Water Implications of Biofuel Development in Semi-Arid Sub-Saharan Africa: Case Studies of Four Countries

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Chapter 22
Water Implications of Biofuel Development in Semi-Arid Sub-Saharan Africa: Case Studies of Four Countries

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Abstract Biofuel production may have considerable impacts on water resources. To analyze the implications of biofuel development on water resources in the semi-arid parts of Botswana, Zambia, Tanzania and Mali, case studies were elaborated. In all four countries plans are under way to develop comprehensive biofuel policies. Botswana and Mali have similarities since they are water scarce countries with high dependency on imported food and energy. Whilst large areas of Mali and Botswana are semi-arid, the semi-arid parts in Zambia and Tanzania are of smaller size and have relatively suitable conditions for biofuel production. In Zambia and Tanzania, there are sugarcane and jatropha-based biofuel projects, whereas in Botswana and Mali biofuel production is mainly based on jatropha. It is shown that the expansion of biofuel projects in all four countries may adversely affect water resources. It is therefore recommended that water scarce countries such as Botswana and Mali should engage in biofuel projects which do not require much irrigation. The production model of integrating biofuel production with food crop production as practised in Mali provides useful lessons for Botswana and other countries. Whilst in Zambia and Tanzania large-scale projects based on contract farming could be expanded to reach the full potential of these countries, it is crucial to carefully monitor their impacts on water resources.

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22.1 Introduction

In Sub-Saharan Africa, as in the rest of the developing world, biofuel development has started to attract growing attention because of concerns about energy security, climate change and rural development (Dufey 2006; Royal Society 2008). Biofuels are therefore likely to play a key role in the energy future of Sub-Saharan Africa. Globally, it is estimated that the amount of land under biofuels is about 11–12 million ha which is 1% of the total area under crop production (de Fraiture et al. 2008; Hoogeveen et al. 2009). In Brazil and USA, which are the leading producers of biofuels, the area under biofuel production is estimated at 2.5 million ha and 4 million ha (5% and 4% of the area under cropland), respectively (de Fraiture et al. 2008). The expansion of biofuel production will lead to an increase in the demand for land and water resources which are already constrained by the need for agricultural production. Water use efficiency varies according to the type of energy crop, climate, growing period, and agronomic practice, as well as the processing of biomass into biofuels and biomaterials (Demirbas 2009; Berndes 2008). It is also determined by whether or not the crop is cultivated under rain-fed or irrigated conditions.

Many countries of Sub-Saharan Africa have suitable conditions and very large areas of land which could be used for biofuel production. However, the production of biofuels on the scales necessary to meet national and global demand for these fuels could result in adverse impacts on water resources and contribute to the conflict between water for food and water for fuel. The large and fast growing economies of India and China are likely to experience serious water scarcities as they try to meet their demand for feed, food and biofuels (Berndes 2008; de Fraiture et al. 2008). According to de Fraiture et al. (2008), irrigation withdrawals for biofuel production globally amount to 44 km^3 or 2% of the total water withdrawals of 2,630 km^3. The successful implementation of biofuel policies on a global scale is likely to result in an additional use of cropland of 30 million ha and irrigation water withdrawals of 180 km^3 (de Fraiture et al. 2008). In fragile semi-arid regions of Sub-Saharan Africa already experiencing water scarcity, additional water use for biofuel production will add more pressure to water scarcity, and the problem may be worsened in the future by changes in water availability resulting from climate change (Bekunda et al. 2009; de Fraiture et al. 2007). In addition, international trade in biofuels will increase virtual water flows, and this may contribute to the deterioration of global water resources.

This chapter examines how water use is likely to be affected by the expansion of biofuel production aimed at meeting national goals in the semi-arid parts of the selected countries of Sub-Saharan Africa. The specific research objectives of this chapter are to: (1) examine the structure of water management systems in these countries, (2) assess the potential for irrigation of biofuels in key river basins, (3) identify the types of energy crops suitable for growing in these regions in terms of water availability, (4) assess if irrigation is required for producing biofuels, and (5) contribute to considerations for future biofuel policies. This chapter does not assess the implications of biofuel development on water quality. It is also crucial to note that no attempt has been made to discuss the details regarding the patterns of water use at a micro-level, as this would require field visits to study areas, a task beyond the scope of this study.

22.2 Sustainability of Biofuels and Water Resources

Today, there are growing concerns that the development of biofuels is associated with risks that result in adverse effects on sustainability (Naylor et al. 2007). The euphoric view that biofuels are mainly associated with positive aspects of sustainability has been proved to be incorrect by numerous scientific studies (Von Maltitz and Brent 2008). The major issues of concern about the sustainability of biofuel development revolve around the following themes: (1) greenhouse gas emissions, (2) biodiversity, (3) water resources, (4) land-use change, (5) impacts of increased nutrients and pesticides, (6) competition with food, and (7) human welfare and well-being (Smeets 2008; Yang et al. 2009; Royal Society 2008). More relevant to this chapter is the concern that the expansion of biofuels production may lead to the diversion of water resources from other development demands in Sub-Saharan Africa. Concerns related to biofuels sustainability have led to the development of certification schemes for biofuels, whereby the buyers of these fuels will ensure that their production complies with certain standards or sustainability criteria in order to avoid adverse environmental, economic and social impacts (Smeets 2008).

