC (all Non-Annex I Parties)

	Potential sources of financing	Nature of donor contributions	Bioenergy activities supported	Financial instrument/delivery mechanism used	Geographical range
12	IFAD - ICRISAT Biopower strategy	IFAD funds	Cultivation of sweet sorghum stalks & cassava roots to produce ethanol cultivation of seeds of jatropha in producing biodiesel	Fund grants	Asia, Africa and South America
13	Kyoto Protocol Adaptation Fund (AF)	Share of proceeds from Clean Development Mechanism (CDM)	-	Grants	Developing countries that are Parties to the Kyoto Protocol
14	Renewable Energy & Energy Efficiency Partnership (REEEP)	Donors from Developed counties	Renewables & energy efficiency	Grants or co-funding	Global, with a preference in African countries and the Pacific region

6. CONCLUSIONS

There is vast opportunity for modern bioenergy in Africa due to the high productivity of biomass, which include wood and agricultural waste, as well as agricultural crops such as sugar cane, maize, sorghum, and cassava. Some African countries are already implementing modern bioenergy projects as part of a sustainable development strategy because of its diverse benefits which include reduced GHG emissions, creation of rural livelihoods, foreign exchange savings and reduced dependence on imported sources of energy. The reduced GHG emissions can earn credits under CDM for African countries. Additional benefits include opportunities for new export markets in the emerging global trade in biomass as bioenergy products have become attractive because they satisfy, to a certain extent, national needs for high investment and hard currency earnings.

African counties can also take advantage of existing bodies of regional economic integration to enable different countries in each region to mutually benefit from modern bioenergy markets by pooling their resources and jointly utilising their comparative advantages in global markets. These bodies of regional economic integration include the East African Community (EAC), Southern African Development Community (SADC), the Economic Community for Central African States (CEMAC) and Economic Community of West African States (ECOWAS).

Owing to the substantial upfront investments required for bioenergy development, African governments need to implement policy actions to incentivise the private sector to invest in the value chain ranging from producers to consumers of bioenergy (farmers, processors, traders and consumers). These policy actions include fuel tax exemption, government support to research, and production in government-owned facilities.

There are, however, some trade-offs that need to be considered in the development of bioenergy in Africa, particularly with respect to the use of agricultural and forest land, and the impact on food production and prices. Large-scale bioenergy feedstock production may compete with other land uses, in particular food production, but it is important that African governments adopt an integrative food policy approach that also incorporates the transfer of food from food surplus areas of a country to its food deficit areas. Such a policy move and improving post-harvest storage can improve food security and reduce the tensions between food and biofuel production. To ensure that bioenergy development does not constrain access to land, many African countries need to reform their land laws and to build in checks and balances to ensure that local communities and indigenous peoples are not dispossessed of their land by large-scale plantations for bioenergy crops.

To promote the integration of modern bioenergy technologies into present and future energy systems in African countries, a fully coordinated approach at regional, national and local level is required. This can be achieved through formulation of sound integrated policies, and effective institutional, legal and regulatory frameworks in the respective countries that covers all aspects related to the industry such as biomass production, conversion technologies, environmental issues, biodiversity and socio-economic issues. These policy and legislative aspects include: i) bioenergy targets; ii) excise duty exemptions; iii) fiscal incentives and investment subsidies; iv) market development; v) environmental considerations; and vi) research and development.

Although some external funding sources exist for financing bioenergy development in Africa, African countries should also mobilise internal sources of funding and instruments for bioenergy development. These internal sources of funding and instruments include: (i) national budgets and other public financial rearrangements; (ii) fiscal and policy instruments; (iii) municipal budgets and other arrangements; (iv) national funds (e.g. the national energy fund); and (v) private sector sources of funding.

REFERENCES

Achten, W. M. J., Verchot, L., Franken, Y. J., Mathijs, E., Singh, V. P., Aerts, R., and Muys, B. 2008. Jatropha Bio-diesel Production and Use. Biomass and Bioenergy, 32: 1063–1084.

