Chapter 20
Environmental Impacts of Biofuel Production in Africa

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Abstract Although total bioethanol production in Africa in 2006 was less than 500 million litres, the potential is considered high. South Africa and East Africa alone are estimated to have an annual potential of 7.3 and 1.3 billion litres, respectively. In addition, there is intense interest in biodiesel with large-scale projects being developed across the continent. The land considered for biofuels is significant, estimated at 5.5 million hectares, some of which will be located in fragile ecosystems and in ecologically sensitive environments. In Mali, Ghana, Sudan, Ethiopia and Madagascar, up to 2.5 million hectares of land has already been allocated to foreign investors for biofuel production. The motivating policy goals for biofuels production and the high degree of biodiversity and diverse climatic conditions notwithstanding, increased production, different agricultural practices especially on highly degraded land due to long-term agricultural mismanagement portend key environmental issues associated with land requirements and farming systems, conversion technologies and scale of operation. Impacts include destruction of habitats and biodiversity, deforestation, and declining water quantity and quality. Whilst these impacts may not be apparent in Africa, they present important researchable questions for planning as Africa gears for increased participation in the international biofuels markets. Tools to define and assess areas suitable for sustainable biofuels production exist, and should be used by governments to include biofuels into an overall energy, climate, land-use, water and agricultural strategy. This shall benefit society, the economy and the environment as a whole.

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20.1 Introduction

Biofuel development policies have been driven by concerns over energy security, the need for convenient alternatives to fossil fuel, and a desire to reduce greenhouse gas emissions. From an African perspective, additional themes include the need to (1) provide opportunities to diversify agricultural production, enhance employment in rural areas, raise rural incomes and improve quality of life, (2) diversify fuel supply sources and develop long-term replacements for fossil oil whilst reducing expenditure on imported fossil energy, and (3) boost technological developments in countries with favourable conditions for biofuels production. Unfortunately, biofuels production and use can be a major source of serious environmental impacts which can threaten the overall social and economic development objectives (Lazarus et al. 1995). Thus, incorporation of environmental considerations is an important new area for energy planners.

A key challenge in pursuing this objective is to incorporate strategies to limit negative impacts of biofuels production. In assessing the impacts, the objectives should be to inform biofuels development and utilization policies whilst promoting sustainability standards and criteria for the production of environmentally benign biofuels. In the context of Africa, key questions that need to be addressed in assessing the environmental impacts of biofuels include:

- What are the positive environmental impacts of biofuels production and processing?
- Will biofuels help reduce greenhouse gas emissions and mitigate climate change?
- Do biofuels threaten habitat integrity, biodiversity, soils and water flows and cycles?
- How will enhanced biofuels production impact on agricultural land and other land use alternatives?
- Can environmentally sustainable biofuels production be achieved in Africa?

An additional theme would consider how to ensure that the production and use of biofuels is sustainable.

20.2 Biofuels in Africa: A Historical Perspective and Trends

In Africa, interest in ethanol from biomass to reduce oil imports dates back to the 1970s. In Kenya, efforts to blend ethanol with gasoline declined in the mid 1990s due to conflicting interests amongst petroleum distributors and a lack of concerted policy initiatives. Renewed interest has seen current ethanol production capacity increase to about 125,000 l/day. Zimbabwe began to produce bioethanol to supply a 5% mix in road fuel in the early 1980s whilst Malawi's experience dates back to 1986 with a current installed bioethanol capacity of 32 million litres with plans to double the capacity. Other countries with active liquid biofuels development programmes include South Africa and Ghana where the respective governments have pledged to fund biofuels projects (GRAIN 2007), Nigeria, Tanzania, Burkina Faso, Cameroon, Lesotho and Madagascar.

Although the total bioethanol production in Africa was less than 500 million litres in 2006, the potential is considered to be high. For instance, the potential in South Africa and East Africa alone is estimated at 7.3 and 1.3 billion litres, respectively. In addition, there are intense interests in biodiesel with large-scale projects being developed across Africa. The land considered for biofuels, estimated at 5.5 million hectares, is significant with more than 119,000 ha in 97 large-scale projects in East Africa by early 2008. In Mali, Ghana, Sudan, Ethiopia and Madagascar, up to 2.5 million hectares of land has been allocated to foreign investors for biofuels development.