A number of techniques are used to measure the environmental sustainability of projects and policy programmes such as life cycle analysis, ecological footprint analysis, cost-benefit analysis, environmental assessment, and risk assessment (Paehlke 1999). The most important tools for measuring resource sustainability are life cycle analysis and ecological footprint analysis (Paehlke 1999). The concept of water footprint has been used in a number of studies to assess the impacts of biofuel production on water resources (Yang et al. 2009; Elena and Esther 2010). Hoekstra (2003) defines this concept as the “total volume of fresh water that is used to produce the goods and services consumed by the nation”. It should not be confused with the concept of virtual water which refers to the volume of water used to produce a product “at the pace of production” (Elena and Esther 2010). Whilst the latter concept (virtual water) is defined from the perspective of production, the former is defined from the perspective of consumption (Elena and Esther 2010).

22.3 Study Area and Methods

22.3.1 Study Areas

The study sites for this particular research are the semi-arid (Mean Annual Rainfall – MAR < 600 mm) regions of Botswana, Zambia, Tanzania and Mali. This section provides an overview of the socio-economic and environmental background as well as the status of biofuel policies in these countries. These are four of the eight African countries which participated in the European Union co-funded project COMPETE (Competence Platform on Energy Crop and Agro-forestry Systems for Arid and Semi-arid Ecosystems in Africa).

Botswana is a semi-arid, landlocked country in the centre of southern Africa with a total area of 581,730 km^2. It receives a total mean rainfall of about 416 mm ranging from 250 mm in the south–west to a maximum of 650 mm per year in the extreme north (FAO 2008a). Rainfall distribution is extremely variable with lengthy dry spells, but with common dry years (Pallett 1997). Botswana is an upper middle income country with Gross National Income per capita of 5,900 US$ (2006) (World Bank 2008). Economic growth in Botswana has brought only a moderate success in human development. The 2007/2008 Human Development Report reveals that Botswana was ranked 124 out of 177 countries, with a human development index of 0.645 (where 0 is the minimum and 1 is the maximum value), as compared to the GDP index of 0.804 (UNDP 2007/2008). Thus, the GDP ranking is higher than the ranking of human development, suggesting that there has been moderate success in transforming economic growth into socio-economic development in Botswana. This country has relatively abundant land resources but limited water resources. It is currently in the process of finalizing a policy on biofuels after undertaking a detailed feasibility study on the production and use of these fuels (EECG 2007; Mabowe 2009).

Zambia has a population of 12 million (2006) and it covers an area of 752,610 km^2 (FAO 2007). The mean annual rainfall in Zambia varies from 600 mm in the south to 1,500 mm in the north. The areas with the highest rainfall are located in the north–west and north–east, whereas the driest areas are in the south–west and around the Luangwa and Zambezi river valleys and most of these parts are classified as semi–arid. According to the World Bank (2008), Zambia is a low income country with a gross national per capita income of 630 US$ (2006). Zambia is categorized as a low human development country with a rank of 165 out of 177 countries and a human development index of 0.434 (UNDP 2007/2008). This country has favourable land and water endowments for biofuel production (Janssen et al. 2009).

Like other African countries, Zambia is currently formulating a long-term Energy Strategy (2009–2030) which includes the development of a framework for sustainable production of biofuels.

The **United Republic of Tanzania** consists of mainland Tanzania and the island of Zanzibar. Its mean annual rainfall is 1,071 mm which varies from 500 to 3,000 mm, though most parts of the country have rainfall which varies from only 500 to 1,000 mm.

The highest rainfall of 1,000–3,000 mm occurs in the north–eastern part of the country in the Lake Tanganyika Basin, and in the Southern Highlands (FAO 2008b). It is a low income country with a Gross National income per capita of 350 US$ (2006). In the 2007/2008 Human Development Report the Republic of Tanzania was categorized as a low human development country with a rank of 159 out of 177 countries and a human development index of 0.467 (UNDP 2007/2008). The country has an area of 945,090 km^2, and its population in 2006 was 39 million (World Bank 2008). There are various biofuel initiatives in Tanzania for both local and international investors. However, the country does not as yet have a comprehensive biofuel policy for guiding these initiatives. According to Martin et al. (2009), the biofuel policy for this country is still under preparation and it is being facilitated by the National Biofuels Task Force.

Mali is a low income country with a Gross National income per capita of 440 US$ (2006) (World Bank 2008). Over 65% of the land area in Mali is desert or semi-desert (UEMOA 2009). The climatic groups of Mali vary from the arid desert in the northern part, arid to semi-arid in the centre, and savannah in the south. The Sahara region in the north-west tip of Mali covers 57% of the country and has an arid and semi-arid desert climate. The mean annual rainfall in Mali is 440 mm, and it ranges from 200 mm in the north to 1,200 mm in the south (Ouattara 2008). The amount of rainfall also varies across the three climatic zones of the Saharo-Sahelian with an annual rainfall of 100–200 mm, the Sahelo-Sudanian (200–400 mm), the Sudano-Guinean (400–800 mm) (Green 2009). In the 2007/2008 Human Development Report Mali is categorized as a low human development country with a rank of 173 out of 177 countries and a human development index of 0.380 (UNDP 2007/2008). Mali has a total surface land area of 1,241,000 km^2 and a population of 14 million (2006) of which 33.4% live in urban areas whilst 66.6% live in rural areas.

22.3.2 Methods

This study is a synthesis of information obtained from literature sources. The key sources of information included FAO reports on irrigation potential in Africa, water profiles in the African countries, consultancy reports on production and use of biofuels in Africa, and journal articles on biofuels and water in Africa. Through membership in the EU co-funded project COMPETE, literature on bioenergy relating to the study areas was obtained. A set of maps, produced on the study areas to serve as a template for areas available for biofuel production (COMPETE 2007), was used to guide the research and discussion on water implications of biofuel development in these areas. There is a general lack of recent data on the irrigation potential of the study areas. The only source of data on irrigation potential in most of the river basins in the study areas is the report published by FAO (1997), and more recent sources of data have not been identified.

