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STUDY REPORT ON

NOVEL BIOENERGY CROP POTENTIAL IN THE ECOWAS REGION

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The report was prepared by Quinvita

STUDY REPORT ON NOVEL BIOENERGY CROP POTENTIAL IN THE ECOWAS REGION

ECOWAS CENTRE FOR RENEWABLE
ENERGY AND ENERGY EFFICIENCY
- ECREEE -

Final report to ECREEE; IIBN/UNIDO

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STUDY REPORT ON NOVEL BIOENERGY CROP POTENTIAL IN THE ECOWAS REGION

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Contents

1. BACKGROUND AND STRUCTURE OF THE PROJECT

1.1. General introduction to the project

The project "Regional potential assessment of novel bio energy crops in fifteen ECOWAS countries" was started by the different project partners based on the need to make an overall assessment of a series of novel potential bio energy crops which can or could be grown and processed in the future in the 15 ECOWAS countries. This project fits in a broader strategic analysis of alternative energy needs and production, the key mandate of the main funding partner in the project, ECREEE. The project partners deliberately excluded conventional "bio energy" crops like sugarcane, oil palm, maize or sunflower as target crops, since they believed a sufficient knowledge base on the growing and processing crops was available globally and in the region. The novel bio energy crops chosen as targets for the study are a selection of crops for which either the agricultural knowledge is still limited and/or the use of the crop as an energy source is relatively new. The project team realizes that the list of selected crops is not an exhaustive list of potential bio energy crops and other novel crops may have a potential in the region. The project will develop a methodology that can be followed in the future for analyzing the potential of other crops and does not want to exclude this analysis in the future.

The crops that have been selected for analysis in this project are: False Flax (Camelina sativa), Crambe (Crambe abyssinica), Cassava (Manihot esculenta), Castor bean (Ricinus communis), Cashew (Anacardium occidentale), Groundnut (Arachis hypogaea), Jatropha curcas and sweet sorghum (sweet version of Sorghum bicolor).

1.2. The project has been structured in two phases

In the first phase the project has analyzed these 8 different crops for adaptation to growing conditions and agricultural systems in the 15 ECOWAS countries and will analyze the broad operating context for the establishment of novel bio energy crops in the 15 ECOWAS countries. Based on this analysis 4 crop/region combinations have been selected for an in depth feasibility study in the second phase of the project. Camelina sativa and Crambe abyssinica were not retained for further analysis because they are not suitable to be cultivated in the ECOWAS region.

Ricinus communis produces alternative industrial oil with very interesting attributes but which is too valuable and also technically not optimal to be used as a bio-energy crop. Arachis hypogaea was not retained for further analysis because the project team believes that this crop first needs to be fully exploited as a food crop in the region.

Appendix 1 shows the intermediate report published in August 2012 by the project team that led to these conclusions.

1.3. General observations and conclusions

A number of studies suggest that growing novel bio energy crops in the region does not represent viable solutions for energy production that can be recovered in the existing electricity grid (UNDP and ECOWAS Energy and Infrastructure Division, 2010). However, we believe that selecting the crop/region combinations opens a very important opportunity to further develop off grid energy applications for local energy production and use. This aspect will be analyzed in detail in the second phase of the project.

The full exploitation of this potential will also remove an important concern often associated with the cultivation of these novel bio energy crops: the fact that many projects were started with the primary goal to produce feedstock in Africa for export to important end user markets like India, China and Europe. Indeed the more decentralized production of energy for local use in the first place, will be a direct benefit for local (farming) communities, on the condition that this is integrated with a wider agricultural development policy allowing for more local storage and processing activities, fueled by the produced energy whether traditional or renewable.

The project team believes that a policy development around the production of bio energy crops in the ECOWAS region needs to address this aspect urgently. It should also allow foreign investors to come to the region with confidence but at the same time address the delicate balance between local and global needs. A significant fact is that the selected target areas are predominantly landlocked in the region. We believe this will enhance the (local and foreign) investment in the crop as well as the local use of the feedstock, on condition that the correct policy and regulatory framework is available for implementation.

The full implementation of the potential identified for the 4 crops will also depend on the availability or the development of a strong knowledge base on the professional growing of the crop and the subsequent small and larger scale down stream processing.

2. SPECIFIC CONCLUSIONS AFTER THE FIRST PHASE

Based on the progress report after the first phase of the project, 4 crop region combinations have been selected for further analysis. This is summarized in the project report in Appendix 1. The selection was based on the following key findings.

2.1. Sweet sorghum

Based on the climate based suitability maps we developed for sweet sorghum, theoretically a large area of the ECOWAS countries can develop a sugar-to-ethanol business from sweet sorghum in the future. Sierra Leone and Nigeria have commercial sugar-to-ethanol plants running based on large-scale plantations of cassava or sugarcane. In coherence with the ethanol production, the end markets for ethanol (cooking stoves, heating water, refrigerators, transport fuel and electricity use) have also been developed especially in recent years in Brazil and USA but also on a more limited scale in ECOWAS countries and new applications for bio-ethanol are being created on an ongoing basis. There are two reasons to investigate a potential role for sweet sorghum. Brazilian research has shown that sweet sorghum can be processed in sugarcane mills in times of low cane supply and sweet sorghum can be used for crop rotation in sugar cane fields. Based on these observations, we have 2 regions of interest: the Northern part of Sierra Leone and Liberia and parts of Guinea. Some parts of Nigeria and Ghana with existing ethanol conversion technology from sugarcane and/or cassava can also be target areas for this application. We believe these are areas where dedicated sweet sorghum can be developed into a successful bio energy crop and should be our primary areas of attention (figure 1).

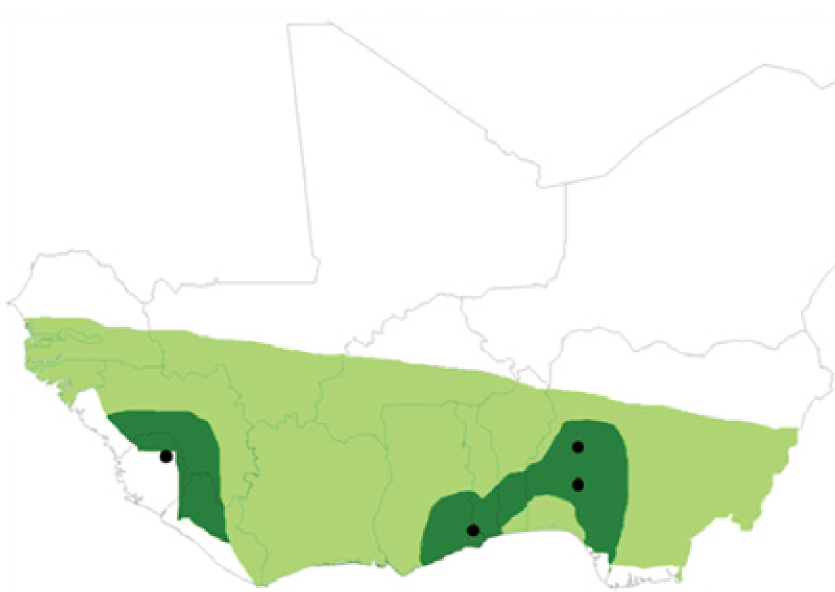


Figure 1: target area for further sweet sorghum study. Dark green: primary focus area; light green: secondary focus area. Black dots show existing ethanol plants processing sugarcane or cassava

One school of thought also wants to develop a sweet version of grain sorghum (in general more resistant to drought). It remains to be seen if the additional income from the sorghum grain can compensate for the lower biomass, and thus sugar production, to be anticipated in the traditional grain sorghum areas in West Africa. The lower rainfall patterns in the traditional grain sorghum growing areas (500-1000mm) will indeed result in lower biomass production capability. In addition, the crops grown in these areas will have to be the sole feedstock for ethanol conversion, as these areas do not allow the large-scale production of sugarcane or to a lesser extent cassava. Will it be possible to implement smaller scale decentralized sugar/ethanol production units, given the known capital intensity of these units?

A phased approach, where dedicated sweet sorghum cultivation can benefit from existing cassava or sugarcane to ethanol know-how, followed by a smaller scale implementation of dedicated sweet sorghum plants moving to the northern growing areas, may be the realistic and preferred route to follow.

2.2. Jatropha

Mali and Burkina Faso have the longest record in Jatropha projects. Most of these projects are located in the Southern part of the countries. In these areas there is a limited Jatropha grain processing capacity and a market for the Jatropha oil, mainly used to power MFPs, to produce soap or to be turned into biodiesel on a small scale. Both countries are landlocked and diesel prices are relatively high. The large plantation projects projected for Ghana and Senegal were less successful so far and were in most cases not realized, although small experiments are ongoing. In the case of Senegal, the primary reason was the fact that Jatropha was pushed in areas suboptimal for rainfall (too dry). In the case of Ghana, the project optimization is still ongoing. Recently major project intentions were also announced in Nigeria. Based on global experience QUINVITA has developed suitability maps for Jatropha to be grown as a sustainable oil crop.

Based on the suitability maps and the ongoing and announced initiatives, a crop-region combination is suggested, using some of the more developed projects in Mali, Burkina Faso and Ghana as examples to build on for the development of centers of excellence. Therefore we like to select the area shown on the map in figure 2 for a further Jatropha plantation evaluation. One of the important pre-judgments we will have to deal with upfront is the persisting belief in some countries that Jatropha is a miracle crop which can be developed into a successful oil crop in areas marginal for land quality and rainfall patterns. The reality is that in these areas (northern boundaries of the selected areas on the map), Jatropha can survive the harsh climatic conditions but will never become a significant source of energy oil. In these areas Jatropha can be evaluated as an anti-erosion crop with very limited to no potential as an oil feedstock crop.

QUINVITA together with some other private breeding companies are developing high yielding variety ideotypes for the cultivation of Jatropha as an economically viable oil feedstock. In these varieties, we select for open pollinated varieties and at a later stage possibly commercial F1 hybrids that are environmentally adapted to the target areas: this adaptation is measured in the combined production of high quantities of Jatropha grain and relatively high oil content (33% plus). This selection process will result in a more reliable and stable production of economic levels of ''oil/ha'' yields from the Jatropha crops grown. It is the preliminary experience of Quinvita that so called ''local varieties'' are in most cases not the delivering the highest oil yield per ha.

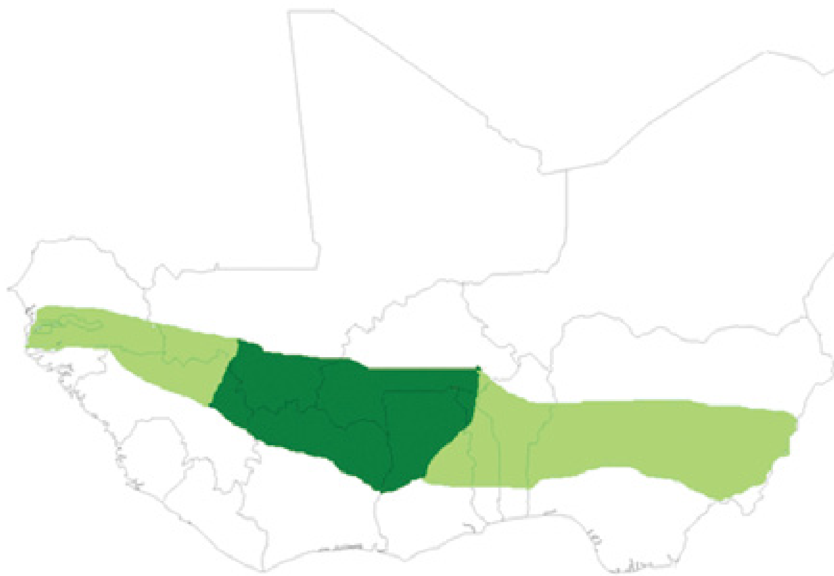


Figure 2: target area for further Jatropha study. Dark green: primary focus area; light green: secondary focus area

2.3. Cassava

Based on climate suitability of cassava, a relatively large portion of the ECOWAS region can develop cassava into a bio energy source. It is very critical that cassava is produced in first instance as a food crop and that supply for food applications is guaranteed. Table 1 summarizes the current supply demand situation for the different ECOWAS countries. Nigeria already has an emerging cassava for ethanol industry. This is the direct result of the fact that the country has a major surplus of production of cassava for food purposes. Very few other countries in West Africa are in a similar condition. Only Ghana, Benin and to a lesser extent Ivory Coast and Togo could consider the development of a cassava to ethanol industry based on a surplus production.

				FAOSTAT	Cassava		
					Tonnes roots		
Country	Area (km²)	Pop. Dens (#/km²)	Arable land/ capita (ha)	Potential arable land in use (%)	Production	Food supply	Surplus/ (shortage)
Benin	112.620	60,0	0,36	19,3	3.996.420	1.165.309	2.831.111
Burkina Faso	274.200	46,0	0,35	17,5	3.967	5.789	-1.813
Cabo Verde	4.033	101,0	0,09	nd	3.591	3.776	-185
Ghana	239.460	85,0	0,16	23,6	12.230.600	4.602.571	7.628.029
Guinea	245.857	32,0	0,26	5,5	989.326	982.551	6.775
Guinea-Bissau	36.120	37,0	0,10	14,7	45.000	43.397	1.603
Cote d'Ivoire	322.460	52,0	0,28	14,1	2.900.000	2.107.122	792.878
Liberia	111.370	30,0	0,16	6,0	493.706	550.000	-56.294
Mali	1.240.000	9,1	0,18	9,4	88.162	21.125	67.037
Niger	1.267.000	8.4	0,44	35,1	107.625	113.277	-5.652
Nigeria	923.768	141,0	0,41	49,4	36.804.300	16.890.305	19.913.995
Senegal	196.190	54,0	0,22	17,7	265.533	212.151	53.382
Sierra Leone	71.740	78,0	0,29	13,7	349.618	370.225	-20.607
The Gambia	11.300	129,0	0,12	21,9	7.370	8.199	-829
Togo	56.785	93,0	0,61	56,6	776.715	657.405	119.310
Total		5.112.903			59.061.933	27.733.193	31.328.740

Table 1: production and consumption of Cassava in ECOWAS countries (FAOSTAT)

In countries where cassava suitability is good but current productivity is too low to supply local food needs, emphasis first needs to be put on the improvement of cassava productivity. In a later phase and only if a surplus production situation is reached, should there be a consideration for cassava to ethanol conversion. In our further study, these countries will currently not be considered. On the map in figure 3, the target area for further study is indicated. The ethanol pro-

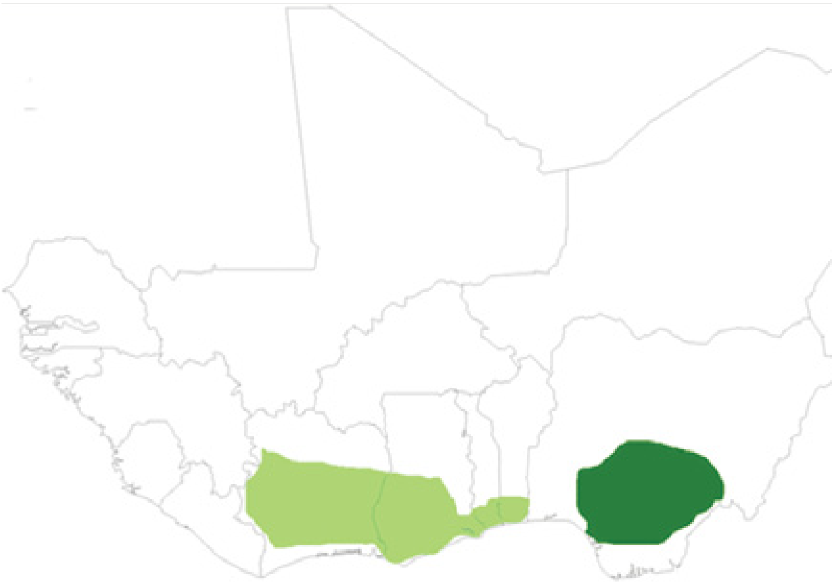


Figure 3: Target area for further Cassava study. Dark green: primary focus area; pale green secondary focus area

duced from cassava in Nigeria can not only be used as transport fuel. It is also put on the market for cooking stove fuel, water heaters, and ovens and it can also be used in different units to generate electricity. In Ghana, Caltech Ventures is planning to build a cassava to ethanol plant. Ghana is a major producer and exporter of various cassava products for food and feed. Cassava into ethanol conversion is ideally done from so-called high-sugar varieties as ideo-types for the production of economically viable sources of ethanol from cassava. Learning from the Nigerian experience, it will be interesting to investigate the potential of these cassava varieties for ethanol production in Ghana and Benin and possibly in Ivory Coast and Togo in the future.

2.4. Cashew

Based on the analysis of the project team, West Africa is the second most important producer of Cashew Nuts in the world (after India).

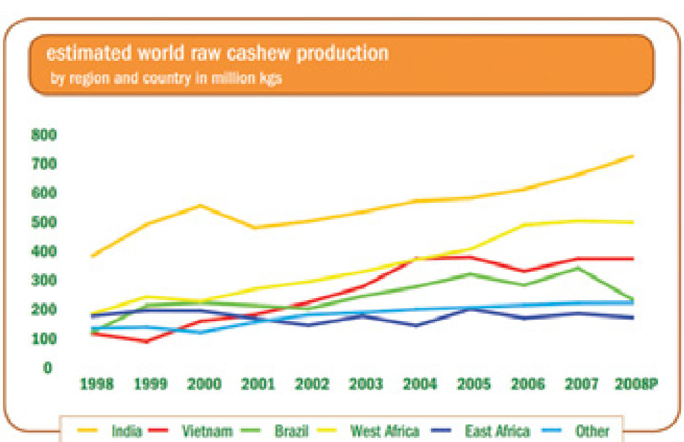


Figure 4: World Cashew Production (source: Red River, Industry, FAO)

During the Cashew production process in West Africa, today the major emphasis lies on the production of the cashew nuts. Nigeria (650K tons), Ivory Coast (350K tons), Guinea Bissau and Benin (100K tons) are the key producers in the area. In Mali, producing 3K tons of nuts, a small industry has been developed to also “market” cashew apples or fruits in analogy with Brazil where this is an important component of the value chain for Cashew farmers. In addition Brazil has also developed a major cashew apple processing industry with a range of end market applications in the food sector. We have not been able to find evidence that a similar development has started on a large scale in West Africa although this could also add significant value to the cashew value chain in the area. This may be due to the lack of marketing efforts towards these applications but can also be based on some cultural barriers to use cashew apples for food applications. The question whether this industrial development into food applications can be accompanied by parallel value capture from the leftovers of the cashew apple processing (after delivery of the sap into a food application stream) into ethanol or biogas bio energy applications is linked to the current state of affairs of the food processing industry from cashew apples.

Given the fact that today Nigeria and Ivory Coast are the primary producers of Cashew in the ECOWAS region, we suggest to focus our primary analysis on the state of affairs of the apple processing in these countries. Potential existing or emerging success stories can then be transposed to secondary target areas like Benin, Guinea Bissau and smaller producers like Ghana, Guinea, Mali, Senegal and Burkina Faso.

It will be very critical that organizations like the African Cashew Alliance, based in Accra, Ghana take a lead role in this eventual roll-out.

The focus map for the Cashew analysis derived from this analysis is shown below.

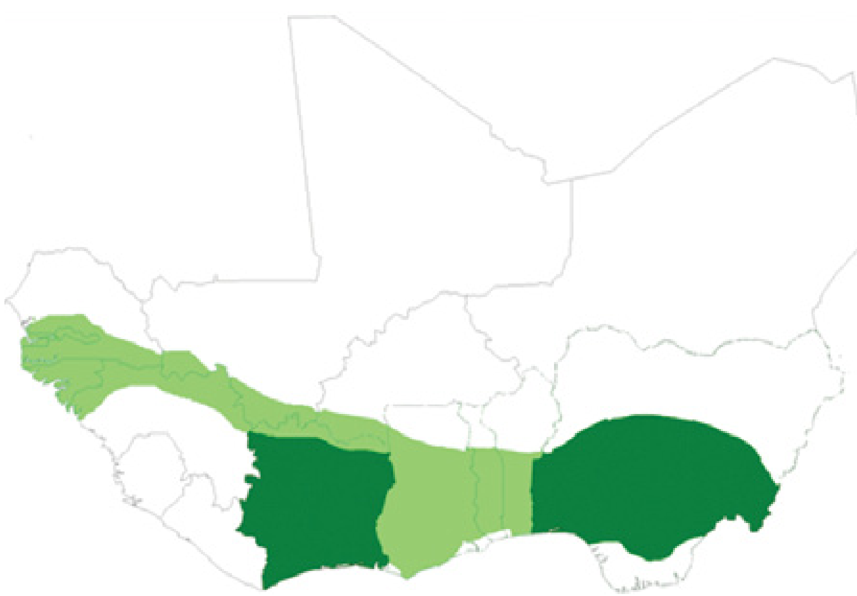


Figure 5: Target area for further Cashew study. Dark green: primary focus area; pale green secondary focus area

This report builds on the knowledge reported in previous reports and summarizes the current knowledge base and conclusions for the four crop/region combinations, on the basis of the fact finding missions executed during the last months of 2012. Many bio energy projects and people involved were contacted and many questions on the feasibility of the projects were asked. A lot of this information was obtained during visits to the region or during interactions on a conference where a lot of the stakeholders of different ECOWAS countries were present. The collected information was complemented by phone calls or email contacts.

3. SETTING THE BOUNDARIES FOR SUSTAINABILITY OF BIO ENERGY CROPS IN ECOWAS REGION

The 4 crops selected for further studies were sweet sorghum, Jatropha curcas, Cassava and Cashew. The planned bio energy component for these crops is summarized in table 2.

Crop	Principal product	Co-product	Bio energy components
Grain sweet sorghum	Grain	Stalks/Sugar	Ethanol
Dedicated sweet sorghum	Stalks/Sugar	Bagasse	Ethanol
Jatropha	Crude Oil	Seed cake	Crude oil Cake biomass
Cassava	Roots	Bagasse/starch	Ethanol
Cashew	Nuts	Apples (food)	Biogas/bio-ethanol

Table 2: Summary of the planned bio energy component for the selected crops

Figure 6 gives a general overview of bio energy generation processes based on crop sources.