Amigun, B., Musango, J. K., and Stafford, W. 2011. Biofuels and Sustainability in Africa. Renewable and Sustainable Energy Reviews, 15: 1360–1372.

Arndt, C., Benfica, R., and Thurlow, J. 2011. Gender Implications of Biofuels Expansion in Africa: The Case of Mozambique. World Development 39:1649-1662.

Arthur, R., Baidoo, M. F., Brew-Hammond, A., and Bensah, E. C. 2011. Biogas Generation from Sewage in Four Public Universities in Ghana: A Solution to Potential Health Risk. Biomass and Bioenergy, 35: 3086-3093.

Atmosfair gGmbH (undated). Production d'energie renouvelable à partir de la gazeification de biomasse. Project Idea Note. Available at: https://www.atmosfair.de/en/our-projects/

Atmosfair gGmbH and LHL e.V. 2008. Efficient Fuel Wood Stoves for Nigeria. Available at: https://www.atmosfair.de/index.php?id=336

Atmosfair GmbH. 2010. Nairobi River Basin Biogas Project. Available at: https://www.atmosfair.de/fileadmin/user_upload/Projekte/Kenia_Biogas/Project_Idea_Note_Kenya.pdf

Azar, C., and Larson, E D. 2000. Bioenergy and Land-Use Competition in Northeast Brazil. Energy for Sustainable Development, 4: 64-71.

Barrick. 2008. Barrick Gold Tanzania. Barrick Biodiesel Project Report.

Batidzirai B., Faaij A. P. C., and Smeets E. 2006. Biomass and Bioenergy Supply from Mozambique. Energy for Sustainable Development? Volume X No. 1. March 2006. 54-81.

Bekunda, M., Palm, C. A., de Fraiture, C., Leadley, P., Luc Maene, Martinelli, L. A., McNeely, J., Otto, M., Ravindranath, N. H., Victoria, R. L., Watson, H., and Woods, J. 2009. Biofuels in Developing Countries. Pages 249-269 in Howarth, R. W., and Bringezu, S. (eds) Biofuels: Environmental Consequences and Interactions with Changing Land Use. Proceedings of the Scientific Committee on Problems of the Environment (SCOPE) International Biofuels Project Rapid Assessment, 22-25 September 2008, Gummersbach Germany. Cornell University, Ithaca NY, USA. Available at: http://www.worldbiofuelsmarkets.com/reports/Biofuels_SCOPE_Diofuels_for%20_DevelopingCountries.pdf

Brüntrup, M. 2011. African Developments: The Comprehensive Africa Agriculture Development Programme (CAADP) is an Opportunity for African Agriculture. In Briefing Paper, 4. German Development Institute. Available at: http://www.die-gdi.de/CMS-Homepage/openwebcms3.nsf/(ynDK_contentByKey)/MSIN-8EZLUE/$FILE/BP%2004.2011.pdf

Couth, R., Trois, C., Parkin, J., Strachan, L.J., Gilder, A., and Wright, M. 2011. Delivery and Viability of Landfill Gas CDM Projects in Africa - A South African Experience. Renewable and Sustainable Energy Reviews, 15: 392–403.

Cotula, L., Dyer, N., and Vermeulen, S. 2008. Fuelling Exclusion? The Biofuels Boom and Poor People's Access to Land. London: International Institute for Environment and Development and Food and Agriculture Organisation of the United Nations. Available at: http://pubs.iied.org/pdfs/12551IIED.pdf

Denton, F. 2004. Reducing the Gap Between Projects and Policies: A Comparative Analysis of the 'Butanisation' Programme in Senegal and the Multifunctional Platform (MFP) Experience in Mali. Energy for Sustainable Development l Volume VIII No. 2 l June 2004, 17-29.

Donald, M. 2011. Biofuels in Africa: Opportunities, Prospects, and Challenges. The World Bank. Available at: http://africaknowledgelab.worldbank.org/akl/sites/africaknowledgelab.worldbank.org/files/report/Biofuels_Full_report.pdf

Duku, M. H., Gu, S., and Hagan, E. B. 2011. A Comprehensive Review of Biomass Resources and Biofuels Potential in Ghana. Renewable and Sustainable Energy Reviews, 15: 404–415.