22.4 Water and Biofuels in Botswana

According to FAO (2008a), Botswana acquires its water resources within the four major river basins, namely the Okavango in the north–western part of the country, the Limpopo in the extreme east, the Zambezi which forms the Chobe tributary in the far north of the country and the Orange River which originates from the Lesotho highlands with some tributaries in the southern part of Botswana. Botswana shares these major water resources with other SADC countries: Angola, Namibia, Zimbabwe, Zambia and South Africa. Apart from the perennial rivers and wetlands in the north and the over-utilized Limpopo and its tributaries in the east, Botswana suffers from a lack of surface water and therefore it is partly dependent on groundwater resources. Groundwater resources have an overall recharge rate of 1.7 km^3/year and they are found in small quantities almost everywhere in the country, being the main source of water for many rural households, livestock, and small-scale irrigation. However, there are some aquifers in current use which are not receiving any recharge. In many rural areas and remote towns, there is total dependence on groundwater resources (FAO 2008a). The major drainage systems of the Okavango, Chobe and Limpopo have irrigation potential, and abstraction of water for irrigation is limited to these rivers in Botswana (Masamba 2009).

22.4.1 Limpopo Basin

The Limpopo River and its tributaries are important sources of water in the eastern part of the country. The basin is estimated to account for 14% of the total area in the eastern part of the country (FAO 1997). The quantity of water produced by the Limpopo River within Botswana is estimated at 0.6 km^3/year, whilst the irrigation potential in the basin is estimated at 5×10^{-4} km^3 (FAO 1997), or less than 0.1%. The major towns of Botswana are located in the south–eastern part of the country, including the capital Gaborone situated on the Notwane River basin, one of the tributaries of the Limpopo River. This region has high water demand for residential and industrial use. The use of water for large-scale biofuel production in this area will therefore add pressure to the already existing water management challenges. However, this will depend on the kind of energy crops grown.

22.4.2 The Okavango Basin

The Okavango River, originating from the Angolan highlands, flows for over 500 km before it reaches the border between Angola and Namibia, and a further 113 km before reaching the Okavango Delta in Botswana. The Okavango Delta, a Ramsar Site of international importance, is an important attraction for tourism, the second most important economic activity after diamonds (Kgathi et al. 2007). The average

Table 22.1 Zambezi basin: irrigation potential, water requirements and areas under irrigation

Country	Irrigation potential ha	Gross potential irrigation water requirement m³/ha/year	Gross potential irrigation water requirement Total (km³/year)	Area under irrigation ha
Angola	700,000	13,500	9.450	2,000
Namibia	11,000	5,000–25,000	0.255	6,142
Botswana	1,080	5,500	0.006	0
Zimbabwe	165,400	10,500	1.737	49,327
Zambia	422,000	12,000	5.064	41,400
Tanzania	0	11,000	0.000	0
Malawi	160,900	13,000	2.092	28,000
Mozambique	1,700,000	11,000	18.700	20,000
Total	3,160,380		37.303	146,869

Source: FAO (1997)

rainfall in the Botswana part of the Okavango Basin is 495 mm, ranging from 415 to 570 mm (FAO 1997). Mean annual discharge of the Okavango River at Mohembo is 9 km³. According to FAO (1997), the maximum irrigation potential for the Okavango basin in Botswana is 9,060 ha of which 3,000 ha would require construction of infrastructure and storage. This suggests that the actual irrigation potential is 6,060 ha (FAO 1997). Currently, irrigation in the Botswana portion of the Okavango Basin is limited to 125 ha of vegetables in Shakawe in the upper part of the Okavango Delta called the Panhandle, and also around Maun in the form of small and medium-scale horticultural enterprises. Much of the land in the Okavango Delta is either protected or in the form of Wildlife Management Areas. The promotion of commercial irrigated agriculture for biofuels and other crops conflicts with national and district conservation objectives of land use zoning in the Okavango Delta (van der Heiden 1991) as it is associated with the use of agro-chemicals, which may have an adverse effect on the environmental sustainability of the ecosystem and the tourism industry.

22.4.3 The Zambezi Basin

The Chobe River, one of the tributaries of the Zambezi River, forms the border between Namibia and Botswana. Originating in western Zambia and Angola, this river crosses the Caprivi Strip, where it has an annual discharge of 1.3 km³. It flows back into the Zambezi River with an annual discharge of 4.1 km³ at a point where the four countries of Botswana, Zambia, Namibia and Zimbabwe meet. The irrigation potential for the Botswana part of the Zambezi basin is 80 ha without major water development works and 11,080 ha if major water development works are undertaken (FAO 1997). However, 10,000 ha of this total area is located in the Pandamatenga Plains outside the Zambezi basin in the north–eastern part of Botswana, suggesting that total irrigation potential in the Botswana part of the Zambezi basin is 1,080 ha (Table 22.1). There is a plan to transfer 495 million m³ of water per year (0.495 km^3/year) from the Chobe/Zambezi River for agricultural development in Pandamatenga area (Water Resources Consultants 2008). Currently, the land-uses of Chobe District include the Chobe National Park, forest reserves, commercial farms and traditional subsistence farming. The expansion of commercial farms in this area may also be in conflict with other forms of land use. In the Pandamatenga area, about 5,000 ha of land has been identified as marginal land and it is regarded as potential area for biofuel production by the Ministry of Agriculture as the soils are not suitable for food crops (Modise 2009).