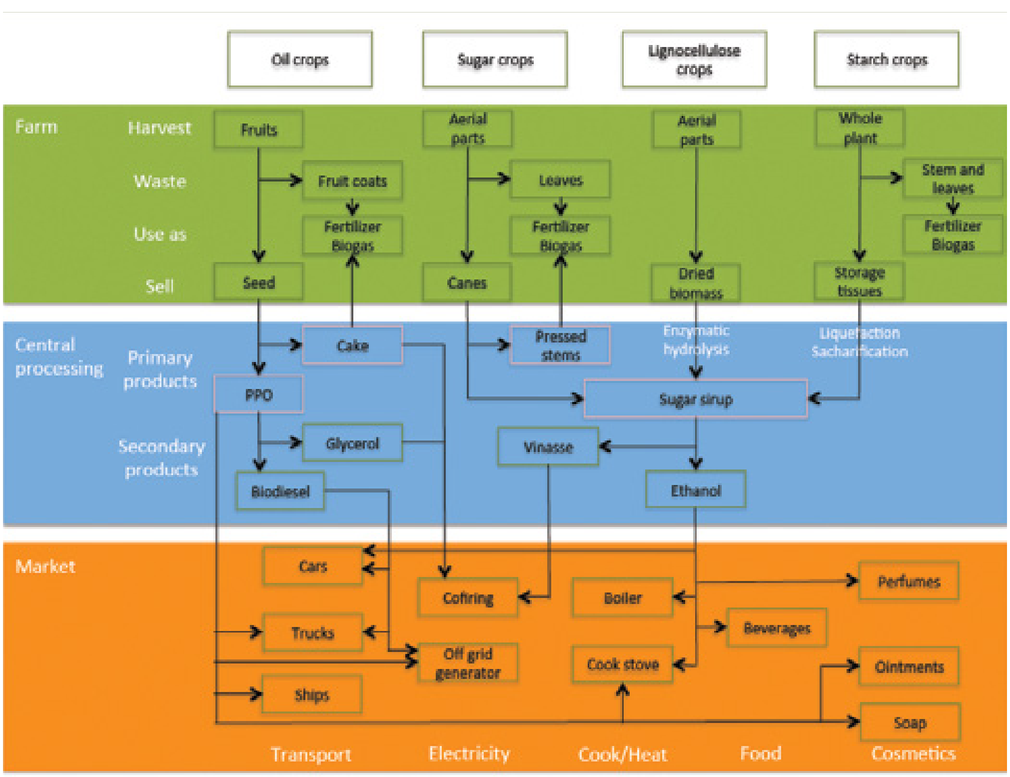


Figure 6: overview of the way energy carriers are being obtained from various types of bio energy crops and how these carriers are utilized in the market

The costs for energy carriers derived from renewable sources are determined by three major factors: the cost of the feedstock, the cost of logistics of collecting the feedstock prior to conversion (linked to volumes of processed raw materials and the cost (complexity) of the conversion process. For pure plant oil (PPO) and biodiesel, the conversion processes are relatively simple. The majority of the cost (more than 80%) is feedstock production/acquisition costs. The logistics costs must be based on the collection cost of the processed produce; in the case of Jatropha, these are the dried grains obtained after the de-husking (on farm) of the Jatropha fruits holding the grains. A first estimate tells us that ''production/collection'' circles of maximum 100 km are probably still economically viable although a more concentrated collection circle is more adviseable. For ethanol from sugarcane the costs of feedstock is more than half of the production costs. In this case production/ collection circles are very limited (less than 20 km) due to the fact that sugarcane or sweet sorghum stalks need to be processed immediately. For ethanol from starch crops or lignocellulose crops, feedstock cost is less than half of the production costs, because the ethanol production process is capital extensive and is more or less effective depending on the feedstock source used for fermentation into ethanol (Bindraban 2009). Cassava has the major advantage as a starch based ethanol crop that farmers can produce and store cassava chips that can be stored under proper conditions for a longer period of time before they are transported to final starch into ethanol plants. In this way one needs to develop primary collection circles of 20-30 km with their own chip production and storage facilities; secondary collection centres where chips are centralized can be of a larger dimension (50-100 km) and should then house a central starch into ethanol plant.

In the case of cashew fruits, we are in a similar situation as for sugarcane and sweet sorghum; the fragile nature of the cashew fruits are the challenge to store and transport the fruits over a long distance will likely reduce the logistics circles again to less than 20 km. It would be logical to integrate this operation in cashew nut processing operations.

Given the relative importance of the feedstock production costs, it is important to analyze the cost drivers behind them. Like in all crops, feedstock production costs are strongly influenced by the yields achieved for the bio energy component of the feedstock in the field.

For Jatropha the fruits are collected. De-cortication of the fruits leads to the production of a large volume of fruit coats, which can be left in the field as mulch or as composted material. Crushing the grain results in crude Jatropha oil, the principal energy source from the crop and a seedcake with very interesting attributes as a fertilizer (4% nitrogen content) and a soil conditioner (40% organic carbon content). This seedcake can be used as a fertilizer/soil conditioner in Jatropha or on co cultivated cash crops. During the dormancy period of the Jatropha crop, the plant also sheds its leaves, adding biomass back to the field. Fertilizer needs for economical Jatropha production are currently being studied. A recently published finding could have interesting effects on the economy of Jatropha (Madhaiyan et al, 2012). It states that a nitrogen fixing bacterium associated with the roots of Jatropha was found. If this bacterium indeed assists Jatropha in nitrogen fixation, this could improve the economics of the crop dramatically and turn Jatropha into a key companion crop for food and energy farms in its area of adaptation. It is going to be critical to have in the immediate vicinity of a central Jatropha crushing facility a market for the use of Jatropha seedcake as a fertilizer/soil conditioner. This is the principle reason why the team strongly suggests to INTEGRATE food production (using the seedcake) and energy production based on Jatropha in mixed farming concepts.

Sweet sorghum produces sugar as the principal source for energy in the stalks and leaves of the plant. In a model where dedicated sweet sorghum for energy production is produced, this is the principal product of the crop. In a model where sweet versions of grain sorghum hybrids are developed, the crop is expected to produce much lower volumes of biomass due to the lower rainfall areas where the grain sorghum is grown but it will also produce sorghum grains as an additional product. In both these models, very little of the biomass that was produced will be returned to the soil, demanding supplementary fertilization to avoid soil depletion and to guarantee an economic production level of the crop. Cassava produces its biomass feedstock under the form of starchy roots. A number of high sugar/starch content varieties have been developed as a more dedicated feedstock for cassava based ethanol production. As indicated above the roots can be turned into chips that can be dried and subsequently stored. The areal parts of the plants can be used as animal feed or as fertilizer. In case of the latter, almost nothing of the crop is returned to the soil and additional measures for fertilization have to take place to keep production per ha at acceptable levels.

Finally in the case of cashew nuts, the principal product is the nut. These are typically removed from the apples on the farm and the nuts are collected and centralized in processing plants where more or less finished products of the cashew nut value chain are produced. The apples today are mostly left on the farm as leftovers. In a number of places, cashew apples are sold as a fruit but a lot of them are wasted. It was demonstrated that cashew apples are very rich in vitamin C and can thus be a very interesting target to be converted on farm or in small village based decentralized units into valuable food products (jam, etc.). It will be very challenging to centralize intact cashew apples in sufficient volumes for further processing into energy but the opportunity to use large volumes of apples as a feedstock for decentralized biogas production needs to be studied.

The development of a smart nutrient management strategy of these crops together with a similar strategy for co-cultivated food crops must prevent further nutrient depletion of the soils, which is already a major problem in the region (figure 7). The use of Jatropha seedcake and the maximal recovery of organic matter, left over from other production processes can alleviate this concern somewhat and can also have a positive effect on the fertilizer budget of individual farmers and on overall productivity of food and cash companion crops to the bio energy crops. Because the goal is to recover a maximum as biomass under the form of compost/ fertilizer products, it is very critical that for all considered crops, co-cultivation of food and energy crops is stimulated in creative integrated mixed farming systems rather than automatically assume that food crops will be replaced by energy crops. It would be a good step if these intentions are also considered in policy development for energy crops.

Figure 7: Status of mineral depletion of soils in West Africa (Bindraban 2009)

The produced energy carriers have to compete or their use integrated with the local energy sources being used at this moment in the region, which are either from traditional biomass (crop residues, waste, dung, wood) or from mineral sources (diesel, gasoline and gas). The cheapest sources are traditional biomass, while mineral sources are relatively expensive. There is a relation between the income of a family and the energy sources they use for their needs (figure 8).

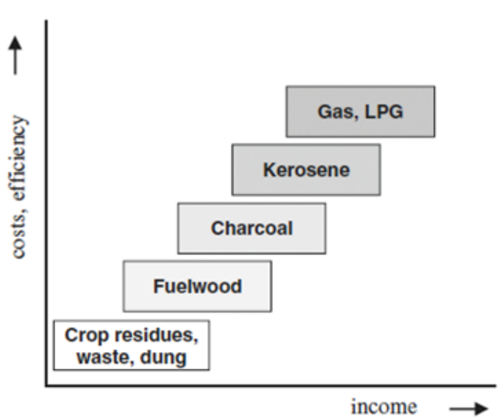


Figure 8: Fuel use is related to income in Africa (2012 Smeets)

In figure 9 the retail prices for several energy carriers from mineral sources in the ECOWAS region are given. It is very important to realize that in a number of ECOWAS countries, the state governments are subsidizing retail prices of mineral energy sources significantly. This is costing the country in two ways: it has to use its valuable hard currency to buy mineral energy sources and subsequently the country distributes the mineral fuels at a loss through the retail network.

This not only puts bio energy sources at a disadvantage compared to traditional fuels, but it indirectly also hampers the development of a local biobased economy which is expected to generate income for thousands of people based in the country side. In this context we believe it is very critical to take hard currency values paid by the governments into consideration alongside retail prices as reference framework to determine the short and medium term economic feasibility of the bio energy crops.

Country	2012 price
Benin	1,24
Burkina Faso	1,43
Cabo Verde	2,3
Cote d'Ivoire	1.51
Ghana	0,92
Guinea	1,34
Guinea-Bissau	NA
Liberia	1,17
Mali	1,41
Niger	1,12
Nigeria	0,62
Senegal	1,72
Sierra Leone	1,05
The Gambia	NA
Togo	1,16

Country	2012 price
Benin	1,26
Burkina Faso	1,28
Cabo Verde	1,58
Cote d'Ivoire	1,2
Ghana	0,95
Guinea	NA
Guinea-Bissau	NA
Liberia	1,22
Mali	1,25
Niger	1,12
Nigeria	1,09
Senegal	1,53
Sierra Leone	1,05
The Gambia	NA
Togo	1,22

Figure 9: Pump price for gasoline (US$ per liter), right: Pump price for diesel fuel (US$ per liter) (data.worldbank.org)

Only Nigeria is a big oil producing country, but because the processing capacity is limited, Nigeria still has to import most of its generator, transport and aviation fuels just like the other ECOWAS countries. Therefore, one should expect the price of diesel and gasoline to be positively correlated with the distance to a port. Due to price regulation this picture is not so clear. The differences in policies between countries lead to big differences in pump prices even across borders of coastal neighbouring countries, leading to fuel smuggling in the region. For gas a similar picture emerges. The butane price may be as low as 5.5 FCFA/MJ for Ivory Coast and as high as 11.7 FCFA/MJ for Guinea-Bissau (M. Dianka 2012). Prices for wood for household purposes is just a fraction of the gas price, although in urban areas fire wood and charcoal are becoming increasingly expensive due to limitation and greater distances of supply.

The differences in strategies between countries to regulate pump fuel prices have a direct impact on the economic viability of alternative energy sources, e.g. off grid electricity via photovoltaic or diesel generator systems. Figure 10 clearly shows that for a large part of the ECOWAS region, using current diesel retail prices as a reference, diesel generators are more economical than photovoltaic systems, but this does not take into account that for most of the ECOWAS region over 40% of the national budget is spent on import and subsidy of mineral energy sources. In some countries the oil is taxed, creating an additional source of revenue for the government. This may be a source of financing alternative fuel developments. The rising crude oil prices have a dramatic effect on the GDP-growth of West African states (Oil and gas in Africa, African Development Bank 2009). Therefore, this picture may change dramatically if all regulatory measures are abandoned in time and the dependence on mineral energy resources is decreased.

In addition, the project team believes that the choices for different renewable energy sources is not an "or/or" case but an "and/and" case. If one knows that photovoltaic systems and even more so wind energy farms are only effective during a relatively low % of their operational life due to lack of sun and wind respectively, crop based energy production systems can be perfect complementary systems to buffer the "down" times of energy from photovoltaic or wind energy based systems. This increases the chances that even at a smaller scale decentralized off grid systems can work. (Smart power generation Klimstra J. And Hotakainen M., 2011)

The pressure that high international mineral fuels prices put on national budgets often results in periods of relative scarcity or non-availability, especially in remote places. This results in unreliable supply into the transport sector but also in the public (grid enabled) or private electricity supply. This unreliable supply is further complicated by a lack of infrastructure especially in more remote areas.

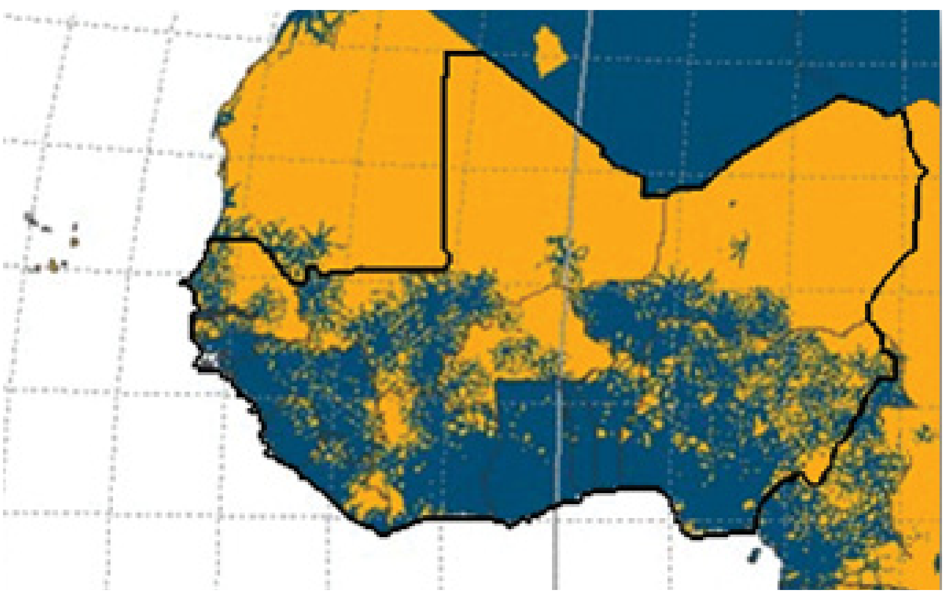


Figure 10: Best economical options for off-grid electricity generations in the ECOWAS region: diesel generators (blue) versus photovoltaic (yellow) systems (S. Szabó 2011)

Besides the regulation of prices for mineral energy sources, one has to take into account that over 70% of the energy used for cooking and heating in the ECOWAS region is still derived from wood or other biomass, which is cheaper but has an impact on deforestation, costs a lot of time to collect and causes health problems for especially women and children (2011 AFREA). On the other hand, new mineral energy sources are being prospected (figure 11) and offer an alternative for energy from agricultural sources in a region where food security is not evident due to regular occurring periods of drought. It is in this setting that renewable energy sources have to be evaluated on grounds of economic,

Figure 11: Oil (black dots) and coal (grey dots) reserves in West Africa (2009 African Development Bank & African Union)

environmental and social sustainability and on grounds of more reliable energy supply. The direct and indirect impacts that these developments can have on local economy and poverty alleviation programs also form a very important element for consideration.

It goes without saying that the establishment of the suggested mixed farming systems need to be done in a sustainable manner.

In the first place internationally accepted criteria need to be respected when it come to social and environmental sustainability. It is obvious that basic human rights need to be respected when developing commercial farming operations growing mixtures of food and novel bio-energy crops or when establishing out-grower networks with similar goals of mixed farming.

In this instance international regulations like ISCC rules on human rights, health and safety and labour rules can form an important guidance for project implementation.

As for environmental sustainability, conservation of HCV (High Conservation Value) areas or high carbon stock areas are critical on these mixed farms; just like the production of food and energy is integrated in the farm management, proper management of possible HCV or high carbon stock areas as an integral part of the management of the project is also critical.

The project team does want to caution though that emerging projects are not overloaded with a heavy administrative burden when it comes to environmental or social sustainability management. Western society has always the tendency to develop strong and elaborate systems from day one because that became the norm for Western society; the project team believes it is very critical to establish from DAY 1 a base layer of sustainability management that can be further developed in the future once the project becomes self-sufficient and economically sustainable but should not be killed by heavy administrative burden from DAY 1.

In the project we have also developed a project assessment tool, which has been applied on a number of Jatropha projects as illustrated in Appendix 2. This tool forms a first qualitative assessment tool to compare a number of existing projects around a crop in a given area. It incorporates factual data, a first economic assessment aswell as environmental and social sustainability factors. It also explores the current state of the project in its research efforts and in its potential role as a demo project possibly in collaboration with local universities. The tool also contains a module that assesses the country in which the project is operating, allowing the users to identify gaps at a higher level and at the level of policy, overall infrastructure etc that hamper the development of novel bio-energy crops.

The tool can be used in telephone interviews, in face to face interviews but even better on the basis of site visits. The tool can also be used to measure progress in a qualitative manner in certain projects/countries over time. The tool is available as a separate excel document in Appendix 6 to this report.

4. JATROPHA CURCAS IN MALI, BURKINA FASO AND GHANA

Jatropha curcas has been around in this region for a very long time but only recently the crop has been considered a bio energy crop. The traditional uses and perception of the crop as a miracle crop has hampered that Jatropha could be developed into a professionally grown, valuable alternative for farmers and an economically viable energy crop.

Traditionally Jatropha plants have been used by small holders for hedges to protect vegetable gardens against animal grazing. The dense planting of these plants however, results in very low levels of fruit production making it uneconomical for farmers to collect. Moreover, Jatropha with its reputation to survive harsh conditions and dry periods has been planted in a very wide climatic range. In a lot of drought stressed areas, it has been shown that the production of fruits is suppressed.

Recently, many publications have shown that Jatropha grains indeed have high oil content with a quality that is very versatile in use. However, it is imperative that the plant has optimal climatic conditions (temperature AND rainfall) in order to produce economic quantities of grain and oil. Additionally the plant needs fertilizer input and proper canopy management practises.

Unfortunately a lot of “believers in Jatropha as a miracle crop” still ignore these realities and continue to promote planting the crop in “marginal areas with limited management practises” as a way to make quick money for farmers. With the current knowledge available on the crop, this is very irresponsible. Farmers who have been advised to follow this strategy, especially in large portions of India (for long considered the cradle of knowledge for Jatropha) have failed completely and in most cases they have abandoned the crop. More than 90% of the planted ha of Jatropha have failed and have prompted the federal government to reconsider its strategies around the crop.

4.1. Processing

In figure 12 the traditional processing of Jatropha curcas is summarized. The major underlying driver of this crop with regard to bio energy is the oil content of the seeds. In the majority of projects today, the crude Jatropha oil is obtained by classical seed-oil pressing processes. The crude Jatropha oil (CJO) can be used directly in low-speed diesel engines either to generate off-grid electricity or to drive tractors. The CJO can also be converted into biodiesel using a trans-esterification process with methanol, delivering glycerol as by product. The biodiesel produced is suitable for fuel in vehicles with high-speed diesel engines. The glycerol can be used in soap production, cosmetics or for combustion.

Extra bio energy can be obtained when the crop residues are being fermented to biogas. In this case fruit coats and press cake are added to other agricultural waste, cattle manure and human waste to a bio-digester. The produced gas can be used for cooking, lighting and heating. The remaining slurry is rich in minerals and can be returned to the field as a fertilizer. Another way to increase the energy yield is to turn fruit coats and seed cake into charcoal and use that for cooking and heating.

QUINVITA is convinced that in the short term fruit coats and seed cake can and should be used as a fertilizer and soil conditioner given the overall state of the degraded soils in the region. With the current knowledge, we believe there is an opportunity to upgrade the degraded soils back to a status that allows their use for food production and/or bio energy crop production.

Some people have questions concerning the biodegradability of phorbol esters in the soil when using Jatropha seed cake as a fertilizer and a soil conditioner. Srinophakun et al. (2012) have demonstrated that Jatropha seed cake can be used successfully for these purposes without any evidence for presence of phorbol esters in the food crops. Phorbol esters are readily degraded in soil (Devappa 2010). From a logistics point of view it is critical to organize the project in such a manner from day one that not only the Jatropha oil can be deployed in a centralized manner for e.g. electricity use but that also the seedcake finds a nearby market for use. The best is to use the seedcake as part of the local trading of Jatropha grains with farmers that grow food-and energy crops. Delivery of Jatropha seedcake should be an integral part of the grain collection system in outgrower networks. In larger scale food and energy farms, the recovery and use of the seedcake on the Jatropha and food production blocks is of course less challenging.

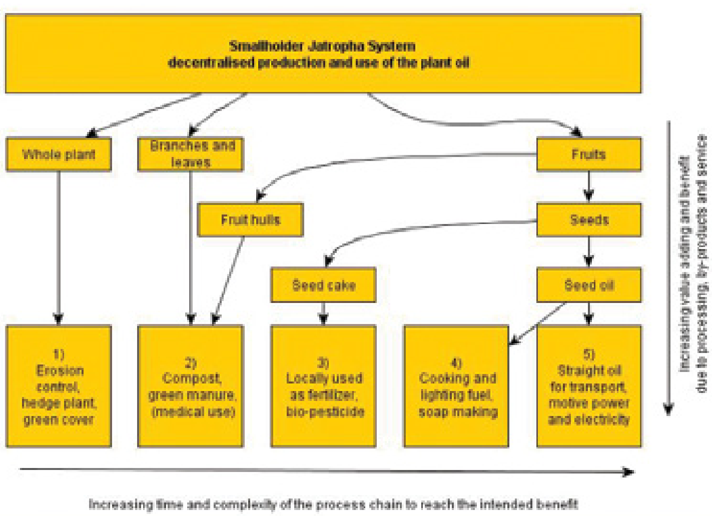


Figure 12: Production and use of Jatropha curcas plant parts (F. Nielsen 2012)

4.2. Mass and energy balance

Assuming that black fruits are harvested from the Jatropha trees, 1 ton of fruit delivers ca. 420 kg of fruit coats and 580 kg of grain. Assuming that the oil content of the grain is around 34%, a classical crushing process would turn 1 ton of grain into 270 kg CJO, 700 kg of cake and 30 kg of filter waste. Practical experience shows that the artisanal crushers used for grain processing in outgrower networks deliver 20 25% CJO from a 1000 tons of grains. The larger scale and more professional crushing units used by the larger projects do deliver 28-30% oil recovery levels. One kg of CJO can be transformed into 1 kg of biodiesel or 1.6 kg of soap.