20.3 Environmental Impacts of Biofuels Production in Africa

Environmental impacts of biofuel production depend to a large extent on the selection of areas that are used for production, the scale of operation, the crops cultivated and the farming practice. From a life cycle assessment perspective, biofuels production can have both positive and negative environmental impacts depending on the type of feedstock and the fuel production pathways and technologies (Rösch and Skarka 2009). The pathway contains five major stages: (1) feedstock production, (2) feedstock transportation, (3) fuel processing, (4) fuel blending and distribution, and (5) fuel use. Although impacts are generated at all stages of the cycle, the most significant consequences occur in the first, third, and fifth stages. Further, the nature and extent of impacts varies according to climatic and production conditions (Berndes 2002), scale of production, cultivation, and land-management practices.

20.3.1 Energy Balances of Biofuels

The contribution of biofuels to energy supply depends both on the energy content of the biofuel and on the energy used for its production which defines the fossil net energy balance (NEB). A fossil NEB of 1 means that the energy needed to produce 1 l of biofuels equals its energy content (no net energy gain or loss), whilst a balance of 2 means that 1 l of biofuel contains twice the amount of energy than required for its production. It was shown that the NEB of biodiesel produced from different feedstocks can vary from 0.46 to 6.35 (Licht 2007). Petrol and diesel have NEB values of 0.8–0.9, implying net energy losses of 19.5% and 15.7%, respectively, because energy is consumed in refining crude oil into usable fuel and transporting it to markets. If biofuels have NEB values exceeding 0.8–0.9, they contribute to reducing dependence on fossil fuels. The favourable NEB for some biofuels illustrates the potential to displace a significant proportion of fossil fuels in Africa. However, in developing biofuels, effort should be taken to optimize energy balances by learning from past experiences and best case scenarios. The selection of crops for large-scale biofuels projects in Africa should be guided by favourable energy balances and crops with low NEB should be discouraged.

20.3.2 Greenhouse Gas Balances of Biofuels

Greenhouse gas (GHG) balances are the result of a comparison of biofuels with fossil fuels with respect to all GHG emissions throughout the entire life cycle. An analysis of greenhouse gas emission impacts of commercial biodiesel production using imported soybean oil from Brazil in South Africa showed that upstream total emissions from the biomass feedstock production, transport and manufacture were less than 16% of fossil baseline emissions. Whilst upstream emissions were significant, they did not outweigh the substantial emissions reductions, even when the oil feedstock is transported for long distances by ship. Fargione et al. (2008) and Righelato and Spracklen (2007) estimated the carbon emissions avoided by various ethanol and biodiesel feedstocks grown on existing cropland (i.e. sugarcane, maize, wheat and sugarbeet for ethanol, and rapeseed and woody biomass for diesel) and found that more carbon would be sequestered over a 30-year period by converting the cropland to forest. Thus, extensive deployment of biofuels will have a positive effect on climate change associated with greenhouse gas emissions in the energy sector.

20.3.3 Biodiversity and Habitat Integrity

High-profiled biofuels development projects in Africa include for example (1) the plan to turn a third of Uganda's Mabira forest (7,100 ha) to sugarcane for the production of electricity and ethanol, (2) the plan to cut down thousands of hectares of rainforest on two islands of Lake Victoria (Kalangala and Bugala) for conversion into a palm oil plantation, (3) Tanzania's model of large-scale, monoculture production of biofuels in regions that can attract investment including Ruipa, Usangu plains and Wami Basin, and (4) Benin's humid areas of Oueme, Plateau, Atlantic, Mono, Couffo and Zou which have been earmarked for palm oil expansion.

Although these developments will intensify deforestation and enhance biodiversity loss, the data and analysis needed to assess the extent and consequences are still lacking. The lack of data notwithstanding, these examples illustrate that the frontiers for increased biofuels production are the remaining wetlands, sacred and communal forests, and fallow lands with rich biodiverse ecosystems comprised of woodlands and forests. Mabira forest for instance, one of the key water catchment sources for the Nile River and Lake Victoria, is estimated to store 3,905,000 ton of carbon dioxide.

Conversion to sugarcane plantation threatens 312, 287 and 199 species of trees, birds and butterflies, respectively, some of which are endemic to the forest.

Although some biofuel crops (e.g. jatropha and castor) have grown in Africa under cultivation and in the wild for decades, the introduction of large plantations of such crops raises serious questions about potential impacts on native ecosystems, especially since certain crops are considered invasive in some parts of the world. Invasion of native vegetation by biofuel crops is a major concern for some feedstock types. Several of the short-cycle woody plants that hold promise for second generation biofuels could also be invasive (Kartha 2006). Such crops must be studied with respect to their potential invasiveness.