22.4.4 Implications for Biofuel Production

Although the Government of Botswana is still in the process of finalizing a policy for biofuels, the available policy statements in various official documents suggest that it will recommend the use of jatropha and sweet sorghum as feedstocks for biofuel production. These crops were recommended by the Feasibility Study on Biofuel Production and Use in Botswana (EECG 2007). The study also revealed that there appears to be sufficient land in Botswana for the production of jatropha and sweet sorghum. It was estimated that only 30% of the 400,000 ha of land demarcated for arable agriculture during the period 2004–2007 was used and the rest of the land (70%) was lying fallow (EECG 2007). It was also found that only 28% of agricultural land was used in eastern Botswana in 2009, and the rest was found to be idle (Kgathi and Mfundisi 2009). The feasibility study also suggested that the production of biofuels in Botswana would not have adverse effects on water resources in the country (EECG 2007). The Botswana National Development Plan 10 (NDP 10), states that a plant of 50 million litres per year, using jatropha as a feedstock, will be constructed by the Botswana Government during this plan period and biodiesel production is targeted for 2012 (MFDP 2009). The plant, which is estimated to cost 100–150 million Botswana Pula (BWP) (15–24.8 million US$), will require 50,000–75,000 ha of land for the production of feedstock (MFDP 2009). According to the Principal Energy Officer in the Department of Energy, a plantation of 20,000 ha will be established by the Government of Botswana for experimental purposes (Mabowe 2009). Due to erratic and unreliable rainfall in semi-arid Botswana (Fig. 22.1), it is intended that groundwater will be used for the irrigation of the crops. It is estimated that six billion litres (600,000 m^3) of water will be required annually to irrigate a plantation of 20,000 ha since 30,000 l of water are required to irrigate one ha of jatropha (Mabowe 2009).

The recommended biofuel crops of jatropha and sweet sorghum have high water efficiencies as revealed by their low water footprints, and are therefore considered suitable to for Botswana with its unfavourable water endowment. It has been found that jatropha requires an annual rainfall of 500–600 mm to produce good yields. Using figures from China and other countries, Yang et al. (2009) revealed that the water footprint for sweet sorghum was 0.7 m^3/l (cubic metres of water/litres of biofuel) as

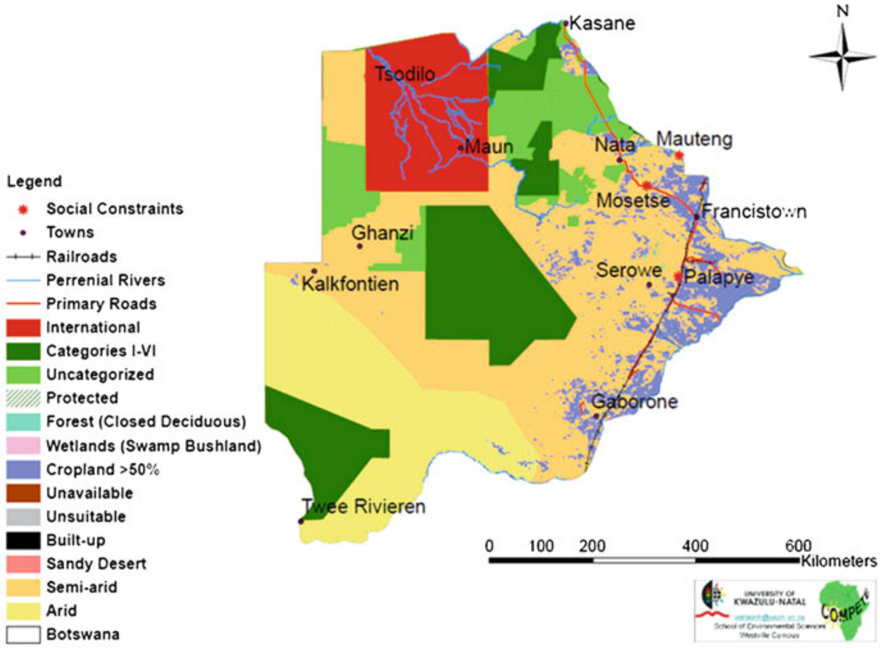

Fig. 22.1 Map of semi-aid areas in Botswana

compared to that of maize, sugarcane, and rapeseed of 1.47, 2.01 and 5.82 m^3/l respectively. On the basis of the amount of rainfall and available water resources, it can be concluded that there are possibilities for growing jatropha and sweet sorghum for biofuel production in river basins in the Chobe, Central, and Gaborone districts. In Chobe District, biofuels could be grown in the Pandamatenga area, where the Government is planning to transfer water from the Chobe/Zambezi River in order to boost agricultural development in the area. A recent survey undertaken in Chobe District revealed that most of the policy-makers held the view that there is a potential for biofuel development in Chobe District though some thought that it is likely to be in conflict with the tourism and forestry sectors. According to the SADC Water Protocol, Botswana is supposed to make a formal request to other member states to abstract water from this river, but such a request has not yet been made (Water Resources Consultants 2008). Given the pressure on water demand in the south–eastern part of the country, near the capital Gaborone, the use of drought resistant crops such as jatropha and sweet sorghum might be an appropriate water conservation strategy in this region. The possibility of using waste-water effluent and contaminated groundwater (e.g. around Ramotswa in the South East District) could also be explored.