The energy value of the various components is given in the table below.

Component	Energy value for combustion (MJ/kg)
Fruit coats	11.1
Grain (34% oil)	25.5
Oil	39.8
Press cake (10% oil)	25.0
Charcoal (wood, cake)	26 - 30

4.3. Current projects

The current projects on Jatropha in Mali, Burkina Faso and Ghana are given in figure 13. The estimate of the surface of plantings in Mali and Burkina Faso occupied with Jatropha plants is based on interviews with operators and the information that typically, farmers have planted about 30% of their farm base in a mixed cropping system with Jatropha trees. The total surface of Jatropha trees is therefore estimated at 24,000 ha in these two countries.

In Ghana the planting of Jatropha is based primarily on managed plantation models, allowing a more accurate estimate of planted ha. The total surface of Jatropha plantings under managed plantations in Ghana is estimated on 7,600 ha. We have not analyzed in detail the outgrower planted Jatropha in Ghana.

In appendix 2 a first preliminary project assessment has been done based on the project assessment tool developed for the project. The planted acreage in all 3 countries does not take into consideration the plants in traditional hedges. In all cases the seedlings used to plant the Jatropha plantings in these 3 countries were raised primarily from locally available seed that was not tested or selected for (high) oil content. In some cases, some first planting was done with seeds of selected cultivars. Some of the projects are also doing agronomy research trials either on farm or in collaboration with some of the local agricultural research centres (see further). The majority of Jatropha is co-cultivated with food crops or cash crops. In Ghana the original plantings were monoculture Jatropha plantations but several projects are starting to consider a mixed farming model with Jatropha and food/cash crops grown in interspersed blocks. In Mali and Burkina Faso, Jatropha is sometimes grown as a distinct block on the farm but in most cases, the plants are planted in a hedge pattern. As indicated before, experience has shown that Jatropha crops that are planted too densely do not result in economical yields of Jatropha fruits. In Ghana, most of the Jatropha is grown in managed plantations and in general seem to be planted again too densely to allow maximum yields.

Based on the suitability maps presented in previous reports, half of the projects in Mali and Burkina Faso seem to be in the suitable Jatropha growing areas. The other half of the projects in Mali and Burkina Faso seem to be in areas too dry for optimal production of Jatropha fruit, a clear relict of the “miracle crop syndrome”. In Ghana most projects are in suitable areas from a climate perspective.

Most of the projects in Mali and Burkina Faso are based on out-grower models; some of them are plantations. In Ghana most plantings are managed plantation models. Yields per ha per year vary a lot. Data were found to range between 100 kg/ha for hedges (confirming our observations above) to 3,000 kg/ha for mature plantations. In this area Jatropha is co-cultivated with groundnut, sorghum, cotton, maize, soybean and sunflower.

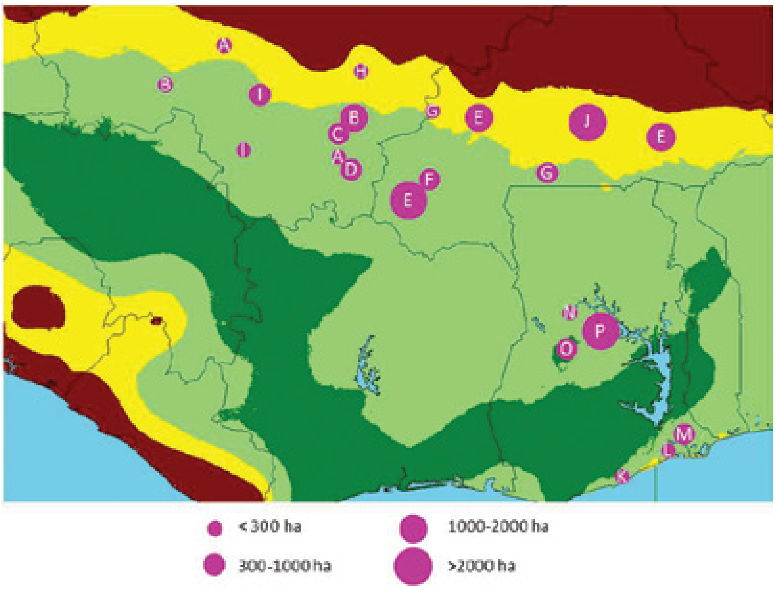


Figure 13: Location of Jatropha curcas projects in Mali, Burkina Faso and Ghana

A Mali folkecenter	**I Mali biocarburant**
B JMI	**J Belwet**
C Geres	**K Symboil**
D Sudagri	**L Bionic Palm**
E Aprojer	**M Galten**
F Fasogaz	**N Jatropha Africa**
G Faso biocarburant	**O Smart Oil Ghana**
H AEDR	**P Kimminic**

In Ghana one of the operators recently established a biodiesel factory (Kimminic) with a capacity of 45,000 ton/year. This is one of the larger commercial units in the ECOWAS area.

Most of the Ghana projects are not in a productive stage yet or have just started the crushing of the first batches of grains. In these cases, Jatropha oil batches have been sold for a range of “Jatropha oil use” experiments to international operators (use as a lubricant; use as biodiesel feedstock; use as feedstock for biojetfuel etc.). In these cases prices of 1,000 USD/ton plus have been obtained CIF Accra.

After an initial investment, most projects in Ghana have arrived at a stage where further growth needs to be financed and are in a re-financing stage.

The project team is also aware of a number of Jatropha initiatives in other countries of the ECOWAS region. In Senegal a number of Jatropha planting initiatives were taken despite the fact that the project team believes that only a limited area of the country (south of the Gambia) is suitable for professional growing of Jatropha. This probably explains why most existing projects have either been stopped or are not delivering the expected yields. One initiative is intriguing: the company Neo SA (French investors) has established a Jatropha crushing facility (12,000 ton/year capacity) close to the city of Gossas, 180 km inland from the Dakar harbour. According to the project team this facility is located in an area that is not suitable to cultivate Jatropha professionally. It does represent, however, one of the most professional Jatropha processing facilities in the ECOWAS region.

It is a prime example of how business decisions have been taken in the region without alignment between the agricultural activities and the downstream processing activities for the crop. It also illustrated why a study like the one presented here is essential in achieving these alignments.

Using the project assessment tool we have developed in the project we did a first assessment of the different projects on hand in Mali, Burkina Faso and Ghana, not judging right now on the business model (managed plantations vs. outgrower network).

Based on this assessment the following projects are most advanced:

In Mali the projects of JMI and Mali Biocarburants are most advanced from an agricultural point of view and in terms of alignment of the end uses of the oil and the seedcake with the state of the project.

In Burkina Faso, the project of Belwet, although unfortunately located in a more suboptimal area to grow Jatropha has done remarkable efforts of aligning the oil and seedcake use with mixed cropping models of farmers who are members of the Co-op. Aprojer has project areas in suitable and less suitable zones and has also developed a professional structure for agronomy support.

In Ghana and based on a first preliminary assessment, the Galten, Smart Oil Ghana and Kimminic projects are most advanced agronomically. All these projects have planted at least 400 ha of Jatropha and up to 5000 ha. Kimminic is also in the process of implementing a professional crushing and biodiesel factory. One of the challenges most of these projects cope with is logistics with a relatively large distance from larger end use markets like Accra. Integrated food and energy farming models where local food can be produced and processed using Jatropha seedcake as a fertilizer and the oil as an energy source and where the surplus oil can be used for decentralized electricity production are business models that can be considered to turn this challenge into an opportunity. These structured projects also form the best options for centres of excellence for further technology testing and transfer and for the roll out of an outgrower network around the centres of excellence.

4.4. Economic Evaluation

For an economic assessment of the Jatropha projects in the region it is critical to make a distinction between the business model followed by the Jatropha operator: managed plantations (primarily the model followed in Ghana) or outgrower networks (models applied in Burkina Faso and Mali). Economic viability of Jatropha projects will depend very much on grain yield/ha achieved in managed plantations or in the outgrower fields. Table 3 summarizes the current and future vision of Quinvita on achievable yields of professionally cultivated Jatropha at maturity (5-6 years after planting). It is critical to realize that most projects we have considered and assessed here have only recently started to plant Jatropha in a more professional manner; traditional Jatropha hedges are expected to deliver yields that are very low (< 1 ton grain per ha) and should only be considered as add-on harvesting opportunities and not as goals by themselves. Yields in professional outgrower networks of 1, 5 ton grain/ha and over time up to 2-3 tons grains/ha at maturity should be possible based on the current knowledge and available genetics. In managed plantations these yield levels can be doubled on a per ha basis. One can see that production economics of managed plantations that produce 5 ton/grain and upwards are becoming very attractive propositions.

Yield at maturity (ton/ha)	outgrowers	Managed plantations	Production cost CJO in managed plantations
By 2017	1,5	3	>1000 USD/ ton
By 2020 (advanced OP seed)	2,5	5	500-600 USD/ton
By 2023 (F1 hybrids)	3-3,5	6-7	< 450 USD/ton

Table 3: yield per ha and corresponding production cost (for managed plantations) of CJO (Crude Jatropha Oil)

In the outgrower model, operators provide seedlings and agronomy advice to a network of small farmers under a service contract. They buy back the harvested grain from the farmers. In Mali and Burkina Faso, buying prices for harvested grain used to be 50-65 FCFA/kg (2011) but these recently went up to 100-150 FCFA/kg (2012-2013) as a result of higher pricing by certain players in the market. In some cases some operators even offered uneconomical prices of 300 FCFA/kg putting a lot of pressure on the market. Assuming 4 kg grain is needed to expel 1 litre of oil, the feed stock costs for the oil is 400-600 FCFA/l before crushing costs. At an average of 500 FCFA/l for feedstock and a crushing cost of 50FCFA/l the CJO cost without logistics for grain collection is 550 FCFA/l. Esterification cost of CJO into biodiesel amounts to another 50 FCFA/l and brings the cost of production of biodiesel to 600 FCFA/l without logistics costs. Knowing that the retail fossil diesel price in this region varies between 600-650 FCFA/l, Jatropha grain can hardly be used to produce biodiesel at prices competitive to the subsidized diesel price. Comparable subsidies for biodiesel as an introductory policy, would overcome this inequality. Indeed, Biodiesel based on the above pricing assumptions is competitive with unsubsidized fossil diesel prices.

Most of the oil today is being used for the production of soap that is sold at 1,700 - 4,000 FCFA/kg or in generators as CJO for ca 600 FCFA/l. In these cases operators can make a (small) margin.

The press cake is being sold at 60-70 FCFA/kg for fertilizer.

For small farmers, it is very critical to see the Jatropha income as an additional income over and above their other farming activities. With the current estimated yields of maximum 0.5 kg of grain per tree and 500 kg per ha, farmers can make an additional 500,000 FCFA on a yearly basis by collecting the Jatropha grain. In case yields per ha can be elevated over time to 1.5 tons of grain/ha this additional income could be 1.5M FCFA per ha. We believe this is the incentive needed for farmers to start considering Jatropha as an integral part of the crop mix on their farm. These yields can only be achieved with better genetics and better agronomy support to the farmers.
In the managed plantation model, current plantations (in Ghana) have the potential to deliver a Jatropha crop of 3 tons of grain/ha. At this revenue base the cost of production of the crude Jatropha oil is at maturity 1,100 USD/ha, the current selling price of a number of "experimental lots" sold to European end users in the electricity, biodiesel or aviation fuel sectors. At this price the production cost for local biodiesel reaches 520 FCFA/liter of CJO. This is again borderline competitive with fossil diesel prices if an add-on conversion is needed to biodiesel.

The production cost for seedcake is 70 USD/ton and this is an interesting cost base to commercialize the seedcake as a local fertilizer/soil conditioner and represents an extra revenue base for the Jatropha operator.

The goal of the Jatropha operators, however, is very simple: if the yield per ha can be increased to 5 tons of grain/ha by planting better genetics and by applying professional agronomy, then the cost base for the CJO ranges between 600-700USD/ton. The corresponding price of CJO is 320 FCFA/litre, a very competitive price for a range of applications.

4.5. Evaluation of R&D activities on Jatropha in the target area

In appendix 3, an overview is given of the public research institutes performing R&D or publishing on the crop in ECOWAS area.

As early as 1987, the German organization GTZ started Jatropha research activities on Jatropha genetics and agriculture in the ECOWAS region (Mali). The results of this first project are summarized on GTZ-Projects (1987 – 1997).

More recently a number of research consortia were created:

A Europe funded program involving the university of Copenhagen, Institut de l'économie rurale in Mali and Mali Biocarburants in Mali, and French initiatives (JatroRef) involving GERES from France and local research groups in Mali, Burkina Faso and Benin followed. More recently the French funding agency ADECIA decided to fund a number of selected private research efforts in Mali and Burkina Faso.

Another EU funded program is being developed in Ghana with local research institutes. The Ghaja project has an overall goal to use the Jatropha plant to improve sustainable renewable energy development and create income generating activities. It is meant to be an integrated approach to ensure sustainable livelihood conditions and mitigate land degradation effects in rural areas of Ghana. (http://www.ghajaproject.net)

In all cases, the initial research focused on agronomy aspects and testing local Jatropha genetics in the field. Unfortunately, most of these programs suffered from the miracle crop syndrome that contaminated the objectives of the early Jatropha development programs. People started from the acquired assumption that Jatropha could survive AND be productive for oil under very marginal climate and soil conditions. No pre-emptive research was done to confirm whether this hypothesis was indeed correct. We know in the meantime that Jatropha can indeed survive harsh conditions but that it needs optimal conditions and management for economical production of Jatropha oil and co-products.

In addition we also know that so called local varieties of Jatropha may survive local conditions as hedges or as an anti-erosion plant but a lot of these varieties have proven to be poor producers of grain and oil.
For these reasons there is an urgent need for the consolidation of ongoing research programs and a need to focus these programs in suitable areas, with genetics selected for high oil productivity and with professional agricultural practices.

The JatroRef and the ADECIA funded programs still have the opportunity to redirect their objectives towards these goals. The advantage of the Ghaja project is that the majority of zones in Ghana are suitable for Jatropha.

4.6. Logistics for Jatropha operations in the region

We have analyzed in more detail the target areas for Jatropha production in the context of the proposed mixed farming operations. Assuming that collection areas of a 100 km diameter are feasible for outgrower networks (the preferred business model for Mali and Burkina Faso), we see logical professional production cycles to be developed around the following major agricultural production centres in areas that are very suitable for Jatropha: Sikasso in south west Mali and probably a second circle north of there.

Bobo- Dioulasso in south east Burkina Faso and a few circles more south of there (Dano etc.).
Projects that are located in Mali close to Bamako and, in Burkina Faso around Ouagadougou and north of there, will be economically suboptimal in the opinion of the project team.

It is encouraging to see that the some of the projects (JMI, SudAgri, Aproger, Fasogaz) are already in the correct areas of adaptation and can be used for further development and as primary hubs in collaboration with the local universities as training and demonstration hubs for further crop and project development.

All these projects do have proximate markets where oil and meal products can be sold.

In Ghana where the preferred business model is managed plantations, the projects south of the western arm of the Volta Lake are the preferred projects for further development. The projects of Kimminic and Smart Oil Ltd have the correct critical mass and professional approach for further development. The proximity of the Volta Lake adds an interesting opportunity for across country shipping logistics and longer term (if appropriate) even for export shipping. Indeed, investment efforts are ongoing to build a pipeline from the most southern point of the Volta Lake (the Akosombo Dam) to the deep sea port of Tema. This allows further distribution by boat or over land also to Accra.

4.7. Observations and conclusions

In Mali and Burkina Faso, the project team identified 9 projects with a good professional basis and a more or less developed agricultural extension support. Most of the projects are based on out-grower systems. With an average planting density of 1,000 trees/ha, the projects translate into 24,000 ha of planted Jatropha. Most of these planted ha are integrated in existing farming operations in mixed farming concepts.

In most cases there is already some capacity to crush smaller to larger quantities of grain into oil and seedcake. The oil is currently primarily used for soap production (a smart way of incentivising women in the local communities to work on the crop) or as a drop-in fuel for generators. Some projects have the capability and infrastructure to produce biodiesel via esterification but the pricing subsidy on fossil fuels makes the production of biodiesel from Jatropha (without equal subsidies) not economical.

Given the current economics of the crop and its competitiveness with other cash crops, the project team believes that the extension services need to be intensified in order to bring the yields to over 2 tons of grain per ha (at maturity 5-6 years after planting). The yield levels today are in most places below 1 tons of grain per ha. At current prices farmers would make maximum 500K FCFA per ha of harvested Jatropha.

An important value added component of the Jatropha production chain is the seedcake, which is used in a lot of projects as an organic fertilizer. The use of Jatropha seedcake on food-or cash crops has a number of benefits for the projects and for the farming community growing the crop.

a) In times where mineral fertilizer is becoming more scarce and expensive, Jatropha seedcake can be a very interesting complementary source of nitrogen fertilization.

b) A lot of the soils in the ECOWAS region are very poor in organic matter content; this can again be complemented with the Carbon residing in the Jatropha seedcake. We believe this can present an opportunity to upgrade the quality of large acreages of degraded soils and can have a beneficial effect on overall productivity of agricultural soils in the area. Some projects we have talked to start to show these beneficial effects.

c) Integration of Jatropha into mixed farming systems and the use of the cake for the purposes described and the oil as an energy source to drive food/cash crop processing and storage, forms a clear opportunity for a smart co-cultivation of food and energy crops. This forms a clear argument against the food vs. fuel discussion frequently occurring on popular networks.

The project team has been very impressed with the efforts in Mali to gather the industry, government and farmers' interest in one platform for discussion, decision making and policy development. It is indeed critical that the public and private sector players gather in this kind of platform and discuss technical, financial and political matters related to both the agricultural and the industrial aspects of these complex projects. Bio energy projects often focus too much on end use infrastructure development and forget the absolute necessity to have a strong agricultural base to the project. Likewise, some projects have started agricultural production of bio energy feedstock without the (financial) commitment for the investment into down- stream processing capabilities. Both activities need to be developed hand in hand for projects to be successful.

In Ghana, the current managed plantations produce to a maximum of 3-4 tons grain per ha on some isolated blocks. Most of the projects are currently involved in add on financing/funding routes but have a very good potential for further development. The projects of Kimminic and Smart Oil Ghana are actively planting and are clear focal points to be developed into centres of excellence for further successful development of the crop. The current project economics are suboptimal due to the current low yields. These lower yields are the result of a number of factors: suboptimal financing of the projects led to lower input applications; at the moment of the planting of the current productive ha, the agronomy knowledge for these plantations was still underdeveloped leading to suboptimal canopy management and nutrient management practices. In addition the fields were often planted with non-selected or limited selected genetics and we know that grain yield and oil content are traits that are strongly inherited genetically in Jatropha. It will be crucial that newly planted ha plant better Jatropha cultivars with adapted agronomy practices. Yields of 5 tons of grain at maturity can then deliver crude Jatropha oil at a cost of 600 700 USD/ton. In addition, in smart integrated food and energy farms, the Jatropha seedcake can be used on the spot and can generate additional income early in the project lifetime under the form of productive food crops. The project of Smart Oil Ghana has recently entered into a contract with QUINVITA to further improve the yields of the crop.

Another important element that needs to be considered strategically is the end use diversification for both the oil and the seedcake short and longer term.

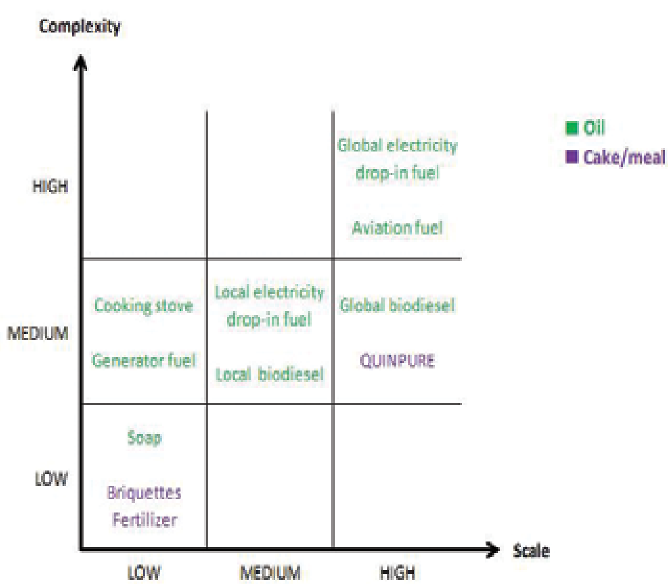


Figure 14: Jatropha end-use applications

Figure 14 shows a number of optional end-use applications for Jatropha derived products. A lot of the original Jatropha large scale projects were launched with the goal to become large production machines for exporting oil into Europe as electricity or biodiesel feedstock. It now becomes clear that these are only options when sufficient economy of scale (5,000 ha plus) has been combined with productivity per ha (5 ton/ha plus). In the stages where ALL Jatropha projects are today, local deployment of the oil and the seedcake has to be favoured. Therefore it is absolutely essential that the products derived from Jatropha (oil, seedcake as fertilizer) are not put at a competitive disadvantage vis-a-vis fossil fuels and fertilizers due to subsidy policies of the government. At a minimum, similar subsidy schemes have to be applied on Jatropha derived products compared to fossil products. In addition, however, creative marketing should be allowed to create additional value in the Jatropha chain:

Use of Jatropha oil as a feedstock for soap, candle or oil lamp production or as a feedstock for cooking stoves and use of seedcake as a feedstock for e.g. mushroom production or as biomass for the production of briquettes as an add-on energy source over and above wood and charcoal are just some examples where projects can make money in a build up stage of the project.

To that extend, economic synergies can also be achieved in co-cultivation projects of food and Jatropha. In a project we are analysing for start in Togo, we have demonstrated that the use of Jatropha oil as a local energy source for storage of e.g. corn grains can increase the value of the corn for the co-operative with whom we are working by factor 2-3; if the energy can be used at a later stage for fuelling local processing facilities, this can increase to a factor 5-6. This would be a formidable example of poverty alleviation and local empowering of organized farming communities.