Some biofuel plantations will be based on single species characterized by low levels of genetic diversity (such as sugarcane) which increases the susceptibility of these crops to new pests and diseases. Further, a preference for genetically modified crops will create risks mainly associated with the increased use of herbicides, affecting soil micro-organisms and birds. The replacement of local crops with large-scale mono-cropping for biofuels might (1) lead to the simplification of agro-ecosystems, and (2) increase the susceptibility of agro-ecosystems to diseases and pests, making such systems more dependent on pesticides. These processes make farming systems less stable, less robust, and unsustainable, and reduce the resilience of the systems to both bio-physical and socio-economic shocks including pathogen infestation and uncertain rainfall (Lambrou and Laub 2006).

Positive effects on biodiversity have been noted in marginal areas where new perennial mixed species have been introduced to restore ecosystem functioning. Experimental data from degraded and abandoned soils (Tilman et al. 2006) show that low-input high-diversity mixtures of native grassland perennials offer a range of ecosystem services, including wildlife habitat, water infiltration and carbon sequestration (IFAD/FAO/UNF 2008).

20.3.4 Land-Use Change, Land Conservation and Soil Erosion

In discussing the impacts of land-use change, land conservation and intensification resulting from biofuels production, it should be recalled that most of the land in Africa is highly degraded, e.g. due to agricultural mismanagement. Thus, it might be difficult to single out potential impacts of biofuels production, especially at large-scale. Care should be taken not to associate all existing environmental impacts to biofuels.

Planting of perennial biofuel crops such as jatropha on marginal lands has the potential to prevent soil erosion and regenerate agricultural potential, providing shade and nutrients for other crops (Becker and Francis 2003). Similarly, some crops such as rapeseed are commonly used as rotational crops to provide soil cover in between other harvests whilst other crops like jatropha and croton can help to reforest degraded areas replenishing soils and local hydrology over time. Similarly, intercropping, rotations, use of nitrogen-fixing plants, windbreaks, wildlife corridors, conservation tillage and use of organic fertilizers can all improve environmental impacts.

Although large-scale estimates have been made for future expansion of biofuels production without damage to existing agricultural systems or natural ecosystems based on the use of "unused", "fallow", "marginal" and "waste" lands in some countries such as Kenya (GOK/GTZ 2008), it is important to note that advancing the agricultural frontier into natural habitats is an international environmental concern (Biofuelwatch 2007). Biofuels may also displace other economic and land use activities, leading to displacement effects which are often not well understood or ignored (Turner et al. 2007).

20.3.5 Water Resources

Hoogeveen et al. (2009) assessed the impact of increasing demand for biofuels on global water resources in the coming decade and estimated that around 1% of all water withdrawn for irrigation was used for the production of bioethanol, mainly for irrigated sugarcane and maize. It was shown that in 2017, the amount of water to be withdrawn for biofuel production would increase by 74% if agricultural practices remain the same.

Whilst the potential for expansion of irrigated areas may appear high in Africa, the actual scope for increased biofuels production under irrigated conditions on existing or new irrigated lands in the near to medium term is limited by infrastructural requirements to guarantee water deliveries and by land-tenure systems that may not conform with commercialized production systems. Furthermore, many irrigated sugar-producing regions in southern and eastern Africa including Awash, Limpopo, Maputo and Nile river basins are already operating near the hydrological limits of their associated river basins. Thus, current low levels of irrigation water withdrawals in Africa will increase only slowly. In regions with scarce water resources the start-up or extension of biofuels production will lead to problems concerning drinking water abstraction (Berndes 2002; De Fraiture et al. 2008). Only the "blue" water[1] of aquifers, lakes and rivers used for the irrigation of biofuel plants is relevant for the water balance (Rösch and Skarka 2009). Besides, water quality can be affected by using fertilizers and pesticides to grow biofuel plants if these substances end up in surface or ground water.