22.5 Water and Biofuels in Zambia

Zambia experiences a tropical climate, and it is one of the largest countries in Africa with abundant surface water resources. It is drained by the Zambezi and Congo River basins. The Zambezi basin in the south covers about three quarters of the country, whereas the Congo basin in the north covers one quarter. The semi-arid regions of the country are found in the western and southern parts, where there is the Zambezi River (Fig. 22.2). Zambia's surface water resources are estimated at 105 km^3 and most of these resources (80%) are produced internally (FAO 2007). The irrigation potential in the Zambezi basin in Zambia is estimated at 422,000 ha of which 37.7% is located in the upper Zambezi basin, 47.9% in the Kafue River basin and the rest (14.5%) in the Luangwa River Basin (Table 22.2). There are a number of irrigation schemes in Zambia which include the Nakambala Sugar Estate (11,345 ha) in Mazabuka District in Southern Province of Zambia. The company is owned by Zambia Sugar Plc, a registered private company belonging to the Illovo Group. The company accounts for 98% of the total sugar production in Zambia (Kaizen Consulting International 2006). About 65% of the cane is obtained from the estate and the rest (35%) is from outgrowers (Kaizen Consulting International 2006; FAO 2007). The estate is estimated to use over 720,000 m^3 of water per day to irrigate 11,050 ha of sugarcane (FAO 2007).

In line with the national energy policy of ensuring sustainable exploitation of biomass resources, there are plans to expand the production of sugar at Nakambala Estate by 70% from the 2006/2007 production level of 260,000–440,000 ton. This expansion will also lead to an increase in the production of molasses, which will make it possible to produce bioethanol. The construction of a bioethanol plant, which will produce 25 million litres of bioethanol per year, is therefore anticipated (Kaizen Consulting International 2006). It is stated that the expansion will lead to an increase in water demand, but no figures are given. However, it is unlikely that the project will have adverse direct impacts on water supply as the area is endowed with abundant water resources and will not have exploited its full potential.

The semi-arid area of Southern Province of Zambia (Fig. 22.2) seems to have good conditions for biofuel production, particularly around Mazabuka District. The district has an annual rainfall of 708 mm. It is situated 125 km from the capital Lusaka and 360 km from the southern town of Livingstone. The area has sufficient surface and groundwater resources, the Kafue River and its tributaries being important sources of water and hydro-electricity. In addition to the planned agricultural production of sugarcane and its conversion to ethanol, the Southern Province is one area in semi-arid Zambia where additional biofuel projects could be established. Production of biofuels could be launched in other districts of the Southern Province. In addition to sugarcane, drought resistant energy crops such as jatropha and sweet sorghum could be established, particularly in areas which are not swampy.

In other parts of the country with abundant and reliable rainfall, there are several initiatives for biofuel development which occur under rain-fed agricultural conditions.

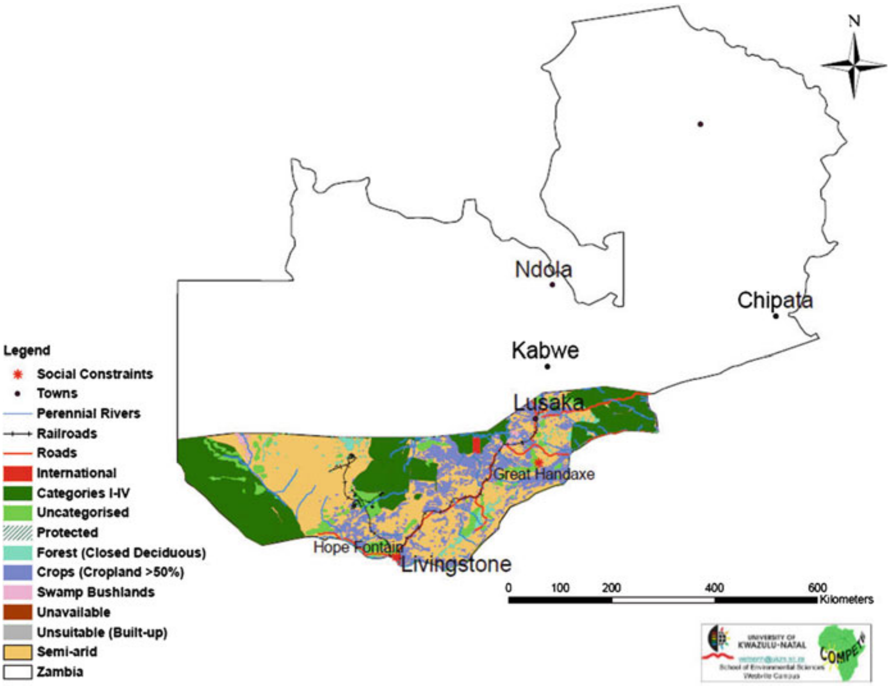

Fig. 22.2 Map of semi-arid areas in Zambia

Table 22.2 Irrigation potential in the different Zambezi sub-basins in Zambia

Types of irrigation	Upper Zambezi river basin (ha)	Kafue river basin (ha)	Luangwa river basin (ha)	Total for Zambezi river basin (ha)
Located	112,000	165,000	14,000	291,000
Groundwater	15,000	15,000	15,000	45,000
Commercial	2,000	2,000	2,000	6,000
Dambos	30,000	20,000	30,000	80,000
Total	159,000	202,000	61,000	422,000

Source: FAO (1997)

In most of these areas the common biofuel feedstock is jatropha. A Zambian Company known as Marli Investment has been involved in jatropha outgrower contract farming since 2003. According to Janssen et al. (2009), the company has distributed more than 12 million seedlings to outgrowers in different parts of the country. A total of 25,000 outgrowers have joined the scheme and their plantations are estimated at 12,000 ha. As long as these schemes continue to be mainly under rain-fed agriculture, it is unlikely that they will have a negative impact on water resources in the country.