Ewing, M., and Msangi, S. 2009. Biofuels Production in Developing Countries: Assessing Tradeoffs in Welfare and Food Security. Environmental Science and Policy, 12: 520-528.

Faaij, A. P.C., and Domac, J. 2006. Emerging International Bio-energy Markets and Opportunities for Socio-economic Development. Energy for Sustainable Development, 10: 7-19.

FAO. 2004. Unified Bioenergy Terminology. Available at: http://www.fao.org/DOCREP/007/j4504E/j4504E00.HTM

FAO. 2006: Introducing the International Bioenergy Platform (IBEP), Food and Agriculture Organisation of the United Nations, Rome, 2006. Available at: http://www.fao.org/sd/dim_en2/en2_060501_en.htm

FAO. 2007: A Review of the Current State of Bioenergy Development in G8 +5 Countries, FAO, Rome. Available at: http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/BIOENERGY_INFO/0805_GBEP_Report.pdf

FAO, UNEP, UN-Energy. 2011. Bioenergy Decision Support Tool, FAO, Rome.

FAO. 2011. First Draft. Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests. Available at: http://www.fao.org/fileadmin/user_upload/nr/land_tenure/pdf/First_Draft_VG_English_Final.pdf

Fehily, T. R. 2007. South-East Region, Bioenergy Implementation Plan. Available at: http://www.sera.ie/media/Regional%20BioEnergy%20Plan.pdf

Gasparatos, A., Stromberg, P., and Takeuchi, K. 2011. Biofuels, Ecosystem Services and Human Wellbeing: Putting Biofuels in the Ecosystem Services Narrative. Agriculture, Ecosystems and Environment (In press).

GBEP. 2010. Financing Options for Bioenergy Projects and Programmes, By Global Bioenergy Partnership. Available at: http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/BIOENERGY_INFO/1004_GBEP_-_Financing_options_for_bioenergy_projects_23april_web.pdf

GEF Small Grants Programme. 2006a. Interventions for the Sustainable Management of Biodiversity in Fombe, Wad 1, Nyanga District (ZIM/SGP/OP3/Y2/CORE/2006/06). http://sgp.undp.org/web/projects/10428/interventions_for_the_sustainable_management_of_biodiversity_in_fombe_wad_1_nyanga_district.html

GEF Small Grants Programme. 2006b. Production of Jatropha Seeds for Income Generation and Promotion of Rural Bio-enterprises, Monduli (TAN/04/02). http://sgp.undp.org/web/projects/9000/production_of_jatropha_seeds_for_income_generation_and_promotion_of_rural_bio_enterprises_monduli.html

GEF Small Grants Programme. 2006c. Biofuel Production in Sustainable Land Management in Selected Communities in the Coastal and Northern Savannah Zone of Ghana. (GHA/SGP/OP4/Y1/CORE/2008/006). Available at: http://sgp.undp.org/web/projects/12459/biofuel_production_in_sustainable_land_management_in_selected_communities_in_the_coastal_and_norther.html

GEF Small Grants Programme. 2006d. Integrated Ecosystem Management: Jatropha, the Efficient Management Tool (CMR/SGP/OP4/Y3/CORE/09/07). Available at: http://sgp.undp.org/web/projects/15150/integrated_ecosystem_management_jatropha_the_efficient_management_tool.html

GEF Small Grants Programme. 2006e. Promoting Sustainable Jatropha Farming in Kwale District (KEN-GEF-06-007). Available at: http://sgp.undp.org/web/projects/12489/promoting_sustainable_jatropha_farming_in_kwale_district.html

GIZ. 2011. The Potential of Sustainable Liquid Biofuel Production in Rwanda. A study on the Agricultural, Technical and Economic Conditions and Food Security. Available at: http://www2.gtz.de/dokumente/bib-2011/giz2011-0017en-biofuels-rwanda.pdf

Goldemberg, J. 2008. The Brazilian Biofuel Industry. Biotechnology for Biofuels 1 (1): 6.