20.4 Towards Environment Friendly Biofuels in Africa

Harmonized approaches to life-cycle analysis, greenhouse gas balances and criteria for sustainable production should be developed in order to ensure consistency. To achieve these goals, three strategies could be adopted: (1) research, (2) application of

[1] Blue-water is made of 38.8% of total precipitation and is equivalent to the natural water resources collected in rivers, lakes, wetlands and groundwater. This water is available for withdrawal (1.5% for direct human use) before it evaporates (1.3%) or reaches the ocean (36%).

tools to define and assess the suitability of areas and technologies, and (3) development and enforcement of policies and rules including criteria and indicators for sustainable biofuels production and sustainability standards.

20.4.1 Research

To date, there is insufficient localized data on land potential, growing conditions and crop suitability. In addition, policies to guide biofuels development are largely non-existent. As a result, most planning and decision making tends to be haphazard. African governments should consider a variety of measures including additional research in (1) development of harmonized product standards, (2) measures to limit the expansion of arable land into high-value natural ecosystems, (3) environmental suitability and agro-environmental zoning for biofuels production as recently undertaken in Kenya (Muok et al. 2010) to delineate sensitive ecosystems such as natural forests and national parks, which though suitable, would be unavailable for biofuels expansion, and (4) environmental performance of advanced generation biofuels such as those derived from wastes and sources such as switch grass and marine algae. To overcome negative side effects there is need to define sustainable agricultural practices in relation to biofuels.

20.4.2 Tools for Environmental Sustainability of Biofuels

A number of tools to assess and define areas and technologies suitable for sustainable bioenergy production exist. These tools include (1) the High Conservation Value (HCV) Areas concept originally developed by the Forest Stewardship Council (FSC) for use in forest management certification but now being expanded to all habitats, (2) the Key Biodiversity Areas (KBAs) methodology for identifying and mapping biologically critical sites at the scale of practical management units to inform protected area targets and identify gaps. KBAs include Alliance for Zero Extinction sites (AZEs) which safeguards key sites where species are in imminent danger of disappearing, and Important Bird Areas (IBAs) where key sites for bird conservation, small enough to be conserved in their entirety and often already part of a protected-area network, (3) Integrated Biodiversity Assessment Tool (IBAT) which facilitates siting and management decisions, (4) the ARtificial Intelligence for Ecosystem Services (ARIES) for rapid ecosystem service assessment and valuation at multiple scales, (5) Agro-Ecological Zoning (AEZ), (6) Environmental Impact Assessment (EIA), as well as appropriate policies, standards, and certification. Although regulatory approaches to standards and certification may not be the best option, they guarantee the sustainability of the production process and maximize the positive environmental and development benefits. For selected crops that can be used for energy purposes like soy, palm oil, and sugarcane, there are commodity roundtables and scorecards such as the Roundtable on Sustainable Biofuels (RSB, focusing on creating a meta-standard), Roundtable on Sustainable Palm Oil

(RSPO) and the Round Table on Responsible Soy (RTRS), the Better Sugarcane Initiative (BSI), the Council on Sustainable Biomass Production (CSBP, focusing on second-generation feedstock) (van Dam et al. 2008); and multilateral scorecards including IADB Biofuels Sustainability Scorecard for pre-project screening and the World Bank Biofuels Scorecard for both project screening and management.

In applying these tools in Africa, it should be clear that no single concept or tool provides all answers and that they define intrinsic/ecological boundaries based on specific procedures and standards to safeguard environmental integrity. Further, the tools have specific pros and cons which have to be evaluated on a case by case basis.

20.4.3 Integrated Energy-Environment Analysis

Lazarus et al. (1995) described three basic principles that underlie integrated energy-environment analysis. Firstly, the analysis considers all fuels and technologies, whether on the supply or demand side, on equal footing. Secondly, the ultimate goal is the provision of end-use services and amenities, rather than simply fuels or electricity, at the least social cost. Finally, the broader analysis seeks to incorporate the economic externalities (most notably environmental and equity impacts) absent from a traditional cost-benefit analysis based on market prices alone.

20.5 Conclusion

Environmental problems fall into specific domains, but a wide range of tools for environmental sustainability exist to guide development and deployment of biofuels in Africa. Since most land in Africa is highly degraded due to agricultural mismanagement, it becomes difficult to single out the potential impacts of biofuels production (especially at large-scale) and care should thus be taken not to associate all environmental degradation to biofuels.

There are areas of research that are vital for sustainable development of the biofuels sector in Africa. From a policy perspective, it will be important to (1) balance growth of feedstock supply against other existing and potential uses of land and (2) deploy an assessment of sustainability that encompasses the complete cycle from growth of the raw material to end use.

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