22.6 Water and Biofuels in Tanzania

Tanzania lies within nine major drainage basin systems of Lake Victoria, Lake Nyasa, Lake Tanganyika, Lake Eyasi/Bubu depression, Lake Rukwa, Pangani River, Rufiji River, Ruvu/Wami River, and Ruvuma River (FAO 2008b). Of the total renewable surface water resources of 93 km^3/year, 90.3% are produced internally. Groundwater resources amount to 30 km^3/year. In 2002, the total water consumption in mainland Tanzania was estimated at 5,142 million m^3 (5.1 km^3), of which the largest share (90%) of 4.624 km^3 was consumed by agriculture. The Irrigation Water Master Plan Study of 1992 estimated the irrigation potential in mainland Tanzania at 2,123,700 ha (FAO 2008b). The regions with the highest irrigation potential are Mbeya and Iringa, Morogoro, Arusha and Kilimanjaro, and Mara, Mwanza and Kagera (FAO 2008b).

The semi-arid regions of Tanzania, in the central and southern parts, have good conditions for growing biofuels such as sufficient rainfall, abundant land resources, and potential for irrigation of crops, particularly in Morogoro District, where the potential is 376,000 ha. The country has identified several feedstocks for biofuel development such as jatropha, sugarcane and palm oil. There are already sugarcane and jatropha initiatives in mainland Tanzania. According to Martin et al. (2009), biofuel initiatives (including those of biogas) in Tanzania can be categorized into the following scales of development: (1) micro-scale (up to 200 ha), (2) small-scale (200–2,000 ha), (3) medium scale (2,000–50,000 ha), and (4) large–scale (over 50,000). Figure 22.3 shows the location of these initiatives. Micro-scale initiatives are mainly in the form of biogas (introduced in 1993) and jatropha oil production for electricity generation (introduced in 2006). Small- and medium-scale initiatives mainly focus on jatropha production (Martin et al. 2009). An example of a medium scale initiative is Diligent Tanzania Limited. The company intends to produce 1.5 billion litres per year of jatropha-based biodiesel for export to the European market (Martin et al. 2009). Although based in Arusha, the company covers other parts of the country, including those in the semi-arid parts (Martin et al. 2009). Large-scale initiatives are still in infancy as they were introduced in 2007, and they aim at producing sugarcane and jatropha based biofuels in the study areas as well as in other parts of Tanzania (Fig. 22.3).

Currently, the use of water for biofuel development does not seem to have adversely affected water resources in Tanzania as indicated in Table 22.3. The table compares water withdrawals associated with the production of sugarcane for biofuel production in Tanzania with those of other countries. It shows that the total water demand for ethanol production in Tanzania was estimated at 0.10 km^3 in 2008 and it is projected to increase by 50% to the level of 0.15 km^3 in 2017. The amount of water withdrawn for biofuel production in Tanzania in 2008 as a percentage of agricultural water withdrawals in 2000 was only 2% and this figure is projected to increase to 3% in 2017. By comparison, water withdrawals for biofuel production in Brazil, South Africa, Ethiopia, and Mozambique in 2008 as percentages of agricultural water withdrawals in 2000 were 14%, 11%, 5%, and 7%, respectively.

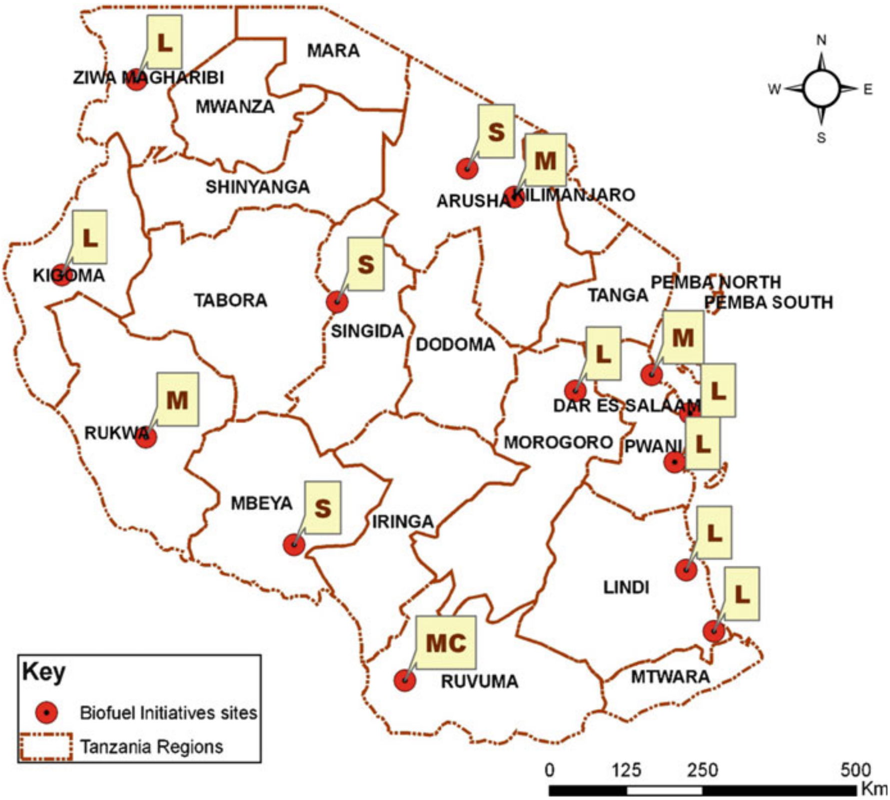

Fig. 22.3 Biofuel initiatives in Tanzania; Notes: *L* large-scale biofuel, *M* medium scale, *S* small-scale, *MC* micro scale (Source: Martin et al. 2009)

In addition, stress on water resources as indicated by the amount of water withdrawals as a percentage of the total agricultural water withdrawals in Tanzania was only 5%, compared to 16% in South Africa, 4% in Ethiopia, 29% in India and 15% in China.