Gomez-Barea, A., and Leckner, B. 2010. Modeling of Biomass Gasification in Fluidised Bed. Progress in Energy and Combustion Science, 36: 444–509.

Gordon, D.R., Tancig, K.J., Onderdonk, D.A., and Gantz, C.A. 2011. Assessing the Invasive Potential of Biofuel Species Proposed for Florida and the United States Using the Australian Weed Risk Assessment. Biomass and Bioenergy, 35: 74-79.

GTZ. 2009. Jatropha Reality Check. A Field Assessment of the Agronomic and Economic Viability of Jatropha and other Oilseed Crops in Kenya. Available at: http://www.worldagroforestry.org/downloads/publications/PDFs/B16599.PDF

Habib-Mintz, N. 2010. Biofuel Investment in Tanzania: Omissions in Implementation. Energy Policy, 38: 3985–3997.

Hao, X., Yang, H., and Zhang, G. 2008. Trigeneration: A New Way for Landfill Gas Utilisation and its Feasibility in Hong Kong. Energy Policy, 36: 3662– 3673.

Hazell, P. 2006. Developing Bioenergy: A Win-win Approach that Can Serve the Poor and the Environment. Focus 14 Brief 12 of 12. In: Hazell P. and Pachauri R. K. Eds. Bioenergy and Agriculture: Promises and Challenges. Available at: http://nachbar.wustl.edu/~anthro/bnc/articles/IFPRI_biofuels.pdf

Hoogwijk, M. 2004. On the Global and Regional Potential of Renewable Energy Sources, Ph.D. Thesis, Utrecht University, Utrecht, the Netherlands.

Hunsberger, C. 2010. The Politics of Jatropha-based Biofuels in Kenya: Convergence and Divergence Among NGOs, Donors, Government Officials and Farmers. Journal of Peasant Studies, Vol. 37, No. 4, 2010, 939-962.

IISD. 2011. Summary of the Irena High-Level Africa Consultative Forum on Renewable Energy: 8-9 JULY 2011. IISD Reporting Services Vol. 30 No. 5. Available at: http://www.iisd.ca/irena/acfre/

IEA. 2009. Bioenergy – A Sustainable and Reliable Energy Source: A Review of Status and Prospects, IEA, Paris. Available at: http://www.massey.ac.nz/~ychisti/IEABio09.pdf

IEA. 2010. World Energy Outlook 2010. Available at: http://www.iea.org/Textbase/npsum/weo2010sum.pdf

IEA. 2011a. Statistics and Balances. Available at: http://www.iea.org/stats/index.asp

IEA. 2011b. Energy for All: Financing Energy Access for the Poor. Special Early Report on the World Energy Outlook 2011. Available at: http://www.iea.org/papers/2011/weo2011_energy_for_all.pdf

IPCC. 2011. Special Report on Renewable Energy Sources, Chapter 10 Mitigation Potential and Costs.

IUCN. 2009. Biofuels and Invasive Species: Exploring the Links between Biofuel Production Systems and Invasive Species. Available at: http://cmsdata.iucn.org

Johnson, F. X., and Matsika, E. 2006. Bioenergy Trade and Regional Development: The Case of Bio-ethanol in Southern Africa. Energy for Sustainable Development, 10: 42-53.

Junginger, M., Faaij, A., Rosillo-Calle, F., and Wood, J. 2006. The Growing Role of Biofuels - Opportunities, Challenges and Pitfalls. International Sugar Journal 108: 618 -628. Available at: http://igitur-archive.library.uu.nl/chem/2007-0621-201957/NWS-E-2006-232.pdf

Karekezi, S. and Kithyoma, W. 2006. Bioenergy and the Poor. Bioenergy and Agriculture: Promises and Challenges. Focus 14 Brief 11 of 12. In: Hazell P. and Pachauri R. K. Eds. Bioenergy and Agriculture: Promises and Challenges. Available at: http://nachbar.wustl.edu/~anthro/bnc/articles/IFPRI_biofuels.pdf

Li, X., Liu, X. 2005. Foreign Direct Investment and Economic Growth: An Increasingly Endogenous Relationship. World Development, 33: 393-407.