It is the challenge of the ECOWAS policy makers to create an environment where the development of bio-fuels is supported alongside the budgetary efforts of the different countries to reduce their dependency on hard currency hungry fossil fuels. Bio-fuels will never replace fossil fuels but a 5% replacement can already represent a major saving on the hard currency deficit of the ECOWAS countries. Smart policies that promote integrated production of food and energy rather than continue to emphasize the induced and perceived “food vs. fuel” issue can further enhance these policies.

The active support of selected, professional projects like the ones described above in conjunction with the development of centres of excellence which can function as examples in the country and for the region at large is one way of enhancing the development of bio-fuels in the country. At least 3-4 projects are on their way to demonstrate this business model successfully.

5. SWEET SORGHUM IN SIERRA LEONE AND NIGERIA

Sorghum belongs to the Poaceae (grasses) family. It is a C4-crop that has a high radiation and water use efficiency with regard to the production of biomass. In general 4 different sorghum types are recognised:

• Grain sorghum. Relatively small plants (< 1m) that are grown for the production of grain rich in protein and used to prepare flour, which is subsequently used for the production of bread or beer. Sometimes the grain is also used in animal feed.

• Fibre sorghum. Tall varieties grown for their stems, which are rich in cellulose and hemi-cellulose and used for the production of paper or board.

• Forage sorghum. Tall varieties with a high protein and fibre content in the stems. These are grown for the production of hay, which is used as an animal feed.

• Sweet sorghum. Tall varieties having thick stems with high sugar content. These are grown for the production of sugar from which alcohol can be obtained after fermentation and distillation in a process similar to the production of alcohol from sugarcane.

Sweet sorghum has attracted a lot of attention due to the capacity to produce 2.5-3 tons of ethanol per ha annually without irrigation in Brazil, Southern Europe, and USA. These figures were realised in either a single slow maturing crop or in a double fast maturing crop. In East Africa using a double cropping system with additional irrigation, even six tons of alcohol was obtained in research trials. However, in West Africa similar research trials using a single cropping system without irrigation yielded 1.5-3 tons of alcohol per ha per year.

ICRISAT has developed new varieties that are suitable to grow in semi-arid tropics and do accumulate high sugar levels in the stems, according to the school of thought that one should make Grain Sorghum into a sweet variant, while maintaining the option to also harvest the grain. This is completely logical within the mandate of ICRISAT that develops crops for farmers operating in semi arid regions. It is however not yet proven that in these areas, "sweet grain sorghum" will, under low rainfall patterns, produce economical levels of stems and sugar. In addition it has been demonstrated that the production of optimal sugar yield in the stems is not synchronized in time with optimal grain production.

When the panicles are removed, stem sugar concentration is much higher. When the panicles are left on, stem sugar concentration starts to reduce when panicles ripen (figure 15).

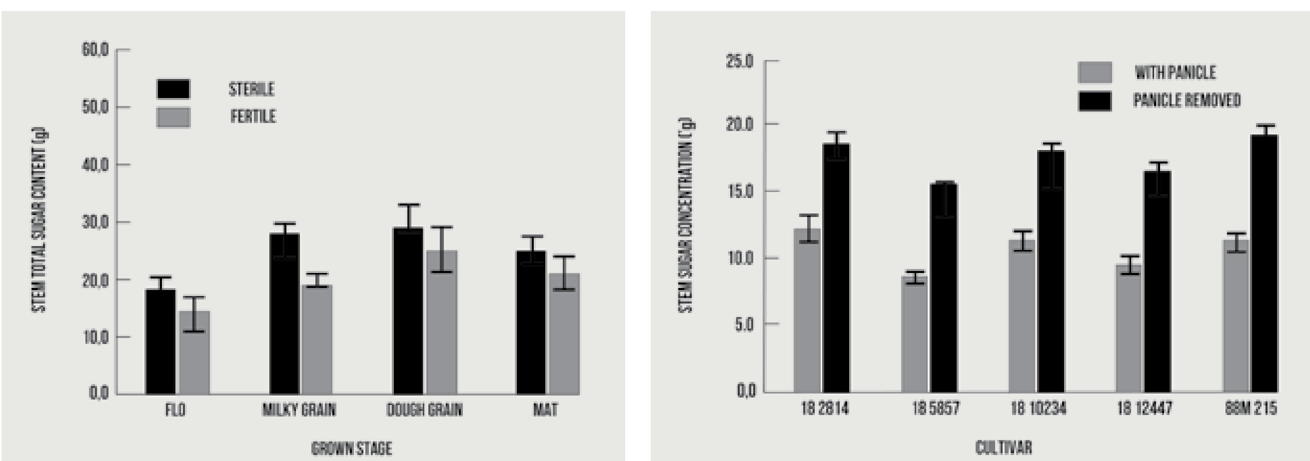


Figure 15: left: sugar content in stems at various stages of panicle development and right: with or without panicles for various varieties (2010 Gutahr)

However, even when the panicles are removed, the sugar content in the stems is less than the total sugar content of stems and panicles of intact plants, giving rise to the thought that the sink activity of the stems may also be a limiting factor.

In Brazil dedicated sweet sorghum hybrids have been developed by public and private breeding groups and are tested in co-cultivation schemes with sugarcane plantations. These schemes show a lot of promise because sweet sorghum can be cultivated on the 20% land base, which is left one year fallow on typical sugarcane estates. In addition the timing of the sweet sorghum harvest can be synchronised with the downtime of sugar mills when sugarcane harvesting season is over. This way, sugar and ethanol plants can be used optimally. We are investigating the potential to develop similar co-cultivation schemes in ECOWAS countries growing sugarcane and transforming it into ethanol.

In West Africa, however, only research trials have been performed with sweet sorghum. Commercial planting on a significant scale has not been done yet. The research clearly indicated that further development of the crop is necessary. There is no commercial seed available of “appropriate and well-defined cultivars for extensive production systems, adapted to different environments, soil conditions and available agro-techniques” (Zegada-Lizarazu and Monti, 2012). The quality of the available planting seed is low. The current varieties have a poor cold tolerance at an early stage of development, which gives a problem in the more Northern part of the region during cold nights. They also have a considerable lodging sensitivity, which may cause big losses. No information is available on the best agricultural practice per variety/region combination. Unlike sugarcane, sweet sorghum cannot be used to produce sugar, because it gives problems with sucrose purity, so it’s only large scale destinations are ethanol and animal feed and on a small scale sweets for children, one of the current uses of sweet sorghum in West Africa.

Like in Brazil, it would be logical that existing sugarcane plantations test the use of dedicated sweet sorghum as a companion crop to sugarcane. If this test is successful, it overcomes a number of challenges that the introduction of this new crop bring along:

1. Heavy capex burden for sugar into ethanol operations.
2. Limited transportability and accompanied logistics issues of sweet sorghum leaves and stalks.
3. Introduction of a rotation crop for sugarcane.

In the model where sweet grain sorghum is developed, the logistics challenge to harvest and process in time sufficient quantities of sorghum leafs and stalks grown in small or larger farms in combination with the challenge of economy of scale that sugar into ethanol plants represent major hurdles that need first carefull consideration before they are implemented. In this case one also does not have the ‘’add-on’’advantage of a logical sugar companion crop as these areas are too dry for sugarcane cultivation.

5.1. Processing

The processing scheme of sweet sorghum is given in figure 16. The optimal sugar concentration in the stems occurs only during a short time interval before the grain matures and, therefore, has to be monitored closely, leading to a very short harvesting season (around 30 days) and big peaks in labour and processing. To avoid these, slow and fast maturing varieties with various planting dates have to be developed for the optimal growing regions. Like sugarcane, harvesting has to be done mechanically to do it quick and reduce labour costs, but no specific harvesting equipment for sweet sorghum has been developed yet, although this is in progress.

Once harvested, the stems have to be transported to the processing plants immediately. The high moisture content of the stems (ca. 70%) leads to high transport costs. The stems can hardly be stored without significant loss in sugar content. A decay of 15% in sugar content of the stems within 1-3 days has been recorded. In the plant 10% water is added and the sugar rich juice is squeezed from the stems. The remainder of the stems, the bagasse, has a relatively high lignin content, which limits its value for animal feed purposes. Alternatively, it can be used to generate electricity or ethanol as well although the latter demands cellulosic ethanol conversion technology which is still under development and is not yet commercially available for applications on an industrial scale in ECOWAS countries.

The stability of the juice is low, so the juice has to be fermented immediately. After fermentation the ethanol is distilled leaving a vinasse that can either be used to generate biogas or directly be used to generate electricity.

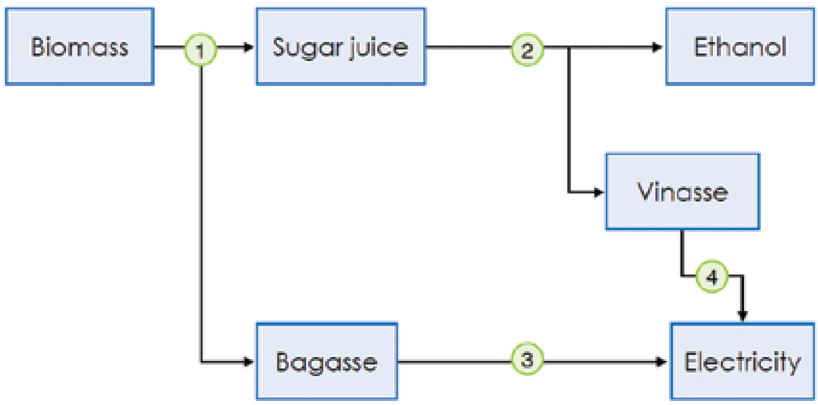


Figure 16: mass stream in sweet sorghum processing (Sweethanol 2011)

5.2. Mass balance

The mass balance of sweet sorghum processing is given in figure 17. Per ha per year 2 tons of grain and 50 tons of stems are harvested using 2 crop cycles. This can be achieved in the regions where sweet sorghum is grown in conjunction with sugarcane. In the absence of additional irrigation, only one crop can be grown and only 25 tons of stems can be harvested annually. This will occur in the traditional grain sorghum belt, which is located more to the North of the region.

Per 50 tons of stems (73% moisture), ca. 5 tons of water is added. Squeezing yields ca. 40 tons of juice (84% moisture) and 15 tons of bagasse (73% moisture). The juice delivers ca. 3,500 l of ethanol and vinasse. The bagasse can deliver another 2,400 l of ethanol. So, the yield per ha per year is close to 6,000 l of ethanol for a double cropping system and half of this value for a single cropping system. The remaining dry plant parts can be used for the production of electricity.

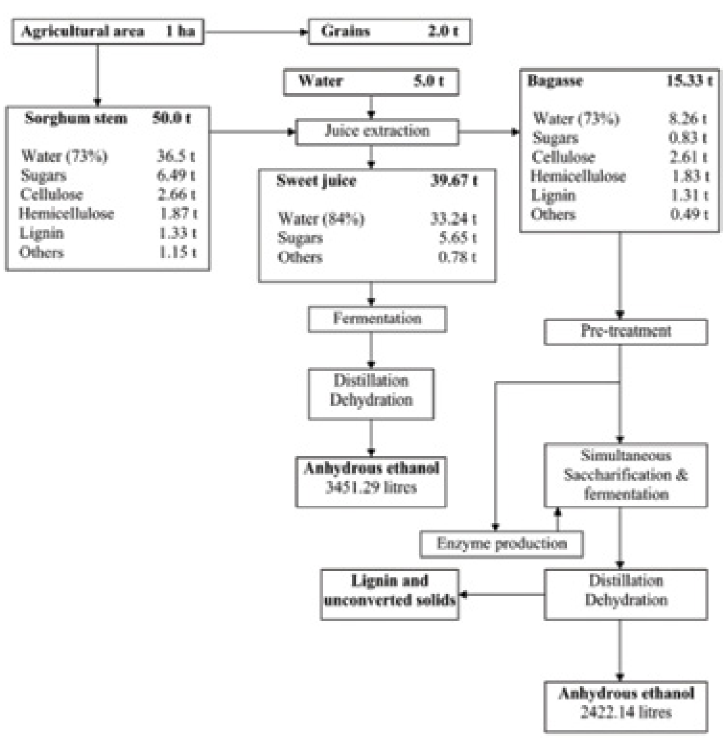


Figure 17: mass balance of sorghum processing to ethanol (Prasad 2007)

5.3. Economic evaluation

From the many questions on the agricultural aspects of sweet sorghum posed in the first part of section 6, it is evident that sweet sorghum is not an established crop yet and, therefore, any economic evaluation for a certain region is purely hypothetical. This is probably also the reason why no commercial projects on sweet sorghum could be found in the region. Also the interest to use sweet sorghum in addition to sugarcane by existing commercial sugarcane companies is negligible. According to several European and Brazilian experts in the field, sweet sorghum is grown at a commercial scale only in Brazil and Haïti. No industrial active in sweet sorghum in West Africa are known today. Also the farmers in the region have no interest in the crop. They grow sorghum for grain and fodder and part of the excess grain is converted in small quantities to ethanol for local use (Braconnier, personal communication). This is however on the bigger scale of things negligible. One of the companies in Nigeria that was very active on the internet until 2009 was Global Biofuels. However, we have not been able to identify a sign of significant field activities today.

Although processing of the stems is a well-established procedure as sugarcane, for sweet sorghum little experience is at hand in the region. Due to the similarities of the process with sugarcane and the knowledge that sweet sorghum stems can be processed in sugarcane mills in Brazil, it is safe to assume that production costs of ethanol from sweet sorghum stems will be similar to the one of sugarcane. However, for the sugarcane process in the region, it is hard to produce ethanol against market competitive prices for butane even if these are not subsidised (Dianka 2011). Ethanol production prices from sugarcane and molasses vary from 9.1 FCFA/MJ to 17.7 FCFA/MJ, while butane retail prices are between 5.5 and 11.7 FCFA/MJ. Gasoline retail prices are higher (14.1 – 22.2 FCFA/MJ), so ethanol from sugarcane may be used as a drop in transport fuel depending on the region. It is important to realize that storage and supply of ethanol into the transport fuel retail network is a challenging business. It may be critical for the countries involved to develop an experience and infrastructure base in this sector first in public transportation and taxi companies.

For the focus region of this study, Nigeria, Ghana and Sierra Leone have the lowest gasoline retail prices in West Africa (figure 9), while Senegal and Ivory Coast have the highest prices. This again illustrates the negative effect that transport fuel subsidies on mineral fuels have on the roll out of bio-fuels in the transport sector. The deployment of ethanol in public transportation systems or concentrated applications in the taxi fleet creates opportunities for equalization between different product types. Today, the ethanol produced in Nigeria and Sierra Leone is not used for transport fuel but for export, beverages and pharmaceutical uses. Use of the ethanol (gel) for clean cooking stoves is also an option, but that is in most places far more expensive than the commonly used wood fuel (1.5-4 FCFA/MJ) and it will depend on the (subsidised) distribution of stoves and income of the people. Therefore, you will find the use of ethanol for cooking only in more urban areas where charcoal is more expensive. Changing the habit of using cooking wood is another challenge that needs to be overcome. A long-term vision on this will need to be taken and school education programs on these practises are one way to enhance this technology. The global clean cooking stove initiative, supported by the Clinton foundation and recently also endorsed by GBEP is spending a lot of resources on possible promotion programs.

In contrast to other bio energy crops evaluated in this study, sweet sorghum does not have much added value in terms of rural employment due to the scale of economy needed to reduce the ethanol production price as much as possible. Of course it will generate a certain amount of high tech jobs at the processing plant, but the investments costs are high and the added value for the rural economy is limited.

5.4. Evaluation of R&D activities on sweet sorghum in the ECOWAS region

In appendix 3, an overview is given of the public research institutes performing R&D or publishing on the crop in ECOWAS area.

The R&D activities in the ECOWAS region to develop sweet sorghum for bio energy purposes are very limited. Several institutes and universities do have activities on agronomy research and extension and breeding and hybrid testing of grain sorghum. These activities are more directed towards cultivation in semi-arid areas in the region due to the adaptation pattern of grain sorghum.

The region is blessed with the presence of one of the ICRISAT substations (in Bamako, Mali). ICRISAT (The International Crops Research Institute for Semi-Arid Tropics) has traditionally focused its R&D activities on crops adapted to semi-arid tropics as defined in its mandate. The headquarters of ICRISAT, based in Hyderabad, India has a strong sorghum breeding program and a couple of years ago, it also started to develop and test sweet versions of the grain sorghum hybrids. In this development model, one assumes that farmers will have a revenue stream from the grains produced on these hybrids and from the ethanol derived from the sweet stalks. The co-products produced in the production process can be fed to animals.

As a result of this development, the WCA ICRISAT unit would be in a very good position to test the potential for "sweet grain sorghum hybrids" in semi-arid regions of West Africa.

This testing should happen in a coordinated effort with other research institutes and universities in the semi-arid areas of the ECOWAS region. Some of these already have ongoing research programs on sorghum (e.g. the CSIR - savannah agricultural research institute in Tamale, Ghana).

Other institutes in the region, like IER (Institut de l'Economie Rurale in Bamako, Mali) and INERA (Institut de l'Environment et de Recherches Agricoles, Ouagadougou, Burkina Faso) can also be involved in testing of genetic material. The Cassava research institutes in Nigeria (IITA- International Institute for Tropical Agriculture, Ibadan, Nigeria and NRCRI, the National Root Crops Research Institute- Umudike, Nigeria) can also be involved in testing as well as exploit the existing know-how on ethanol production.

In the technical discussion on sweet sorghum, we have also referred to a second school of thought on the development of sweet sorghum. In this parallel development path, breeders in different private and public research institutes develop dedicated sweet sorghum hybrids with an adaptation towards sugarcane growing areas. (In general higher rainfall patterns than the traditional semi-arid regions, where grain sorghum is cultivated). In this development path the "dedicated sweet sorghum" hybrids are grown as a rotation crop on sugarcane farms and can be used to fill the idle capacity in sugarcane into ethanol plants which typically exists during a portion of the year.

This business model is under very active development in Brazil. In the USA and some parts of Europe, business models to produce ethanol from sweet sorghum on a standalone basis are also unfolding. Both of these have potential applications in the ECOWAS region. However, since these models are still advancing, we strongly advise the ECOWAS agricultural/energy policy makers to associate themselves with private and public developers of these models.

Agronomy research and active breeding of "dedicated sweet sorghum" is going on in private organizations such as Monsanto and CERES (www.ceres.net) or in public research institutes like EMBRAPA, Brazil or CIRAD, France.
The development of the sugarcane associated sweet sorghum cultivation is being practiced by a number of sugarcane mills in Brazil. A strategic South-South alliance between the Brazilian and selected ECOWAS countries may be one way of further developing this opportunity in the region. If that happens we strongly advise to do this development involving the sugarcane research institutes in the region and the private investors in sugarcane projects.

5.5. Observations and conclusions

Sweet sorghum is not an established crop yet, certainly not in West Africa. The only countries that grow sweet sorghum commercially are Brazil and Haïti. Although sweet sorghum has a great potential to produce large volumes of ethanol per ha annually, many questions on its agronomy, availability of commercial seed and varieties selected for the optimal growing regions are unanswered. Therefore, companies willing to invest in the production of bio-ethanol choose for proven, existing crops like sugarcane and cassava.

In the project we would have liked to analyse opportunities for two models of sweet sorghum deployment in the ECOWAS region: sweet grain sorghum and dedicated sweet sorghum. These need to be considered as almost two different crops as the first one will be more adapted to traditional grain sorghum cultivation zones while the latter will be more adapted to areas immediately adjacent to sugarcane growing areas in higher rainfall areas. Today the cultivation of sweet sorghum in the area is too limited to make this evaluation. The evaluation demands an interdisciplinary approach involving geneticists, agronomists and agricultural economists as well as experts in ethanol conversion technology. We believe that ECOWAS does have a climate very conducive for these crops and could become leaders in exploiting this crop in different ways.

Based on similar models developed in Brazil, there is clear potential synergy between growing and processing sugarcane and sweet sorghum. This synergy probably should be present in the ECOWAS region, where sugarcane from irrigated plantations can be harvested from November to April, leaving opportunities to extend harvesting and stem processing time with dedicated sweet sorghum varieties that mature outside this period. But for the moment, these are not available.

Therefore, the project team recommends developing such varieties in close co-operation with existing sugarcane to ethanol companies, research centres in the region and input from Brazilian varieties, agronomy and processing knowledge.

6. CASSAVA IN NIGERIA AND GHANA

Cassava is one of the staple food crops in the ECOWAS region. Nigeria and Ghana are the largest producers. Unlike some of the other crops under investigation in this project, cassava is a well established crop with a continuous supply of new varieties for various purposes. For the production of ethanol, special high sugar containing varieties have been bred. The new varieties are increasingly being produced by specialised young plant producers, using cuttings from certified mother plants to prevent spreading of (virus) diseases in the crop. The availability of fast and slow tuberizing cassava varieties enables planting and harvesting on a year-round basis. These different varieties provide tuberizing cassava plants in a staggered fashion; in a particular region the growing of a mix of these varieties can not only result on availability of the tubers the year round but can also spread product release on the market resulting in a buffering effect on price. Although cassava is grown primarily for the high quantity of high quality carbohydrates in its tubers, the stems and leaves can also be harvested, dried and stored for use as animal feed.

Cassava is a special crop since it is toxic due to the presence of a cyano-genic glucoside. Proper processing/ preparation of the cassava roots are of the utmost importance to reduce toxicity. Once harvested, the tubers cannot be stored for more than a couple of days. They tend to deteriorate quickly. If storage or transport is needed, the tubers are most frequently being converted to dried chips, which can be sealed in plastic and stored under appropriate conditions for several months.

90% of the harvested tubers are processed in small-scale facilities to local products for the food market. Only 10% is used for industrial processing to generate starch products. The root tubers are processed to various products like starch, garri, wet or dry fufu. Although Nigeria and Ghana are exporters of cassava root derived products, 90% of the production is used locally. Ghana produces enough food to feed its population. In Nigeria the situation varies from year to year. Some years Nigeria has a surplus of production whereas other years primarily due to climate reasons production is lower and does not suffice for local food needs. The northern part of the country is an area particularly vulnerable to regular droughts causing local food shortages in some years.