22.7 Water and Biofuels in Mali

Mali generates its water resources within two major river basins of the Niger and the Senegal Rivers. The Niger River basin covers 7.5% of the continent and spreads over ten countries. In 2001, renewable water resources in Mali were estimated at 100 km^3 (UEMOA 2009).

According to UEMOA (2009) and Ouattara (2008), Mali has a very limited potential to produce food as only 4% of the land area is arable and the rest is either used

Table 22.3 Implications of bioethanol production on water resources per country

	Main feedstock	% of production	Water demand for ethanol production (km^3)		Total agricultural water withdrawals (km^3)	Irrigation water for biofuel production as% of agricultural water withdrawals in 2000		Stress on water resources due to agriculture (%)
			2008	2017	2000	2008	2017	2000
USA	Maize	20	6.21	8.48	198	3	4	6
Brazil	Sugarcane	15	5.18	9.49	37	14	26	0
China	Maize	40	7.71	11.78	427	2	3	15
India	Sugarcane	80	4.18	7.82	558	1	1	29
South Africa	Sugarcane	40	0.85	1.58	7.8	11	20	16
Ethiopia	Sugarcane	100	0.25	0.48	5.2	5	9	4
Tanzania	Sugarcane	100	0.1	0.15	4.6	2	3	5
Mozambique	Sugarcane	100	0.04	0.05	0.6	7	8	0

Source: Hoogeveen et al. (2009)

for pasture (25%) or it is classified as other land used for other purposes (71%). Like Botswana, Mali has a high dependence on imported food and fossil energy sources and therefore its food and energy security situation is very fragile (Green 2009). In 2002, the total area under irrigation in Mali was 2,369 km^2. Irrigation is undertaken on 5% of the arable land, especially in the area around the inner Niger Delta (Ouattara 2008). Within the Niger River basin, the irrigation potential has been estimated at 556,000 ha with 200,000 ha (36%) fully controlled and the remaining 356,000 ha (64%) partially controlled. However, only 187,500 ha (34%) is already under irrigation and the irrigation potential in Mali within the basin is limited by the topography.

The majority of Mali's population has no access to electricity (UEMOA 2009). As a result, around 90% of the population uses firewood and charcoal as the main energy sources (Ouattara 2008). It is estimated that only 15% of the population has access to electricity in Mali and in rural areas the proportion is even lower (Ouattara 2008). The potential for jatropha development remains considerable in Mali as areas not suitable for crop production or which are not fully utilized for arable agriculture could be used for its cultivation (GTZ 2008). Figure 22.4 shows the potential areas for growing jatropha in southern Mali.

Bioenergy development in Mali is given strong support by national energy policy. Small-scale production of oil from jatropha for use in "agricultural machinery and rural electrification" has been going on for two decades (United Nations 2008; UEMOA 2009; GTZ 2008). Jatropha has been traditionally used as a hedge for fences and gardens in Mali, currently estimated at 20,000 km (Ouattara 2008). The potential use of the crop for oil production was recognized in the 1930s, but the activities remained on a small-scale until 1987, when Ouattara reinitiated jatropha activities and various opportunities for using it for rural and bioenergy development were explored. For instance, a local NGO, Mali Folkecenter (MCF), has started a project in southern Mali which aims at producing a 1,000 ha jatropha plantation via the small-scale outgrower farming approach. According to Quattara (2008) and Jumbe et al. (2009), communities living within a radius of 20 km are provided with mechanical power through multifunctional platforms for various purposes such as food processing, charging batteries, and rural electrification.

In 2008, the company Mali Biocarburant, established by the Royal Tropical Institute and financed by the Dutch Government, was established in order to produce biodiesel from jatropha already planted as hedges for the purpose of fencing fields or roads or from trees intercropped with other crops in existing farming systems. Bekunda et al. (2009) emphasize the distinct production model of this company whereby production of biodiesel is entirely based on seeds collected from jatropha trees already planted for fencing rather than from plantations. The company also addresses problems associated with intercropping by leaving a 5-m rather than a 2–3 m space between the crops. This is done in order to avoid the problem whereby the canopy becomes too large to allow the sunlight to reach other crops (Green 2009). The first site chosen for biodiesel production is Kalikoro, located in a semi-arid region. This is one of the areas identified by GTZ as a medium potential for jatropha production (Ouattara 2008). It is estimated that Mali Biocarburant will