Lloyd, P. J. D., and Visagie, E. M. 2007. A Comparison of Gel Fuels with Alternative Cooking Fuels. Journal of Energy in Southern Africa, Vol 18 No 3 August 2007. Available at: http://www.erc.uct.ac.za/jesa/volume18/18-4jesa-lloyd.pdf

Ma, J., Duong, T. H., Smits, M., Verstraete, W., and Carballa, M. 2011. Enhanced Biomethanation of Kitchen Waste by Different Pre-treatments. Bioresource Technology, 102: 592–599.

Mabee, W., Bacovsky, D., Barclay, J. D., Dornelles, R., Edye, L., Foust, T., Grabowski, P., Kujanpaa, L., de Lang, D., Larsen, P., Mkinen, T., McMillan, J., Mnack, A., Murphy, J., Oyaas, K., Pelkmans, L., Poeet, J. C., Prior, B. A., Sey, R., Saka, S., Samehima, M., Sandquist, J., Sidwell, t., Werling, K., Wrobel, A., and Van Zyl, W. H. 2009. Update on Implementation Agendas 2009. Edited by Mafee, W. E., Neeft, J., and van Keulen, B. IEA Task 39 Report T39-P5, 75pp.+ . Available at: http://www.ufop.de/downloads/Task39.pdf

Mamphweli, N. S., and Meyer, E. L. 2009. Implementation of the Biomass Gasification Project for Community Empowerment at Melani Village, Eastern Cape, South Africa. Renewable Energy, 34: 2923–2927.

Martin, M., Mwakaje, A. G., and Eklund, M. 2009. Biofuel Development Initiatives in Tanzania: Development Activities, Scales of Production and Conditions for Implementation and Utilisation. Journal of Cleaner Production 17 (2009) S69–S76.

Mbuligwe, S. E., and Kassenga, G. R. 2004. Feasibility and Strategies for Anaerobic Digestion of Solid Waste for Energy Production in Dar es Salaam City, Tanzania. Resources, Conservation and Recycling, 42: 183–203.

Mueller, S. A., Anderson, J. E., and Wallington, T. J. 2011. Impact of Biofuel Production and Other Supply and Demand Factors on Food Price Increases in 2008. Biomass and Bioenergy 35 (2011) 1623-1632

Onovwiona, H. I., and Ugursal, V.I. 2006. Residential Cogeneration Systems: Review of the Current Technology. Renewable and Sustainable Energy Reviews, 10: 389–431.

Palanichamy, C., Sundar Babu, N., and Nadarajan, C. 2004. Renewable Energy Investment Opportunities in Mauritius—An Investor's Perspective. Renewable Energy, 29: 703–716.

Purohita, P., and Michaelowa, A. 2007. CDM Potential of Bagasse Cogeneration in India. Energy Policy, 35: 4779–4798.

Rao, A. G., Prakash, S. S., Joseph, J., Reddy, A. R., and Sarma, P.N. 2011. Multi Stage High Rate Biomethanation of Poultry Litter with Self Mixed Anaerobic Digester. Bioresource Technology, 102: 729–735.

REN21. 2011. Renewables 2011 Global Status Report. Renewable Energy Policy Network for the 21st Century.

Romijn, H. A. 2011. Land Clearing and Green Hhouse Gas Emissions from Jatropha Biofuels on African Miombo Woodlands. Energy Policy 39: 5751-5762

Rosegrant, M. W., Msangi, S., Sulser, T., and Valmonte-Santos, R. 2006. Biofuels and the Global Food Balance. Bioenergy and Agriculture: Promises and Challenges. In: Hazell P. and Pachauri R. K. Eds. Bioenergy and Agriculture: Promises and Challenges. Focus 14 Brief 3 of 12 December 2006. Available at: http://nachbar.wustl.edu/~anthro/bnc/articles/IFPRI_biofuels.pdf

Salomon, K. R., and Lora, E. E. S. 2009. Estimate of the Electric Energy Generating Potential for Different Sources of Biogas in Brazil. Biomass and Bioenergy, 33: 1101-1107.