Nigeria has embarked on a program to transform its agricultural production system after realizing that crop yields stay far behind in relation to Brazil, India and countries in South East Asia (Adesina 2011). In Nigeria and Ghana yields from local farming are close to 10 tons of rootstock/ha per annum. Using new varieties and improved agricultural methods, i.e. fertilizer applications, over 20 t/ha is obtained per annum. In other countries much higher yields are obtained (up to 40 t/ha annually and expected to increase further) and Nigeria has embarked on a program to spread the knowledge and the varieties enabling such yields in the country as well.

6.1. Processing

Using modern farming techniques and new varieties the yield is around 20 t/ha per annum. For every ton of root circa 0.9 tons of dried stems and leaves can be harvested for animal feed. Cassava roots once harvested cannot be stored and they decay rapidly. Because roots contain at least 50% moisture, they are processed to dried chips with only 15% moisture. The chips can be stored if packed well.

Processing cassava roots to ethanol is an established process and seems to be simpler than the conversion of other plant feedstock to ethanol. A typical ethanol production process is SLSF: slurry – liquefaction – saccharification – fermentation. Slurry is produced by grinding root chips and mixing with an equal weight of water. Liquefaction of the starch in the slurry takes place at 105 °C. Then alpha-amylase is added to saccharify the starch at 55 °C, yielding syrup that is fermented with yeast at 30 °C to produce an 8-10% ethanol containing slurry. The ethanol is distilled from the slurry and dehydrated. In this way 6 kg of root tuber containing 25% starch delivers ca. 1 litre of ethanol.

This technology has been improved to a very high gravity technology, in which less water is needed, saving a lot of energy (ca. 15%) mainly on heating and drying, and in which saccharification and fermentation are done simultaneously, thereby reducing the processing time with 30% and increasing the ethanol concentration in the fermentation product to 14-18%.

6.2. Mass and energy balance

The roots have a moisture content of 65-75%. Typically, 1 ton of roots are processed to 0.5 tons of root chips with a moisture content of 15%. The chips are grinded and 1.7 tons of water is added and mixed. The slurry is liquefied with steam at 120 °C, then cooled down to ca 50 °C for sacharification and fermentation, which releases ca 0.16 t CO_2. The remaining slurry contains 8-10% ethanol, which is distilled. Circa 0.25 tons of water is recycled and around 0.16 tons (200 l, 4688 MJ) of ethanol is obtained. The remaining 2 tons of thick slop contains about 5% solids and can be used for the production of ca 200 m3 biogas, which equals ca. 7 GJ (Piyachomkwan, 2011). Using this process ca. 90% of the original caloric value in the roots is retained in the ethanol. Processing costs are about 2.7 MJ/t feedstock mainly for distillation and drying.

6.3. Economic evaluation and current projects

In Nigeria cassava farmers producing about 15 t/ha per year have production costs per ha of ca. 290 USD and their revenues are ca. 790 USD (off-gate farm price ca. 53 USD/t), so they earn about 500 USD per ha per annum. The average buying price for the processors is ca. 76 USD/t, indicating a collection/chipping/transport cost of 23 USD/t.

The UOMEA review on bio energy (Sustainable Bioenergy Development in UOMEA, 2008) mentions a price of ethanol from cassava for Benin of 17.8 FCFA/MJ, which equals ca. 0.78 USD/l. In Nigeria the extra distillery costs were calculated on 0.28 USD/l (i.e. 51 USD/t) and the ethanol production costs at 0.60 USD/l, leading to a production price of 0.88 USD/l ex profit, which is close to the Benin value reported several years ago. However, this value is still much higher than the current gasoline prices in both countries, making local use for transport fuel unrealistic, which is probably the reason why there are many plans to produce ethanol for transport fuels, but hardly any progress. Again competition with subsidized fossil fuel prices is one of the factors hampering the introduction of ethanol for transport fuel applications.

Nigeria has an internal market demand of 5 billion litres of ethanol for transport fuel and domestic cooking. The Nigerian ethanol production is not sufficient by far to meet this demand. In 2010, 3 companies imported 118.6 million litres of crude ethanol mostly from Brazil. Dura Clean in Bacita and Allied Atlantic Distilleries in Sango-Ota produced only 15.3 million litres from molasses and cassava (Agbro 2012). Atlantic Distilleries is producing 30,000 l from locally sourced cassava feedstock. Dura Clean has yet to begin full operations.

Evidently, USD 3.86 billion has already been committed to construct 19 ethanol bio-refineries, 10,000 units of mini-refineries and feedstock plantations for the production of over 2.66 billion litres of fuel grade ethanol per year. Five companies already exist including the 2 mentioned above with a total installed capacity of 0.2 billion litres per year. Locations are Bacito, Sango-Ota, Ekiti, Bayelsa and Lagos. Another 9 projects are in the development phase. Two of these, located in Nassarawa and Ekiti State, aim to have an integrated bio ethanol refinery and cassava farm. The others will use sugarcane, sorghum or imported molasses. However, the entire supply chain needs to be re-evaluated because currently bio ethanol from cassava is too expensive to use for fuel in Nigeria, which has one of the lowest pump gasoline prices in the region (Agboola, 2011).

To give all these initiatives a fair chance to produce ethanol for transport fuels, the subsidy on importation of (bio-) fuels and reducing pump prices has to be stopped or bio-fuels will also need to benefit as well from the subsidization schemes. In an attempt to increase the pump prices a few years ago the public reacted with a severe unrest, so the price adaptation was reduced. Even after these price adaptations, the current situation in Nigeria is not sustainable.

Ghana does not produce ethanol from cassava at this moment. Caltech Ventures is busy to construct a cassava to ethanol plant with an initial capacity of 70 Mt root-processing /day to yield 10,000 l ethanol/day that has to be operational in 2013. Caltech grows cassava on managed plantations near Ho and estimates it needs just over 1,000 ha with an average yield of 22 t/ha per annum to be able to generate enough feedstock for the ethanol plant. However, the ethanol will not be used for transport fuel because the gasoline pump price is lower than the ethanol production price and a good regulatory and distribution system to blend gasoline with ethanol is lacking. Therefore, the ethanol will be used for beverages, pharmaceutical purposes and export in a first phase (Caltech, personal communication).

6.4. Evaluation of R&D activities on cassava in the region

In appendix 3, an overview is given of the public research institutes performing R&D or publishing on the crop in ECOWAS area.

The development of cassava into an alternative ethanol crop is a very clear option for the region in bio energy crop developments. However, the project team believes it is very critical that in the first place the countries that contemplate such developments focus their developments first on the self sufficiency for food. In case of surplus production, a parallel ethanol production path can then be contemplated. It is therefore very important that the ongoing efforts on agronomy research and breeding of superior cassava varieties going on in reputed institutes like IITA (International Institute for Tropical Agriculture, Ibadan, Nigeria) and the national root crops research institute (Umudike, Nigeria) are further strengthened.

It is for this reason very applaudable that the Bill and Melinda Gates Foundation together with some other sponsors recently started a project nextgen cassava and the cassava base. In concept integrating genetics and agronomy learning and also involving the cassava experts at the Cornell university, USA, the ECOWAS region houses a very innovative concept of sharing field trial data, cassava varieties and expertise.

A number of institutes around the world including IITA, EMBRAPA (Brazil), CIAT (Columbia) and CATAS (China) are working on high sugar/industrial varieties in Cassava, or on varieties with special starch composition like waxy starches. Apart from the challenge to share this new germplasm amongst breeders, one also needs to weigh the value of these developments against the overall food supply objective for cassava as indicated above.

The technical and other challenges for the development of Cassava into a bio energy crop have been discussed in detail at a conference sponsored by IFAD and FAO in Accra, Ghana and have been summarized in http://www.ifad.org/events/cassava/docs/bioenergy.pdf.

6.5. Observations and conclusions

There are very few countries in the region that currently have a surplus production of cassava over and above its food and other industrial needs.

The first projects of cassava into ethanol production are being developed around central nucleus plantation projects (also housing the processing and the ethanol production plants) with the future potential to also attract produce from outgrowers. The advantage of this model is that the nucleus farms can function as model and demo farms for new agricultural technology like better varieties or optimized agronomy practises. Unlike sugarcane, staggering of different cassava varieties results in an almost 100% occupation level of the starch into ethanol plant. Cassava has the added value that the raw material for the plant has extended storability under the form of Cassava chips. This forms a strong operational advantage over sugarcane or sweet sorghum into ethanol operations. It remains to be seen if this also can form a basis for more de-centralized smaller scale processing units.

In any case it does allow logistically for the development of a two step collection system: a first step where the roots are collected and processed into dry starchy chips and a second step where the chips are centralized into one larger scale processing facility. In Nigeria this allows a maximum of flexibility in establishment of projects in the cassava belt. The prime consideration then needs to be given to the location of the central processing facility close to the principal end use market; if again, one opts for integrated food and energy farms where ethanol can be used as a feedstock for different applications (cooking solutions on farm and in urban areas; use in refrigerators or as a source for electricity production etc.) it is strategically important to house these facilities close to large agricultural hubs where today electricity options are limited.

Achieving the major goal of using ethanol as biofuel either for transport, electricity or for cooking will depend on the local prices for alternative fossil fuels like gasoline and butane and the mid-term vision on subsidies for fuel products. As long as fossil fuels are artificially maintained at a very low level using excessive subsidies on import and pump-sales prices, bio-ethanol for transport and cooking does not have a big future in West Africa. Creating a level playing field in terms of subsidies for bio ethanol will already form one element of further support for the emerging industry.

7. CASHEW IN WEST AFRICA

West Africa is (one of) the biggest producer(s) of cashew with a volume of nuts in shells of over 1 million tons in 2010 with a value of 500 600 USD/ton. Raw Cashew Nuts (RCN) are sold nowadays for 650 830 USD/ton and deliver a revenue of 180 USD/ha (GIZ 2010) for small holders. Over 80% of the nuts are exported from the region, mostly to India where they are processed.

Over 95% of the cashew is produced by small holders with an average land-base of 2 ha (range 0.5 -10). Ca 90% of the farmers is male and they own the land. They mainly grow local varieties with varying nut sizes (3-8 g/nut) and a general harvest of 12-15 kg per tree per year. These common varieties are grown at a density of 123 178 trees per ha in a mixed cropping system. The dwarf savannah varieties are grown in a higher density (178-278 trees/ha). New Brazilian varieties produce bigger nuts (11-13 g/nut) but generally produce less kg per tree (5-9). Depending on the region the intercrops are a 4 year rotation cycle of cotton, groundnut, and millet/grain sorghum, or yam, beans, and maize. The 4th year no intercrop is cultured. Generally, no fertilizer is being used leaving only the N-fixing intercrops to resupply the soil with nitrogen.

The yield of RCN per ha depends on the age of the trees. For the 3rd and 4th year 90-100 kg/ha is reported while at maturity (10-12 years) 800-1,200 kg/ha is reported. Nigeria claims to obtain yields at maturity of 1,752-1,990 kg/ha. This is impossible for smallholders. Realistic yields at maturity are between 250-650 kg/ha (average 400-450 kg/ha). Mostly women are tasked with harvesting.

To obtain a high quality kernel in the nut, the kernel has to be given time to fill the nut completely. It is difficult to establish this stage of development from the outside by inspection of the nuts. For this reason, the farmers wait until the apples with the nuts fall on the ground. The nuts are cut from the apples and collected. The apples are usually left on the field to rot. The harvesting time for a high quality nut is different from the harvesting time for a high quality apple.

Processing RCN into shells and kernels is hardly done in the region although many small processing businesses exist. Processing the nuts gives a lot of employment and therefore the establishment of new processing companies is stimulated. For every 1,000 tons of RCN to be processed annually, ca 250 workers are needed of which 85% are women. On average they earn 2 USD/day.

Processing the RCN locally also gives the opportunity to harvest Cashew Nut Shell Liquid (CNSL). The shells contain 20-30% CNSL. This oily liquid contains 70% anacardic acid, 18% cardol, 5% cardanol and 7% other phenols. The liquid is very corrosive, also for the human skin, but has many interesting properties. It is being used to protect wood from termite attack. Heating the oil results in de-carboxylation of the anacardic acids. Subsequent distillation delivers a distilled CNSL containing 78% cardanol, 8% cardol and the rest is polymeric substances and other phenols. Distilled CNSL has a wide range of applications in the production of lubricants, varnish and brake pads.

For every ton of nuts about 10 tons of apples can be harvested as well. Apple is not the correct technical term for it, because it is the swelling of the fruit stalk that produces this structure. The apple contains 85% moisture. It has a tremendous nutritious value. In 3 regions in Ghana the apple was shown to contain 2 15 mg Vitamin C per gram dry matter (over 200 mg/100 ml juice), which is 4-5 times more than kiwi or oranges and 10 times more than pineapple (Lowor 2009). These values are retained in commercial products derived from the apples like juice and frozen pulp (Assuncao 2003). Besides that, the apples have a very high antioxidant activity and a good mineral composition, which could benefit the health of the population as well (Adou 2012). However, the astringent nature of apple and juice seems to be the limiting factor for its acceptance by the population. Strategies need to be evaluated to mix products derived from cashew apples with products derived from other fruits or vegetables to circumvent the taste issues.

In Brazil the nutritious value of the apples has been recognized. A low oxygen packaging technique has been developed to increase the shelf life of the apples from 2 to 12 days in order to make fresh apples available via supermarkets. Apples are also being converted to marmalade, juices, syrup and canned fruit and wine as such or in combination with other juices. In West Africa application of the apples for human nutrition is in its infancy and most of the apples are not used or left on the field. In a region with frequent food shortages that produces over 10 million tons cashew apple annually; not using these for human nutrition is an enormous waste. Investigations are ongoing to use the apples for animal feed purposes as well.

In the above context it is very encouraging that recently a Brazilian investor, Usibras, has announced the establishment of a 15M USD investment in cashew nut processing in Ghana. The project has a second phase investment in the use of cashew nut shells as a biomass for energy generation in the plant and for the community. In the context of this study one should also explore the potential of using the biomass from cashew apples as a bio energy source. One can use the cashew apple juice as a feedstock for ethanol production and a few isolated initiatives are already taken in this field; however the sugar content of the apple juice is too low to make it an economically viable feedstock as such. It is very important that the projects testing cashew apple juice as a feedstock for ethanol production do receive proper advice on possible alternative feedstocks and on the economics of their venture. Another alternative exploitation could be the use of the biomass for biogas production; this is a more viable option in our opinion.

7.1. Processing

RCN is predominantly exported from the region, mainly to India. There the RCN are being processed to kernels and exported to Europe, USA and other countries. A small portion of the RCN is processed to kernels locally. Only 50% of the available processing capacity in West Africa is being used due to the lack of financing to buy the feedstock.

Processing RCN involves several steps: collecting, warehouse storing, nut calibrating, roasting, cooling, shelling, drying, humidifying, husk peeling, kernel grading, fumigating, packing, warehouse and pre-shipment checking. Every 1,000 tons of RCN processing to kernels demands about 250 labourers of which 85% are women. The knowledge and technology used is mainly coming from India. On the other hand, Oltremare sells a completely automated RCN-processing plant, which has been put to practice in Brazil on several places, but which is too expensive in maintenance for West Africa. Because it also leeks part of the CNSL into the kernel fraction, the kernels are discoloured which reduces their quality.

The major product of the processing is kernel (22-30% of the RCN weight). Only 50% of the kernel fraction is sold as entire kernels in 8 size grades, the rest as broken/pieces of kernel in 12 grades. Some of the kernels are roasted, flavoured and salted. A small by-product (2-3% of RCN weight) is the testa, which can be used as animal feed. The biggest by product is the shells (67-76% of RCN weight). The shells can be further processed to obtain the CNSL (yield 20-23.5 % of RCN weight) using classical expellers. The remaining CSNL cake can be used as fertilizer.

As stated above, for every ton of RCN 10 tons of apples can be harvested. However, to harvest a good quality apple the fruits have to be picked from the tree, while for a good quality kernel harvesting this is delayed until the fruits have fallen from the trees. The majority of the apples is left on the field to rot. The ACA and the IRD have programs to stimulate the use of the apples for human nutrition.

An easy process is to use a screw press to harvest the juice. About 55-68% of the apple weight is retained in the juice. The astringent nature of the juice is caused by the high content of phenolics and tannins and can be circumvented by clarifying the juice with PVP, cassava starch, rice gruel, gelatine or microfiltration. The juice starts to ferment quickly and therefore should be used immediately, pasteurized or processed. The juice can be used to make jellies and jams. In combination with the remainder of the apples it can also be used to make marmalades. The only additions needed for these applications are sugar and flavour like ginger or vanilla. Leaving the juice to ferment delivers a good wine with 7.6-15.6% alcohol from which a cashew brandy can be obtained after distillation. Processing cashew apples to products for human nutrition is done on a relative large scale in Brazil, India, Belize and South East Asia. In West Africa over 95% of the apples is not used yet. A small part is used by women in an artisanal way to produce juice, jam and marmalade for the local market. In Ghana one company uses part of the apples to produce cashew brandy for the local hotel and restaurant market.

Cashew can be used for bio energy purposes in several ways. The CNSL can be used up to a 35% blend in diesel. The press cake can only be used as fertilizer or for combustion. The kernels also contain oil, which can be expelled. From 1 ton of kernels about 350 kg oil can be obtained. The 650 kg press cake can be used for human nutrition and animal feed as well as the kernel oil.

So, using the oil in cashew shells and kernels should rely on 2 separate processing streams: one for shells to generate products that cannot be eaten and another one for kernels to generate products that can be eaten.
Another way to use cashew for bio energy is to produce either ethanol or biogas from the apples. This can be done from the cashew apple waste after juice extraction or from the complete apple. The sugar content of both is high enough for either process. A quick calculation learns that in an efficient fermentation process 1 ton of cashew apples will generate 72 kg of ethanol. This is not competitive with other ethanol production routes.

7.2. Mass balance

Processing 1 ton of RCN delivers ca 250 kg of kernels in various grades of qualities, 620 kg of shells and 30 kg of testa. The kernel composition is 43% fat, mainly PUFA (74% oleic acid) and a high level of vitamin E (0.2%), 21% protein, 24% carbohydrates, and the rest being water, ash and fibre. When the oil is expelled from the kernels, this will deliver ca 87 kg oil and 163 kg kernel cake. The oil is very nutritious, has a good fatty acid profile for human consumption and contains almost all the vitamin E. The kernel cake is protein rich, has several vitamins (thiamin, riboflavin, niacin, pantothetic acid, B6, folate, vitamin K) and is ideal for food purposes.

The shells can be passed through an expeller, which will yield about 155 kg of CNSL and 465 kg of shell cake. The CNSL may be added up to a 30% blend in diesel or used for specific purposes like a termite control treatment for wood or a varnish for brake pads. The cake can be used for co-firing, combustion and fertilisation.

For every ton of RCN 10 tons of apples can be harvested. Expelling the juice from the apple by adding water will give around 10 tons of apple juice. The juice is rich in phenolics and tannins, depending on the ripening stage (total ca 500 mg/100 ml). It also has a very high vitamin C content (>200 mg/100 ml). This juice is preserved by addition of citric acid. Fermentation of the juice gives an equal volume of wine. The distillate of the fermented juice is used to produce around 11 tons of brandy. Alternatively, the juice is boiled after adding sugar and flavour, to generate around half of its volume of jelly or jam, or marmalade when a part of the remainder of the expelled and grinded apples is also added. Drying the apple pulp yields about 150 kg of dried apple mass, which is a very nutritious feed. Grinding this mass delivers an equal volume of couscous for human consumption.

If all cashew products are used to generate energy, this delivers from 1 ton of RCN plus 10 tons of apples: 240 kg oil (9.6 GJ) from the RCN, either 720 kg ethanol (21.4 GJ) or 480 kg biogas (26.6 GJ) from the apples, 628 kg RCN-cake (11.3 GJ) and 1,000 kg dry apple mass (15 GJ) for co-firing or charcoal production.

7.3. Economic evaluation

Table 4 gives the sales value per ha for a smallholder cashew grower of the various products made from RCN and apples for market in The Gambia and/or Ghana. From this table it is clear that the major product traded at this moment (RCN) delivers only a limited amount of value to the smallholder. In The Gambia the local varieties produce a relatively large and sweet kernel, which is reflected in the RCN price of farm (ca 1.25 USD/kg). This limits the export potential of the RCN. Export costs for RCN in 2011 were estimated at 0.42 USD/kg. The export prices of RCN vary a lot (500-1,400 USD/t), which will determine if the smallholder gets a good return on his RCN-produce or not. This makes his income on RCN itself very vulnerable.
Another problem with these figures is that the return mentioned in the table is obtained at maturity of the trees, which is after 6-8 years. In the meantime, the farmers must survive on lower yields and other crops. The long gestation times to reach maturity are a big risk taking into consideration the frequent occurrence of bush fires, mostly caused by neighboring farmers. It also hampers the introduction of new higher yielding varieties.
Processing RCN to kernels, shells and testa delivers a much better price per ha: ca 545 USD. The processing

Fraction	Fraction	Destination	Price US$/kg	Yield kg/ha	Value US$/ha
RCN	1	Processor	0,64	420,00	268,80
Kernels	0,25	Food	5,00	105,00	525,00
Shells	0,75	Fertilizer	0,03	315,00	9,45
Kernel oil	0,087	Food	1,00	36,54	36,54
Kernel oil	0,087	Biofuel	0,60	36,54	21,92
Kernel cake	0,163	Food	1,00	68,46	68,46
CNSL	0,155	Specific	0,75	65,10	48,83
CNSL	0,155	Biofuel	0,60	65,10	39,06
Testa	0,03	Feed	0,90	12,60	11,34
Apples	10	Fresh fruit	0,50	4200,00	2100,00
Juice	10	Drink	0,75	4200,00	3150,00
Wine	10	Drink	5,00	4200,00	21000,00
Brandy	11	Drink	8,00	4620,00	36960,00
Jelly/Jam/Marmalade	5	Food	5,00	2100,00	10500,00
Dried pulp	1,5	Feed	0,90	630,00	567,00
Couscous	1,5	Food	1,50	630,00	945,00
Biogas	0,47	Biofuel	0,30	197,40	59,22
Ethanol	0,72	Biofuel	1,00	302,40	302,40

Table 4: calculated sales prices per cashew product per ha

costs are estimated at 3.2-4.5 USD/kg kernels, of which 85% is needed for feedstock purchase. Processing will not add value to the cashew smallholder, but it will add value to the local economy in terms of employment; 250 workers/1,000 tons of RCN processed per year, who will earn around 2 USD/day. The majority of these employees are women (ca 85%). Since the processing needs water and electricity, the local community can also profit from the boreholes and the power net established for the processing plant. Another advantage of local processing to kernels is a 700% reduction of the carbon footprint of the kernels compared to transport to India, processing there and export to North America and Europe. Processing the shells to CNSL and cake even delivers more value per ha: ca 590 USD/ha. However, the investments for processing shells are pretty large and a local use of CNSL has to be developed.