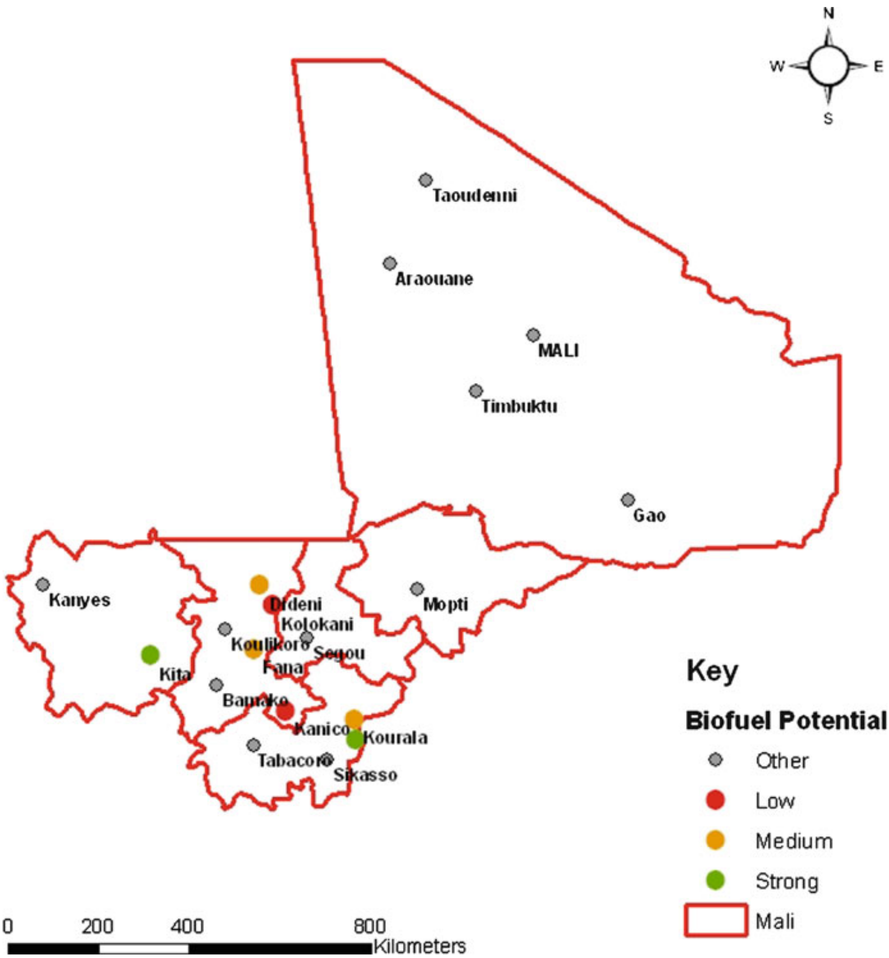

Fig. 22.4 Potential for growing jatropha curcas in southern Mali (Source: Mali Folkecenter 2008)

produce 750,000 litres of biodiesel per year (United Nations Economic Commission for Africa 2008). The company plans to expand to other parts of the country by establishing 20 similar units.

Given the fact that the average rainfall in Mali is 440 mm, the cultivation of jatropha may require irrigation in order to obtain higher crop yields, particularly in semi-arid areas. Studies undertaken in India suggest that if jatropha is grown on marginal land without irrigation, its yield will be 1.1–2.75 ton/ha (Green 2009). Whilst there is potential for irrigation of jatropha in Mali, it is crucial to limit biofuel production to modest levels and not to aim at exporting the fuel as the country is constrained by limited water resources. According to Green (2009, p. 17), "… Jatropha cultivation for biofuel will also be severely constrained by water in Mali and could put immense stress on water resources" and this will be made worse by climate change since various models have predicted drier and hotter conditions for Mali.

22.8 Conclusion

Botswana and Mali have similarities as water scarce countries with high dependency on imported food and energy. In Mali agricultural development is largely constrained by low rainfall and limited water resources. There are initiatives to produce jatropha-based biodiesel using trees already planted as hedges in various parts of the country. This approach is different from other farming systems as it does not lead to production of biofuels on new land. In Botswana, the Government is still finalizing a biofuels policy. However, available policy statements in various official documents suggest that it will recommend the use of jatropha and sweet sorghum as feedstocks for biofuel production. Botswana suffers from a lack of surface water and therefore the country is more dependent on groundwater resources. The major drainage systems of Okavango, Chobe and Limpopo have irrigation potential. On the basis of the amount of rainfall and available water resources, it can be concluded that there are possibilities for growing jatropha and sweet sorghum for biofuel production along river basins in the Chobe, Central, and Gaborone districts.

Whilst large proportions of Mali and Botswana are semi-arid, the semi-arid areas in Zambia and Tanzania are smaller. The semi-arid areas of **Zambia and Tanzania** have relatively suitable conditions for biofuel production. There are sugarcane and jatropha based biofuel projects in these countries, and possibilities for expanding production are being considered. The available land and water resources in these countries make them well positioned to undertake large-scale biofuel projects under rain-fed (e.g. *Jatropha curcas*) and irrigated conditions (e.g. sugarcane). In Zambia, there are plans to expand the production of sugar at Nakambala Estate by 70%. This expansion will lead to an increase in the production of molasses, which will make it possible to produce bioethanol. The construction of a bioethanol plant to produce 25 million litres of bioethanol is under consideration.

Expansion of biofuel projects in these countries has the potential to adversely affect water resources. In water scarce countries such as Botswana and Mali, it is better to engage in biofuel projects which do not require much irrigation. The use of irrigation water to produce fuel from marginal lands may face the primary limitation of water availability, rather than land suitability. The production model of integrating biofuel production with food crop production as practised in Mali can provide useful lessons for other countries. In Zambia and Tanzania, large-scale projects based on contract farming could be expanded to reach the full potential of these countries, but their impact on water resources should be carefully monitored.

In all these countries, detailed environmental assessments, including those of water footprints, should be made mandatory before introducing large-scale biofuel projects likely to deplete water resources. It is also necessary to estimate the theoretical virtual water content of biofuels. When biofuels are produced for export, the export includes virtual water content, which means that there is a net loss of environmental capital. In addition, research and development efforts on second generation biofuels should be continued as the production and use of these fuels is likely to lead to a reduction in water use.

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