Schulz, T. F., Barreto, L., Kypreos, S., and Stucki, S. 2007. Assessing Wood-based Synthetic Natural Gas Technologies Using the SWISS-MARKAL Model. Energy 32: 1948–1959.

Shin, H. C., Park, J. W., Kim, H. S., and Shin, E. S. 2005. Environmental and Economic Assessment of Landfill Gas Electricity Generation in Korea using LEAP Model. Energy Policy, 33: 1261–1270.

Siemons, R. V. 2001. Identifying a Role for Biomass Gasification in Rural Electrification in Developing Countries: The Economic Perspective. Biomass and Bioenergy, 20: 271–285.

Smeets, E., Faaij, A. P. C., and Lewandowski, I. 2004. A Quickscan of Global Bioenergy Potentials to 2050. Bottom-Up Scenario Analysis of Regional Biomass Production and Export Potentials, Fair Biotrade Project, Utrecht University.

SNV (undated). SNV Tanzania. Tanzania Domestic Biogas Programme. Available at: http://www.snvworld.org/en/Documents/SNV%20-%20Domestic%20Biogas%20Brochure%20Tanzania.pdf.

Tirado, M. C., Cohen, M. J., Aberman, N., Meerman, J., and Thompson, B. 2010. Addressing The Challenges of Climate Change and Biofuel Production for Food and Nutrition Security. Food Research International, 43: 1729–1744.

Toulmin, C. 2008. Securing Land and Property Rights in Sub-Saharan Africa: The Role of Local Institutions. Land Use Policy, 26: 10–19.

UNDP and WHO. 2009. The Energy Access Situation in Developing Countries: A Review Focusing on the Least Developed Countries and Sub-Saharan Africa. http://content.undp.org/go/cms-service/stream/asset/?asset_id=2205620

UNEP. 2009. Financial Aspects of Landfill CDM projects in Africa: Two Case Studies. Available at: http://www.energimyndigheten.se/Global/Internationellt/CDM%20och%20JI/Financial%20Aspects%20of%20CDM%20Landfill%20Projects.Todd%20Ngara.pdf

UNEP. 2011. Cogeneration for Africa Project: Project Brief. Available at: http://cogen.unep.org/

UNFCCC. 2010. AMS-II.G. Energy Efficiency Measures in Thermal Applications of Non-Renewable Biomass. Clean Development Mechanism Methodology Booklet November 2010 (up to EB 56). Available at: http://cdm.unfccc.int/filestorage/C/D/M/CDM_AMSUT12SPEL6M69U60GBKV3OOYZERRHLK/AMS_II.G_ver01.pdf?t=clN8bHVoenhpfDCODNeOi9bNvjGqtwDtksTq

Verdonk, M., Dieperink, C., and Faaij, A. P. C. 2007. Governance of the Emerging Bioenergy Markets. Energy Policy, 35: 3909–3924.

WHO. 2009. Global Health Risks. Mortality and Burden of Disease Attributable to Selected Major Risks. Available at: http://www.who.int/healthinfo/global_burden_disease/GlobalHealthRisks_report_full.pdf

Wicke, B., Smeets, E., Watson, H., and Faaij, A. 2011. The Current Bioenergy Production Potential of Semi-arid and Arid Regions in Sub-Saharan Africa. Biomass and bioenergy, 35: 2773-2786.

Yang, H., Zhou, Y., and Liu, J. 2009. Land and Water Requirements of Biofuel and Implications for Food Supply and the Environment in China. Energy Policy, 37: 1876–1885.

Zamalloa, C., Vulsteke, E., Albrecht, J., and Verstraete, Willy. 2011. The Techno-economic Potential of Renewable Energy Through the Anaerobic Digestion of Microalgae. Bioresource Technology, 102: 1149–1158.