Based on the positive economic evaluation of processing RCN to kernels, a lot of processing capacity has been installed in the region, but only a fraction of it is being used. The major problem here is the high interest for the funding required to buy the feedstock. Although a lot of knowledge and equipment has been imported from India, the lack of a good professional business attitude and experienced managers within the processing production chain is a big problem. Both are needed to maintain good quality control measures in the processing plants, of which only 2 have recently obtained the ACA Seal Approval; a quality control certificate that will help to export kernels to Western markets.

The major value to the smallholder cashew grower is added by artisanal use of the apples. The fresh market will not easily be developed due to the astringent taste of the apples, but even when a fraction of the sales price mentioned in table 3 is obtained, the added value per ha is great. Small scale local processing of the apples to jam, jelly and marmalade circumvents the taste issue due to the addition of sugar, flavors and/or other fruits. Processing is very simple but will cost a lot of energy/fuel to damp of 50% of the liquid, which may be a burden for the local firewood supply. But the added value per ha is great when all the apples are being used. Even if a small fraction of the apples is used for this purpose, it still is worthwhile doing it to increase the smallholders' income. Cashew jam is traded on the European market for over 5 € per pot of 450 g.

Processing the apples to juice, whine or brandy depends on the possibility to do this at a relatively large scale. The juice starts to ferment very quickly and good quality control measures have to be maintained. And although the added value per ha is great, the problems connected to these products are also great. Large scale processing depends on transport of the apples to central processing facilities. Since 85% of the apples is water, a lot of mass has to be transported on roads that for the majority are in a deplorable state, leading to killing transport costs and reduction of apple quality. Some small-scale processing to juice and whine is being done in The Gambia and Ghana. In Ghana one company produces brandy from part of their plantation apple production. This company is also looking at the production of juice for the local market with the help of Brazilian technology in the next couple of years.

Processing RCN and apples to bio energy carriers only gives a fraction of the amount of economic return that can be expected from processing towards food and feed applications. The most profitable bio energy application is processing the apples to ethanol, but this will depend on the scale, the costs for transport of the apples and the (local) market for ethanol. The first indications of cost price to produce ethanol from cashew apples are not very promising: ca 50% higher costs than for ethanol produced from sugarcane or cassava (Uomea report), making it even more difficult to compete with butane. Gel-based ethanol for cooking is even 20-30% more expensive. Because of the very nutritious value of kernels and apples and the higher economic return of the food and feed applications at this moment, the application of cashew products for the bio energy market is not recommended. But we have to bear in mind that food applications of the apple are rare products on the market nowadays and prices may devaluate once cashew apple processing becomes a mainstream business.

Another more realistic approach would be a two step process, whereby local collection units are organized for the cashew apples and focused food directed processing delivers a first (higher value) food oriented value stream; the by products from this process will be a type of apple mash that can be used subsequently for biogas production; this biogas can be the energy source for the food processing unit.

7.4. Evaluation of R&D activities on cashew in the target area

In appendix 3, an overview is given of the public research institutes performing R&D or publishing on the crop in ECOWAS area.

Although the region is one of the most important producers of cashew nuts in the world (esp. Nigeria), the region also houses the African cashew alliance initiative and valuable projects are under development in certain countries (e.g. The CEP or The Gambia river basin cashew value chain enhancement project under the auspices of the International Relief and Development program and supported by USDA-USA), the research efforts on genetic improvement and agronomy for the crop are limited. They are summarized in annex 3.

This is partly understandable given the fact that most of the cashew nuts are exported for processing and limited value creation/addition through local processing has been achieved so far in the region. The African cashew alliance is in this perspective a key initiative also for the ECOWAS region.

We believe however that in support of further development of the crop more extensive research on improved hybrids for the crop and on agronomy towards higher production is critical. For the policy makers in the area, an alliance with institutes like the Naliendele Agricultural Research Institute (NARI) in Tanzania or EMBRAPA, Brazil that has a mature program on Cashew nuts genetics, agronomy and processing would be a very important first step in further support of the crop.

7.5. Observations and conclusions

It is clear from the economic observations on cashew, that bio energy applications of this crop can never compete with its food and feed applications. Given the very nutritious value of kernels and apples, it would also be a waste to use these for energy directly. We therefore suggest a TWO STEP approach for the value use of cashew apples: in a first steps organizations like ACA should explore different options in different target growing areas for the development of palatable food products based on cashew apples; the left-overs after this food processing activity can then be used in a second step for e.g. biogas production.

However, the income of the farmer is at risk if he has to live only on the sales price he gets for the RCN. For most smallholders, the yield per ha of RCN is too low and the RCN-sales price is too volatile to generate a guaranteed income. Therefore, initiatives have been taken by IRD and ACA to enhance the cashew value chain with feed products made out of the apple and setting up RCN-processing units and quality standards for these units. Also higher yielding varieties are being investigated for their use under local climatic conditions. All these initiatives need to be further supported.

The policy development and government support in the cashew producing countries should focus on the following value added steps for cashew:

1. Moving from export of RCN to local processing of the crop. This not only delivers immediate jobs and value added for the local economy. It also produces a very interesting stream of co-products like cashew shells and cashew nut shell liquid (CNSL) with interesting potential for industrial applications or bio energy applications. The investment of Usibras in Ghana is a clear example of this positive development and can be a catalyser for other developments.

2. Implementation of decentralized units to exploit in the first place the nutritious value of the cashew apples for humans. This can not only have significant health benefits for the local community but is again creating jobs and additional income stream for the local producers. If these food processing units are co-ordinated on a village level, the secondary biomass streams will have sufficient economy of scale to also generate sufficient

energy from biogas units locally. In these cases surplus energy can again be used in decentralized electricity units supporting the villages.

3. The project team believes that at this stage a bio energy application of ethanol produced from cashew apple juice is NOT a route to follow. Examples from other crops that are lot more productive on an ethanol per ha basis (sweet sorghum, sugarcane, cassava) demonstrate that even there, competition with ethanol imported from Brazil forms a major barrier for the development of an ethanol based bio energy strategy. Less economical ethanol from Cashew apples is therefore even less sustainable in this context.

4. Experience to produce food products from cashew apples exists in Brazil and organizations like EMBRAPA could be used as consultants for further development of this avenue. The local governments need to make sure that they have some upfront agreements with the Brazilian authorities to allow the sustainable development of local integrated businesses that add value to the local economy.

5. In cases where larger scale plantations are being developed or considered for cashew production, a more integrated RCN and apple processing/ biogas production unit can be considered from day 1. A good example of this strategy is MIM Agro and Industrial Products in Mim, Ghana. These initiatives need to be fully supported by the local and regional authorities as they can develop into successful case studies for further roll out and for integration with outgrower networks. The concentration of the RCN processing as well as the apple biogas production units is going to be essential given the fact that otherwise the logistics costs are going to kill the economics of both operations very quickly. Once these economics are fully understood for these larger scale operations, one can explore if a more decentralized approach is also an option.

8. Conclusions and recommendations

Apart from the individual crop/region conclusions and recommendations we have also developed a number of general conclusions and recommendations.

• In the policy development on renewable energy, bio energy crops cannot be treated in isolation of other renewable energy sources (hydro, solar, wind energy). The key will be to exploit geographical spread and use bio energy crops as buffering tool for solar and wind energy optimization.

• The polarized food vs. fuel debate needs to be transformed into a more constructive debate on integrated food and energy farm concepts, both at a large plantation scale and at an out grower level. The use of the BEFS analytical framework, developed by FAO, can be a very strong tool for objective evaluation of these opportunities. It is however critical in this analysis that for the bio energy crops, objective science based data are utilized as a basis for decision making. This will be the best guarantee for poverty alleviation and for exploitation of a maximum of synergies between food and energy production. In addition, the value added to decentralized business/energy models brings value to rural areas of the countries and can partly compensate for suboptimal transport infrastructure. . We believe that the installation of decentralized energy units in combination with storage and in a second phase processing facilities creates a formidable opportunity for value addition to local farming projects/ communities. The added benefits offered by surplus production of energy under the form of electricity or air conditioning will also have a very positive impact on local communities.

• Bio energy crops need to be co-owned by agriculture AND energy policy makers. Bio energy crops need to be developed on the basis of professional agriculture like any crop AND need to produce affordable and needed energy. Both groups of policy makers need to work hand in hand in order to make sure that projects are developed in the correct location both from a crop suitability point of view as from an energy needs point of view. In the deployment of projects also other key strategic aspects like environmental and social impact clearly need to be considered in the decision making.

• It is very critical that myths in relation to novel bio energy crops are abandoned a.s.a.p. and that decision making is based on facts about suitability and economics of the crops. These novel bio energy crops are NOT miracle crops and need to be treated on face value like any other agricultural crop. Bio energy crop development needs to be part of the countries agricultural policy development integrating cropping choices for food and bio-energy crops.

• Analysis of existing R&D efforts and available centres of excellence for the crops revealed significant gaps in R&D activities especially for sweet sorghum and cashew. For these crops, R&D mandates need to be allocated to existing R&D institutes or national programs and are ideally further developed in public-private partnerships.

• For crops like Cassava and Jatropha R&D networks have been established, involving local institutes and universities but also local and international industrial players and international research institutes. These initiatives especially for crops like Jatropha, sweet sorghum and cashew need more coordination and financial resources in order to be successful.

• In the case of Sweet Sorghum, the ECOWAS region first needs to analyze if dedicated sweet sorghum or rather sweet grain sorghum or both are the preferred business models to follow. The existing centers of excellence around sorghum cultivation and ethanol conversion need to do some further research to reveal the strategic choices to be made on this; as indicated before, the answer to this dichotomy may vary from area to area in the ECOWAS region.

• In the ECOWAS countries the development of affordable bio energy crops is hindered by the existing subsidy systems for traditional fossil fuels. These fossil fuels cost the country double: through the use of hard currency to buy expensive fossil fuels combined with country specific subsidizing towards affordable fuels on the local market. Bio-fuels can complement the fossil fuels use for a certain percentage and specific local uses. This will result in a positive effect on hard currency balance for the country, in the creation of local jobs and decentralized economy and over time possibly in case of surplus production in a positive hard currency balance in case of export of e.g. biofuels. In order to achieve this objective, bio energy and other renewable energy systems need to be considered as an integral part of the overall energy policy of the country. To that extend bio energy crops and other renewable energy sources need to be treated on an equal basis for subsidy systems.

• On a case by case basis the above conclusions support the overall vision of organizations like FAO, IFAD, GBEP, UNIDO on individual topics. However, to our knowledge ECREEE is the first organization that catalyzes the integration of the complex subject matters derived from integrating energy and agriculture policies; integrating traditional and renewable energies; integrating grid based and decentralized energy production and possibly integrating decentralized food production, storage and processing with parallel rural energy policy development. We believe these complex interfaces and the fact that a number of myths need to be removed around specifically a number of novel bio energy crops calls for a conference where these different aspects are covered. Given the possible impact on the ECOWAS economy, support and presence of the international organizations listed above would be most welcome.

• It goes without saying that during the implementation of the mixed farming concepts proposed in this study, the basic internationally accepted rules of social and environmental sustainability need to be fully respected. The project team suggests that especially in an initial stage, the projects are not overly loaded with a strong administrative burden and that systems to track sustainability compliance are introduced stepwise and tailor made for Africa based operations; the risk is that emerging projects are immediately becomes non-viable if the administrative burden is too large.

Appendix 1: Intermediate report of the project selecting the four crop/region combinations

REGIONAL POTENTIAL ASSESSMENT OF NOVEL BIO-ENERGY CROPS IN FIFTEEN ECOWAS COUNTRIES

ECOWAS CENTRE FOR RENEWABLE
ENERGY AND ENERGY EFFICIENCY
- ECREEE -

2nd progress report to ECREEE
August 2012

Contents

1. EXECUTIVE SUMMARY

1.1. General introduction to the project

The project “Regional potential assessment of novel bio-energy crops in fifteen ECOWAS countries’’ was started by the different project partners based on the need identified to make an overall assessment of a series of Novel potential bio-energy crops which can or could be grown and processed in the future in the 15 ECOWAS countries. This project fits in a broader strategic analysis of alternative energy needs and production, the key mandate of the main funding partner in the project, ECREEE. The project partners deliberately excluded traditional ‘’bio-energy’’ crops like sugarcane, oil palm, maize or sunflower as target crops, since they believed a sufficient knowledge base on the growing and processing crops was available globally and in the region. The novel bio-energy crops chosen as targets for the study are a selection of crops for which either the agricultural knowledge is still limited and/or the use of the crop as an energy source is relatively new. The project team realizes that the list of selected crops is not an exhaustive list of potential bio-energy crops and that other novel crops may have a potential in the region. The project will develop a methodology that can be followed in the future for analyzing the potential of other crops and does not want to exclude this analysis in the future.

The crops that have been selected for analysis in this project are: Camelina sativa, Crambe abyssinica, Cassava (Manihot esculenta), Castor bean (Ricinus communis), Cashew (Anacardium occidentale), Groundnut (Arachis hypogaea), Jatropha curcas and Sweet sorghum (Sweet version of Sorghum bicolor).

1.2. The project has been structured in two phases

In the first phase the project will analyze these 8 different crops for adaptation to growing conditions and agricultural systems in the 15 ECOWAS countries and will analyze the broad operating context for the establishment of Novel Bio-Energy crops in the 15 ECOWAS countries. Based on this analysis 3 crop- region combinations will be selected for an in depth feasibility study in the second phase of the project. This report summarizes the results of the first phase of the project.

1.3. Selection of the crop-region combinations

In the project 3 crops and respective regions for analysis have been selected:

Cassava was selected with a primary target region central and south of Nigeria and secondary target regions in Ivory Coast, Ghana, Togo and Benin. The target areas for the use of Cassava as a bio-energy crop have today been limited to the region described because this region shows a surplus production of Cassava roots and derived products for in country food consumption. For the other broad area in the ECOWAS countries where Cassava is grown successfully, the project team believes it is critical to first increase the overall productivity of the crop to meet in country self sufficiency for food needs. Countries that are succesful in this can a later stage benefit from the experiences of converting surplus root production into ethanol in the selected target areas.

Jatropha curcas was selected with a primary target region in the Southern parts of Mali and Burkina Faso and the Northern parts of Ivory Coast and Ghana. A secondary target area extending in a more or less horizontal band west and east in Senegal and the Gambia (to the west) and into Nigeria (to the East) was selected subsequently. It is important to note that Jatropha has traditionally been positioned for cultivation more to the North of the region and as an anti-erosion crop. This application has clear potential value in itself. However, the project team wants to stress that the oil productivity in these dry areas will be very limited. Hence, a cultivation of Jatropha as an anti-erosion and at the same time significant bio-energy feedstock crop is probably not realistic.

Sweet Sorghum was selected with a primary target area south west of south east in the region as extension areas for projects that today grow and process sugarcane and cassava into ethanol. As a secondary target area the project has identified a broad band extending south of a line starting in southern Senegal and ending in central East Nigeria.

The other five crops were not selected for further analysis in the second phase of the project for the following reasons:

Camelina and Crambe were found not to be adapted to the climate conditions of the fifteen ECOWAS countries.
Castor Bean is potentially a very interesting cash crop for future cultivation in the region and is adapted to the drier zones in a central-north horizontal band in the region. Castor oil is becoming more and more valuable as a renewable feedstock for the production of a broad range of industrial products like lubricants and for the green polymer industry developing in different parts of the world. Because of these applications, castor oil is expensive and is typically not used as a feedstock for bio-energy applications. For this reason, it has not been retained for follow up in the study. Nevertheless, the project team is convinced this could be a very valuable crop to be developed as a potential cash crop in the region.

Groundnut was not retained for further analysis because it is a very valuable food and cash crop in the region where also an important export business is thriving on in several countries of the region. In theory, the oil from the groundnuts in surplus production, could be used as a bio-energy source. However the project team felt that the existing business streams of the crop could be disturbed significantly, should this parallel application be considered. It may be worthwhile to analyze this option separately in a separate study at a later date.

Cashew was not considered further for the following reasons: in the case of cashew, it is the co-products derived from the fruits that have a potential in bio-energy applications (conversion into biogas via anaerobic fermentation and conversion into ethanol). The project team had to make a difficult choice between this application stream and the one developing in Cassava and Sweet sorghum into ethanol. The decision was taking to focus at this moment on the latter two crops since conversion technology exists and is readily available. Again, the project team is convinced that further analysis of this opportunity is a worthwhile undertaking and did not take this on for budget constraint reasons.

1.4. General intermediate observations and conclusions

A number of studies suggest that the growing of novel bio-energy crops in the region does not represent viable solutions for energy production that can be recovered in the existing electricity grid. However, the selection of the crop region combinations opens we believe a very important opportunity to further develop off grid energy applications for local energy production and use. This aspect will be analyzed in detail in the second phase of the project.

The full exploitation of this potential will also remove an important concern often associated with the cultivation of these novel bio-energy crops: the fact that many projects were started with the primary goal to produce feedstock in Africa for export to important end user markets like India, China and Europe.

The project team believes that a policy development around the production of bio-energy crops in the ECOWAS region needs to address this aspect urgently. It should also allow foreign investors to come to the region with confidence but at the same time addressing the delicate balance between local and global needs. A significant fact is that the selected target areas are landlocked in the region. We believe this will enhance the (local and foreign) investment in the crop aswell as the local use of the feedstock, on condition that the correct policy and regulatory framework is available for implementation.
The full implementation of the potential identified for the 3 crops will also depend on the availability or the development of a strong knowledge base on the professional growing of the crop and the subsequent small and larger scale down stream processing. This will be another important subject of focus in the second phase of the project.

2. GENERAL INFORMATION

PROJECT TITLE	Regional Potential Assessment of Novel Bio-energy Crops in Fifteen ECOWAS countries
PROJECT NUMBER	OBS.9/WP11/REG/BIO-1
REPORT NUMBER	Second report
REPORT TO	ECREEE
REPORT DATE	August 09, 2012
PROJEC LEADER	dr. H. Joos

3.PROGRESS REPORT

This report concerns the progress in phases 3.1 to 3.8 of the project.

3.1. Shortlist of 5-8 target bio-energy crop species

The project description mentions the following crops to be analysed: Jatropha, Camelina, Sweet Sorghum, Cassava and Crambe. Local crops would also be taken into consideration. During our first project management team meeting in January with representatives of ECREEE, UNIDO/IIBN and QUINVITA, Castor, Ground Nut and Cashew were added to the crops to be analysed, because some of these are grown in the ECOWAS region and sometimes even on a relatively large scale. The following table list some of the characteristics of these crops. This

Crop name	Type of crop	Cropping period (months)	Harvested product	Energy use	Produced in ECOWAS
Camelina	Annual	4-5	Seeds	Seed oil	-
Cashew	Perennial	n.a.	Fruits	Fruit hulls for ethanol/biogas Seed oil	+++
Cassava	Annual	9-14	Root tubers	Ethanol production	+++++
Castor	Annual	6-9	Seeds	Seed oil	+
Crambe	Annual	5-6	Seeds	Seed oil	-
Ground Nut	Annual	3-4	Fruits	Seed oil	+++
Jatropha	Perennial	n.a.	Seeds	Seed oil	++
Sweet Sorghum	Annual	4-5	Stems	Sugar for ethanol	-

Table 1: Novel bio-energy crops to be evaluated for the ECOWAS region.

completes the crops to be analysed in this project.

3.2. GIS-based climate suitability maps for ECOWAS region countries per target bio-energy crop species

The ECOWAS region is characterized by several climate gradients (figure 1). Going from North to South the minimum temperatures go up, the maximum temperatures go down, the precipitation per annum increases and the length of the wet season also increases. For rain-fed agriculture this leads to a similar gradient in the length of the cropping season (increasing from North to South from 4 to 12 months) and in the possibility to have more than 1 crop per annum in the Southern half of the region (figure 2). Due to these gradients specific vegetation zones and cropping belts exist: the most Northern belt is Millet due to its short cropping season, followed more South by Cotton, Grain Sorghum, Corn, Cassava and, in some countries, ending in Oil Palm and rain-fed sugar cane (figure 3 and 4). In the neighborhood of big rivers, these zones are crossed with belts of rice cultivation. With the exception of a few small spots, Cape Verde is not suitable for rain-fed agriculture of the crops in table 1.

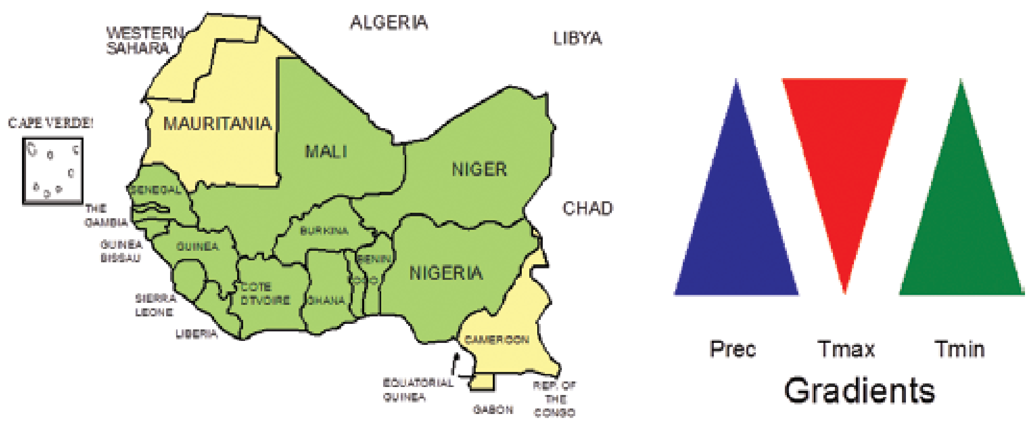


Figure 1: left: the ECOWAS region, right: gradients in average annual precipitation and average annual minimum and maximum temperature existing in the region.

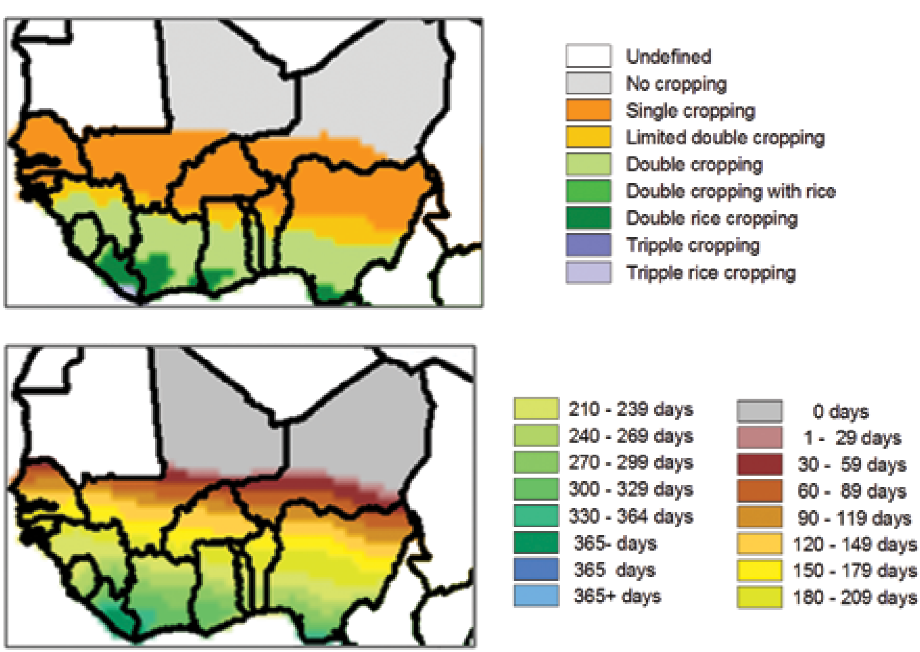


Figure 2: Top: none, single and multiple cropping zones. Bottom: Length of the growing period in the ECOWAS region (IIASA)

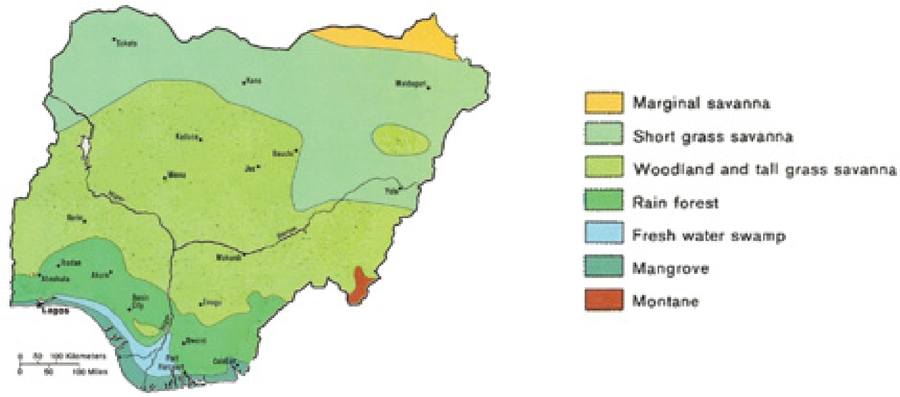


Figure 3: Example of vegetation zones map for the ECOWAS region: Nigeria

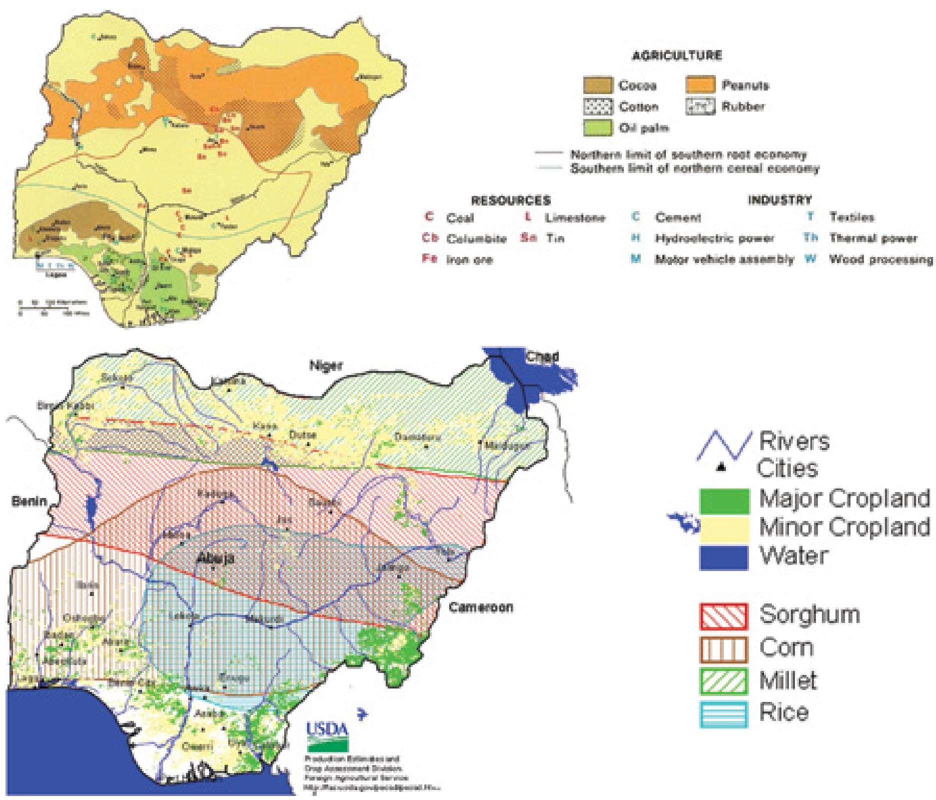


Figure 4: Example of cropping zones maps for the ECOWAS region: Nigeria

The optimal climate data to guarantee a good yield in the crops listed in table 1 have been collected from literature and on basis of these data a first impression was made on the overlap of suitability of the crops with specific cropping belts in the region (table 2). Note that the overlap can be partial or complete. On basis of this evaluation

Crop	Probably suited for crop belt
Camelina	None
Cashew	Cassava
Cassava	Cassava
Castor	Cotton, Grain Sorghum, Millet
Crambe	None
Ground Nut	Cotton, Grain Sorghum, Corn
Jatropha	Cotton, Cassava, Corn, Grain Sorghum
Sweet Sorghum	Cotton, Corn, Grain Sorghum

Table 2: Probable suitability of the new bio-energy crops for existing cropping belts in the region.

the first maps on climate suitability in the region were generated for these crops.

3.2.1. Camelina sativa

Camelina belongs to the family of Brassicaceae and is a crop originating from northern Europe and temperate central Asian regions. Different Brassica crops have been developed into oil crops or vegetable crops adapted primarily to temperate (e.g. winter rapeseed in Europe and China) or subtropical areas (e.g. rapeseed or mustard grown during the mild winters in India and Australia). The different Brassica species have more or less good tolerance to drought. Brassica napus needs higher total rainfall for optimal production areas. Brassica juncea needs lower total rainfall. Based on the information we have collected, Camelina has an adaptation pattern similar to Brassica juncea and will be adapted in the first place to dryer and hotter areas in the Mediterranean and south of the classical Canola belt in North America and China.

The climate criteria used were:

Parameter	Zones			
	Green	Light green	Yellow	Red
Precipitation wettest quarter (mm)	150-250	100-150 and 250-350	0-100 and 350-450	>450
Mean temperature wettest quarter (°C)	16.2-22	5.7-16.2 and 22-24	< 5.7 and 24-26	>26

The suitability maps for Camelina show the following: On basis of these maps it is clear that the ECOWAS region is not suitable to grow Camelina. To our knowledge winter variants of Camelina spring types do not exist right now and for that reason we cannot judge the potential for Camelina during mild winters in places like India and Australia, where traditionally mustard (B.juncea) is grown. In any case we have not found any areas in the ECOWAS region that have a climate pattern adapted to this crop.

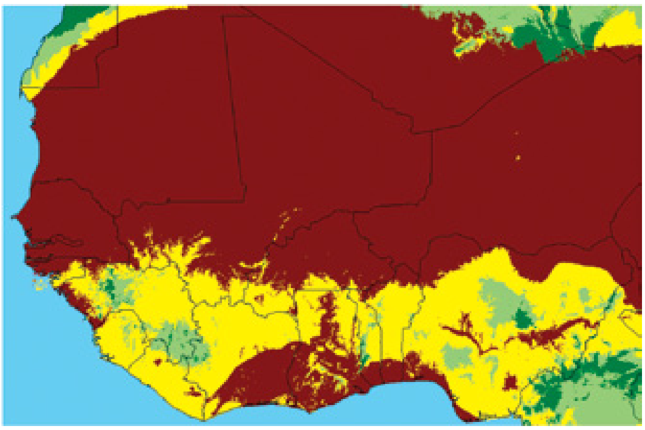


Figure 5: Camelina climate suitability maps for the ECOWAS region: mean temperature wettest quarter. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria

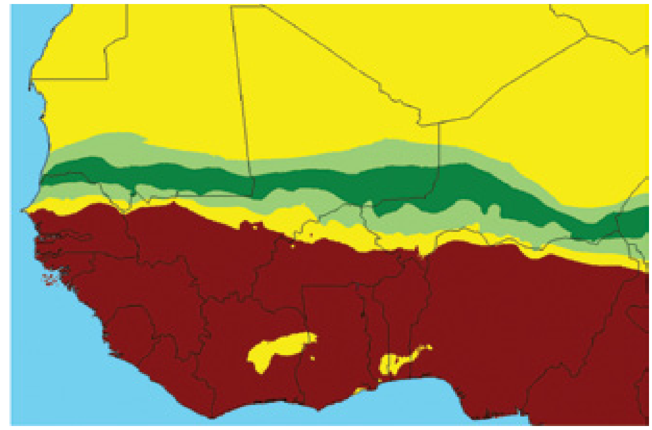


Figure 6: Camelina climate suitability maps for the ECOWAS region: precipitation wettest quarter. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria

3.2.2. Cashew (Anacardium occidentale)

The cashew is a tree belonging to the family Anacardiaceae. Its English name derives from the Portuguese name for the fruit of the cashew tree, caju, which in turn derives from the indigenous Tupi name, acajú. Originally native to northern South America, it is now widely grown in tropical climates for its cashew seeds and cashew apples. The fruit itself contains only 1 seed that is toxic but can be eaten after roasting or frying. The apple is a false fruit originating from the flower stalk. One ha produces 10-23 ton of fresh weight volumes of fruit. 75% of the fresh weight is sap and can be used for the production of ethanol or caju wine, marmalade or other food applications. This is done on a large scale in Brazil but knows today very limited applications in West Africa (except on small scale in some countries). The (left-over's of the) fruit can be used to produce bio-ethanol/biogas. One does need to consider the fact that large volumes of the fruit sap can be used for the production of higher value food applications.

The climate criteria used were:

Parameter	Zones			
	Green	Light green	Yellow	Red
Precipitation annual (mm)	1400-1600	1000-1400 and 1600-2000	600-1000 and 2000-2400	<600 and >450
Mean temperature wettest quarter (°C)	28-32	25-28 and 32-35	20-25 and 35-40	<20 and >40

The climate suitability maps are shown below. Our preliminary judgment is that cashew has a good potential for the ECOWAS region. It is a perennial crop that will do well in the more southern part of the region.

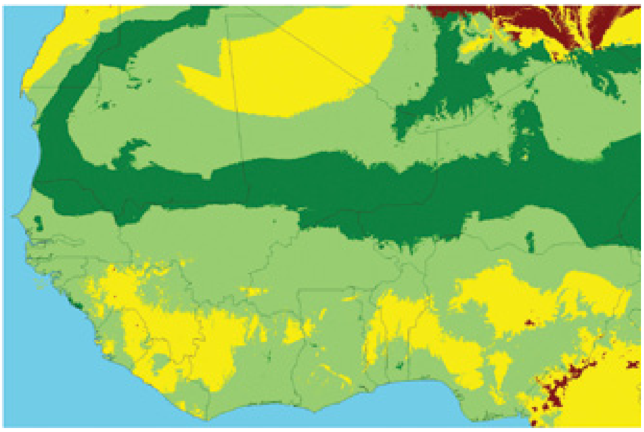


Figure 7: Cashew climate suitability maps for the ECOWAS region: mean temperature wettest quarter. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria

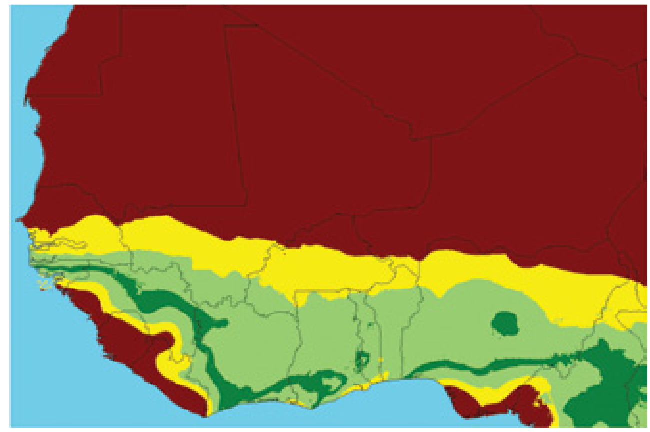


Figure 8: Cashew climate suitability maps for the ECOWAS region: annual precipitation. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria

3.2.3. Cassava (Manihot esculenta)

Cassava is a shrub belonging to the Euphorbiaceae family. It is native to South America, but grown all over the tropics and subtropics because of its starchy root tubers. Cassava is the major staple food in the developing world, providing the basic diet for over 500 million people. Its tubers are their major source of carbohydrates. When the roots are dried, the powdery extract is called tapioca. The fermented flaky version is called garii. When the root tubers are disconnected from the plants, their composition changes rapidly, but in the soil the root tuber can be stored a long time. For this reason the tubers are used in the dry season as a staple food when other crops are not available anymore.

Although cassava is a good source for carbohydrates, it is a poor source for protein and a cassava diet should be supplemented with a good protein source. Cassava roots come in sweet and bitter varieties. The bitterness is caused by the presence of cyanogenic glycosides, which render the plant more resistant to pests. These substances have to be removed before consumption. Improper preparation causes cyanide intoxication and goiters. Various very sweet varieties have a high free sugar content in the tubers and are used for the production of bio-ethanol.

The climate criteria used were:

Parameter	Zones			
	Green	Light green	Yellow	Red
Precipitation annual (mm)	1400-1800	1100-1400 and 1800-2000	800-1100 and 2000-2500	<800 and > 2500
Mean temp. wettest quarter (°C)	25-29	20-25 and 29-32	10-20 and 32-35	<10 and > 35

The most important suitability maps are shown below. On basis of these maps it is clear that cassava has a good

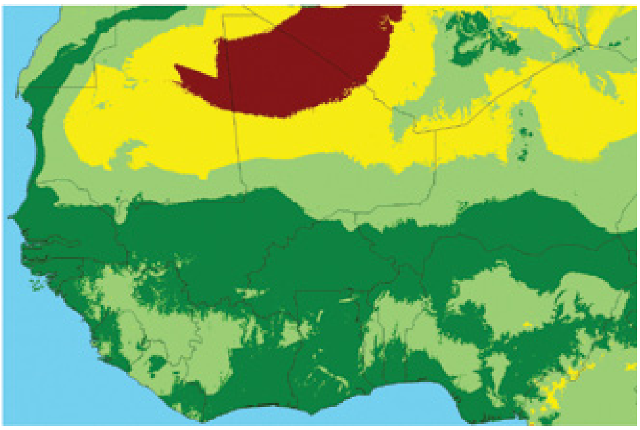


Figure 9: Cassava climate suitability maps for the ECOWAS region: mean temperature wettest quarter. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria

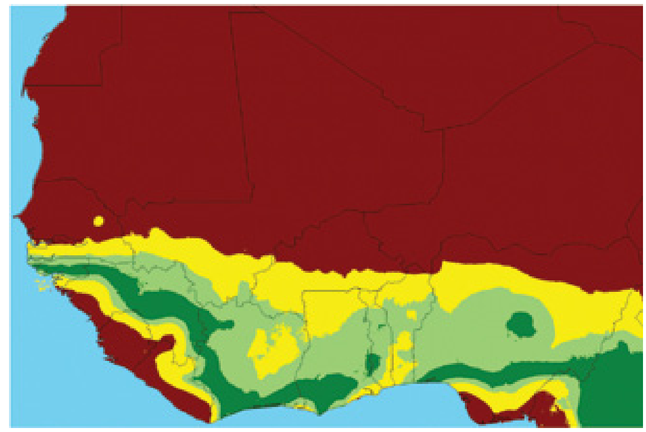


Figure 10: Cassava climate suitability maps for the ECOWAS region: annual precipitation. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria

potential in the more Southern part of the ECOWAS region, where it is already actively grown in countries like Nigeria and Ghana. This is supported by the Cassava suitability map from IIASA, given in figure 7, which is based on actual yield data.

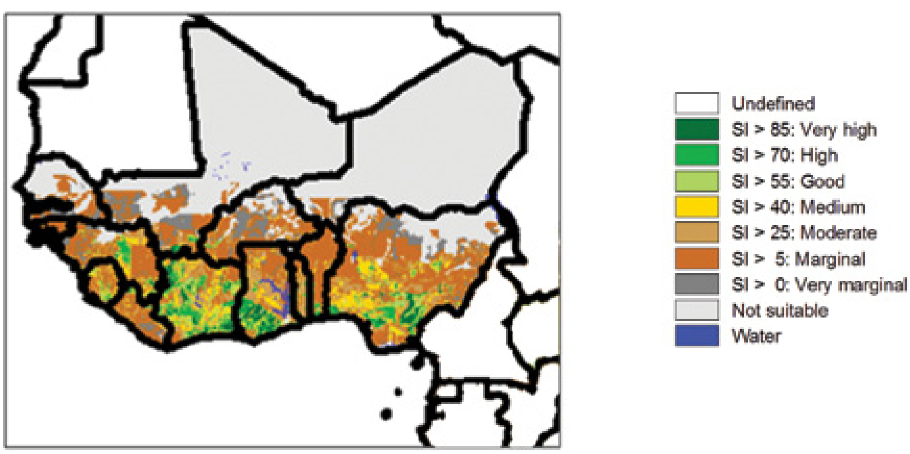


Figure 11: Cassava suitability map by IIASA.

3.2.4. Castor (Ricinus communis)

The castor oil plant, Ricinus communis, also belongs to the Euphorbiaceae family. The name in Latin means tick, which probably reflects the tick-lookalike structure of the seed. Its seed is the well-known castor bean, which, despite its name, is not a bean but a nut. Castor probably originates from East Africa. It is used already for 6000 years by the Egyptians and for at least for 4000 years in India. Nowadays, the plants are widespread in the tropics and the subtropics, grown either as perennials or annuals for oil production but also as an ornamental plant. The seed is highly toxic due to the presence of ricin, a protein synthesis inhibitor in eukaryotic cells. The seed oil has medicinal uses as purgative and is rich in the triglyceride ricinolein, which is used as lubricant and for the production of bioplastics.

The climate criteria used were:

Parameter	Zones			
	Green	Light green	Yellow	Red
Precipitation annual (mm)	350-750	250-350 and 750-1000	60-250 and 1000-1200	<60 and >1200
Mean temperature wettest quarter (°C)	20-27	27-30 and <20	30-33	>33

The suitability maps are shown below.

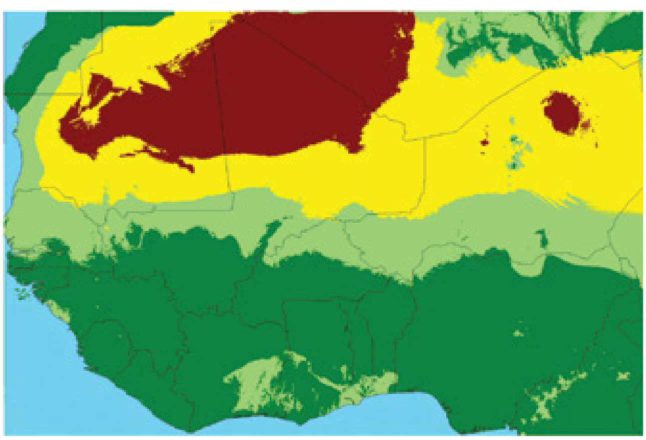


Figure 12: Castor climate suitability maps for the ECOWAS region: mean temperature wettest quarter. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria

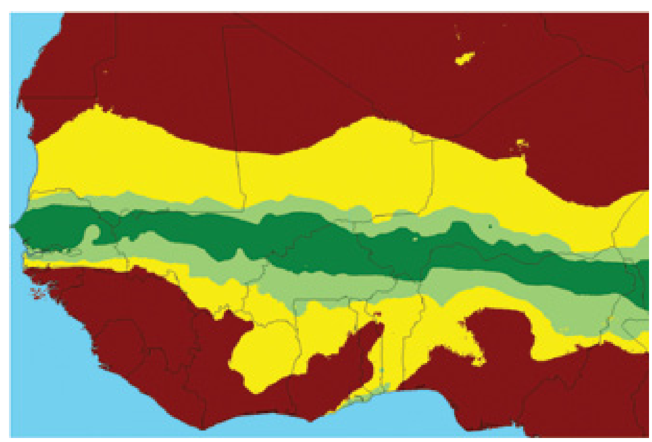


Figure 13: Castor climate suitability maps for the ECOWAS region: annual precipitation. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria

The climate criteria were tested by making a suitability map for Brazil and India; the major producers of castor to date. The maps clearly showed that the most suitable regions coincided with the major production areas for castor in these countries. The maps for the ECOWAS region show a very narrow belt of suitability along the central part of the region. So, there is a possibility to grow castor, but the yields may vary considerably from one year to another. In our evaluation of Castor as a potential bio-energy feedstock crop, it is critical to understand that the current applications of Castor oil are primarily of an industrial nature other than as an energy feedstock; in fact castor oil as a result of its unique fatty acid profile is suboptimal for the use as feedstock in biodiesel production (based on trans-esterification) but is very well suited for applications as a lubricant or as a feedstock for green polymer chemistry. Because of its value for these niche applications, Castor oil is quite expensive and currently also not economical as an energy feedstock. Development of new genetics and/or larger scale professional production of the crop may change this application pattern in the future.

3.2.5. Crambe abyssinica

Crambe abyssinica is an oilseed crop, native to the Mediterranean area. According to the Alternative Field Crops Manual, it is used as an industrial lubricant, a corrosion inhibitor, and as an ingredient in the manufacture of synthetic rubber. It can also be used in surfactants and slip and coating agents. Recently it has been identified as a potential feedstock crop for bio-energy production.

The climate criteria used were

Parameter	Zones			
	Green	Light green	Yellow	Red
Precipitation wettest quarter (mm)	150-250	100-150 and 250-350	0-100 and 350-450	>450
Mean temperature wettest quarter (°C)	16.2-22	5.7-16.2 and 22-24	< 5.7 and 24-26	>26

For the same reasons as described above for Camelina, we believe that the current variants of Crambe are not suitable to grow in the ECOWAS region. The most important suitability maps for Crambe are shown below. From

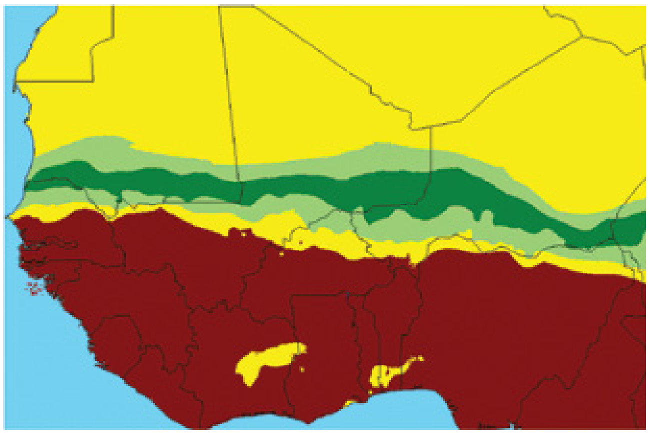


Figure 14: Crambe climate suitability maps for the ECOWAS region: precipitation wettest quarter. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria

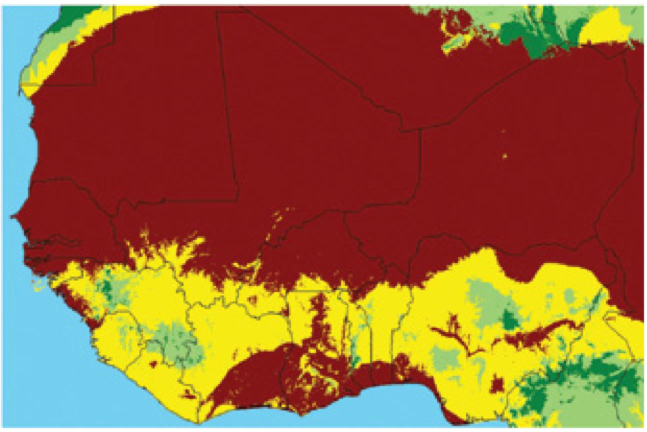


Figure 15: Crambe climate suitability maps for the ECOWAS region: mean temperature wettest quarter. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria

these maps it is clear that the ECOWAS region is not a good place to grow Crambe. This crop is suited for more temperate zones, probably just south of existing canola/rapeseed belts.

Another key factor to consider is the characteristics of Crambe oil. It is very rich in a long chain fatty acid, erucic acid, and is for this reason quite popular for high-value applications in polymer chemistry and other industrial applications (synthetic rubber, plastic films, adhesives). This makes it a relatively expensive oil and today not economical for bio-energy production.

3.2.6. Ground nut (Arachis hypogaea)

In contrast to castor bean, the groundnut is not a nut but a real bean. The plant belongs to the family of the Fabaceae and is able to bind atmospheric nitrogen, making it independent of nitrogen fertilisation. Humans have cultivated this plant for at least 7000 years in the northern part of South America and in Mesoamerica. When the flowers are pollinated, the flower stalks start growing and pushes the young bean into the ground where it develops further. The bean contains 2-4 seeds that have a relatively high oil content, which contains only a small amount of saturated fatty acids and a high level of tocopherol. Now the plant is grown in the semi arid tropics and in the warmer temperate zones. Because groundnut is being used as a food crop, its use for bio-energy production can only be considered in case of overproduction.

The climate criteria used are:

Parameter	Zones			
	Green	Light green	Yellow	Red
Precipitation wettest quarter (mm)	900-1200	800-900 and 1200-1300	300-800 and 1300-1400	<300 and >1400
Mean temperature wettest quarter (°C)	24-29	21-24 and 29-33	18-21 and 33-37	<18 and >37

The climate suitability maps are shown in figure 10.

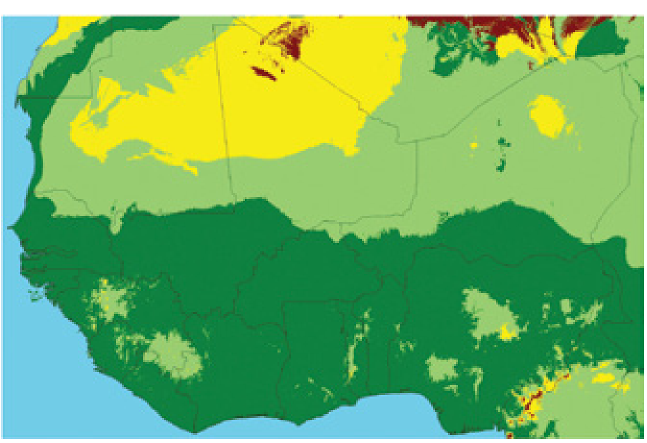


Figure 16: Climate suitability for groundnut: mean temperature of the wettest quarter. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria

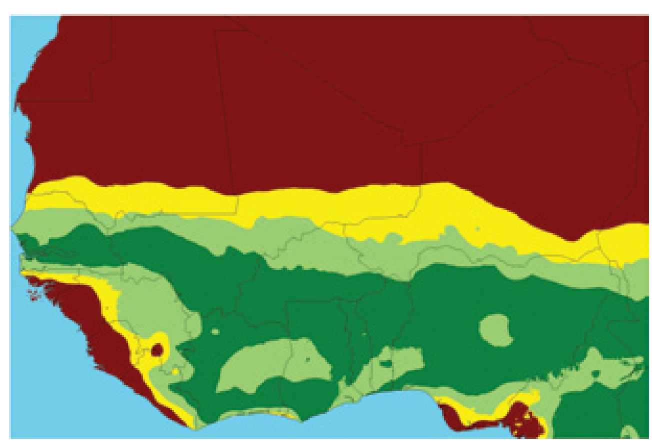


Figure 17: Climate suitability for groundnut: precipitation wettest quarter. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria

Our judgment is that groundnut has a good potential for the ECOWAS region, since it is grown here extensively. It is an annual with a 4-months growth cycle, especially suited for the more central-south part of the ECOWAS region, as can be observed from the IIASA map shown in figure 18.

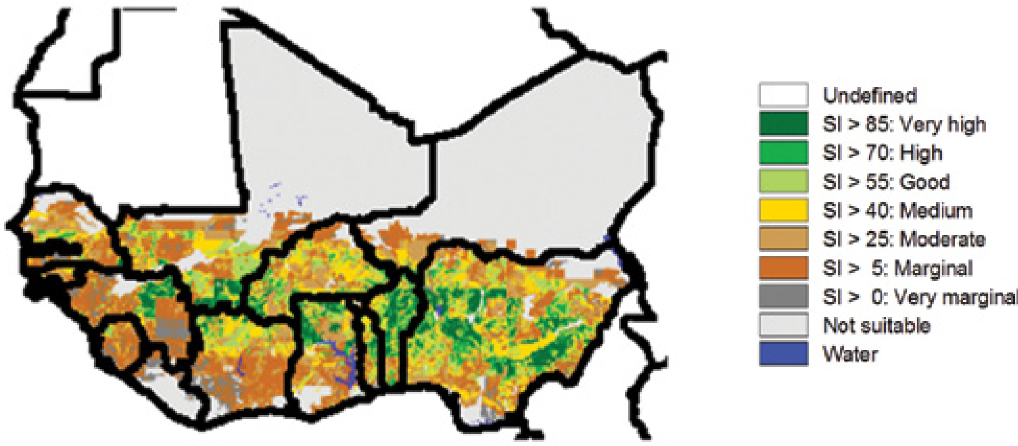


Figure 18: IIASA map for suitability of the West African region for groundnut.

3.2.7. Jatropha curcas

Jatropha curcas is the third plant species in this evaluation belonging to the Euphorbiaceae family. It grows into a shrub or a small tree. The plant is native to Central America. It is said that Portuguese traders in the 16th century took Jatropha to Africa and India, where its fast growth, easiness to propagate by sticks and inedible leaves make an ideal plant for fences to prevent animals grazing on food crops.

The oil in the grains was quickly discovered for different artisanal applications. The plant produces bunches fruits with a diameter of 2-3 cm, which contain usually 3 black 1 cm long seeds or grains. The grains have thick black hulls protecting the grain kernels. The kernels are rich in oil and protein. One ton of Jatropha grains typically results after processing in 300-350 kg of oil, 350-400 kg of combustible hulls and the balance in a Jatropha Kernel Meal containing up to 65% proteins.

Jatropha curcas can be planted as a commercial crop in a band 25 degrees north and south of the equator on a range of soil types and has the potential to evolve into a widespread non-edible feedstock crop on condition that adapted genetics of the crop are planted in suitable areas and are managed professionally towards productive cultivation. The crop is very sensitive to frost and periods of continuous rain. The crop should not be planted in areas where water stagnation is a risk factor. For these reasons, Jatropha curcas will not be cultivated successfully in areas of high elevation and in areas where tropical rainforests thrive. These biological attributes of Jatropha are generally stated as some of the foundations for the potential environmental sustainability of Jatropha curcas. In recent years Jatropha curcas has been planted as a non-edible feedstock crop for bio-energy in a number of production systems around the world. The crop is grown in a number of smaller scale plantations typically managed by early investors in the crop. The crop is also grown in a number of out-grower networks, which have been established in several countries as a result of a combination of government support and private investment. The oil produced by Jatropha has attributes making it a very good feedstock for esterification into biodiesel or hydrogenation into green diesel and green kerosene respectively. The Jatropha oil can also be utilized as a direct energy source in generators adapted for vegetable oil feedstock and has traditionally been used in oil lamps or as a feedstock for the production of soap products or candles.

More recently, early evidence has been gathered that the Jatropha Kernel Meal can be turned into a protein rich feedstock for animal feed production. The protein digestibility and the amino acid composition of the Jatropha Kernel Meal Proteins are similar to the ones of Soybean meal. The cake resulting from a simple pressing of the Jatropha grains has been utilized as a biomass source for the production of energy rich briquettes and has also been used as a (co-) fertilizer.

The climate criteria used were:

Parameter	Zones			
	Green	Light green	Yellow	Red
Annual rainfall (mm)	1270 – 1800	865 - 1270 and 1800 -2300	680 - 865 and 2300 - 2800	< 680 and > 2800
Precipitation wettest quarter (mm)	500 - 700	700 - 900	900 -1200	>1200
Max temperature warmest month (°C)	31-36	26-31 and 36-38	22-26 and 38-42	<22 and >42
Precipitation seasonality*	66 - 117	45 - 66 and 117 - 140	0 - 14, 23 – 45 and 140 - 165	14 - 23 and > 165

*Precipitation seasonality: standard deviation of monthly precipitation x 100 over mean monthly precipitation

The most important suitability maps are shown below.

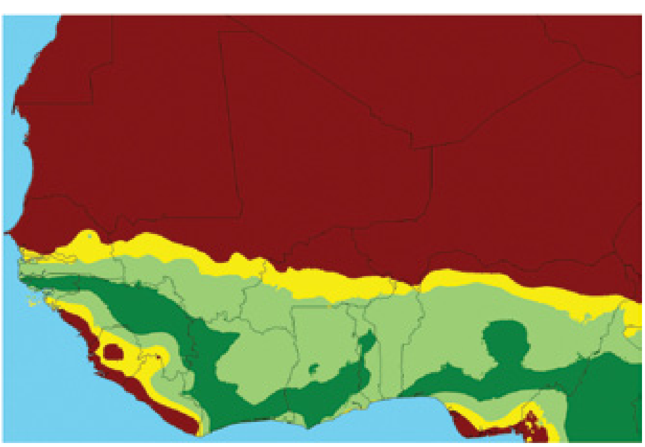


Figure 19: Jatropha climate suitability maps for the ECOWAS region: annual precipitation. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria.

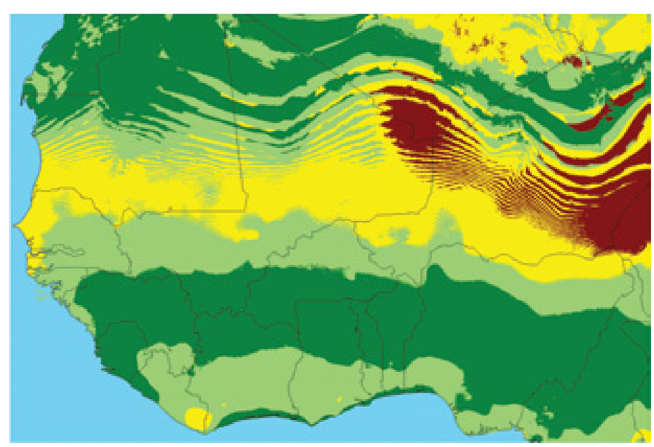


Figure 20: Jatropha climate suitability maps for the ECOWAS region: precipitation seasonality. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria.

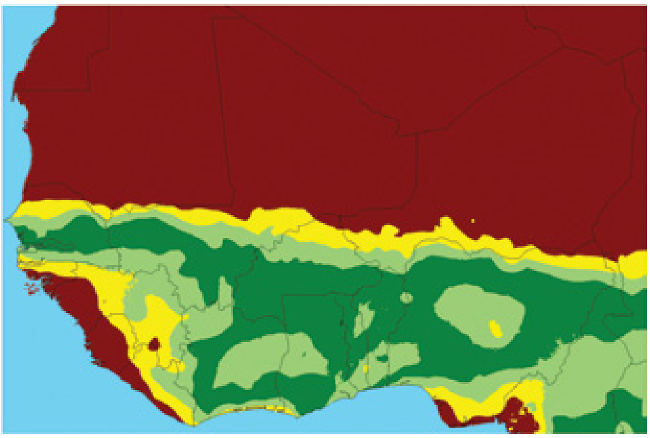


Figure 21: Jatropha climate suitability maps for the ECOWAS region: precipitation wettest quarter. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria.

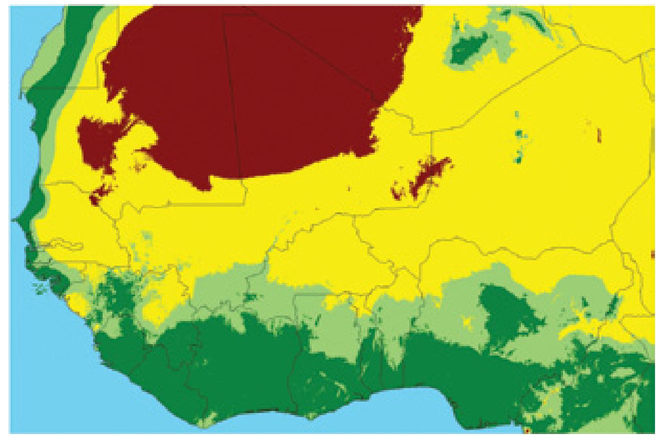


Figure 22: Jatropha climate suitability maps for the ECOWAS region: maximum temperature of the warmest month. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria.

From these maps it is clear that the optimal regions for Jatropha fall within the Cassava belt and the Grain Sorghum belt. The Millet belt is too dry for Jatropha to be grown.

QUINVITA has observed, on the basis of a large number of data collected worldwide in Jatropha projects that the following factors limit the crop significantly:

• Jatropha is very frost sensitive and as a perennial crop should never be planted in areas where over a long term there is even a small chance on frost. In addition we have observed that lower night temperatures in the colder months result in a higher incidence of fungal diseases like Oidium.

• Jatropha plants are very sensitive to water logging. For this reason One should avoid planting Jatropha in areas with excessive rainfall; a general rule of thumb is that areas well suited for oil palm cultivation should at all cost be avoided as target areas for Jatropha planting.

• Jatropha also responds very strongly to different seasonality factors in relation to rainfall: it prefers to have a period of drought and as a succulent can then best exploit its unique water management characteristics. On the other side, we have observed that excessive rain and overcast weather during the flowering period of Jatropha results in suboptimal insect pollination of the crop and thus lower fruit setting and oil production.

• Jatropha responds strongly by flower- and bud abortion on excessively high temperatures in the field during flowering; this again limits the oil yield potential of the crop under these circumstances.

• Finally, Jatropha can survive periods of severe drought but areas with systematic low total rainfall patterns will have a greatly reduced grain- and oil yield. Jatropha like any other oil crop needs a minimum rainfall pattern to allow optimal fruit development and oil filling in the grains.

• The characteristics of Jatropha curcas make it a crop that can survive as a plant very adverse conditions but under these climatologically ''marginal'' conditions the yield of Jatropha grain and oil, its primary output product, are greatly reduced to a point where growing the crop becomes un-economical. QUINVITA strongly believes that the attribute ''Miracle Crop'' to be grown in ''marginal areas has resulted in a lot of frustration amongst early believers in the crop. Apart from the fact that ''Miracle crops'' do not exist, we believe a professional approach to Jatropha adaptation, better genetics and agronomy is the only guarantee to develop Jatropha curcas into a viable crop integrated as a valuable addition to the crop portfolio of farmers in ECOWAS and around the world.

3.2.8. Sweet Sorghum (sweet version of Sorghum bicolor)

Sorghum is a genus from the Poaceae (grass) family with species occurring in any continent. Grain Sorghum is an important staple food for rural people in the semi-arid tropics, where it is grown primarily for grain and as fodder plant under relative dry conditions. Sweet Sorghum has the property of accumulating a high sugar level in the stems of the plant, just like sugar cane, but in contrast to sugar cane, it does not need so much water. This does not mean that by definition Sweet Sorghum will produce very well in the Grain Sorghum belt, but it will thrive better under dry conditions than many other crops primarily grown for syrup production. The stalks are used to squeeze out the syrup, which is then fermented to ethanol.

The climate criteria used were:

Parameter	Zones			
	Green	Light green	Yellow	Red
Precipitation wettest quarter (mm)	600 - 1000	400 – 600 and 1000 - 1200	300 – 400 and 1200 - 2500	<300 and >2500
Mean temperature wettest quarter (°C)	24-26	21-24 and 26-32	18-21 and 32-40	<18 and >40

The most important suitability maps are shown below.

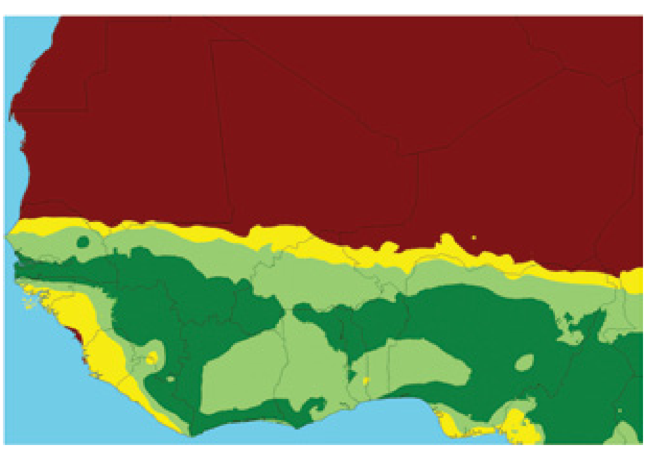


Figure 23: Suitability maps for Sweet Sorghum: precipitation wettest quarter. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria.

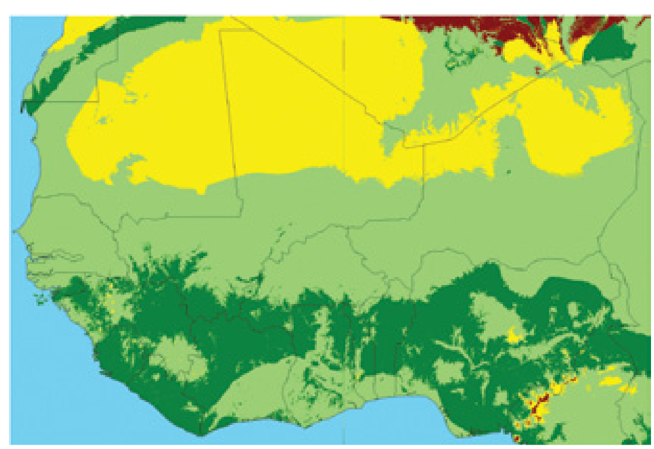


Figure 24: Suitability maps for Sweet Sorghum: mean temperature wettest quarter. Green = very suitable, light green = suitable, yellow = less suitable, red = unsuitable according to the specific criteria.

These maps clearly show that the ECOWAS region is suitable to grow Sweet Sorghum. One of the conceptual decisions to be taken for Sweet Sorghum is which varieties/hybrids will be grown. In the Sweet Sorghum research communities there are two schools of thought: one school believes that the goal of a sweet sorghum development should be the conversion of grain sorghum hybrids into ''sweet'' versions. The advantage of this strategy is that farmers can continue to harvest grains from their crop and, at the end of the season, they can also harvest biomass as a feedstock for ethanol production. The disadvantage of this approach is that the biomass yields will reach a genetic and an economic ceiling and that grain yields will in such a development program also be suboptimal as breeding for grain yield is not anymore the top priority for these hybrids.

The second school of thought believes one needs to develop dedicated ''energy sweet sorghum'' and one needs to essentially ignore the grain yield one will obtain from these hybrids. The advantage of this approach is the much higher biomass yields of these dedicated hybrids; the disadvantage is the fact that farmers will collect very limited amounts of grain from these hybrids. In light of the above we believe that the best production areas for Sweet Sorghum will depend on the strategy followed: ''the sweet grain sorghum hybrids'' will have an adaptation largely overlapping with the current grain sorghum grown area; ''the sweet energy sorghum hybrids'' can still benefit from the relative drought tolerance of Sorghum as a crop but are expected to give higher biomass yields with slightly higher rainfalls compared to the typical ''grain sorghum''.

QUINVITA believes it would be very unwise at this stage to make a choice between the ''sweet sorghum'' schools of thought. In fact it may be that both models are economically viable and that as a result the potential area for Sweet sorghum as a whole is widened when both types of hybrids reach the market place in parallel. The comparison of both models will be an important research topic for a ''sweet sorghum '' center of excellence in the ECOWAS region.

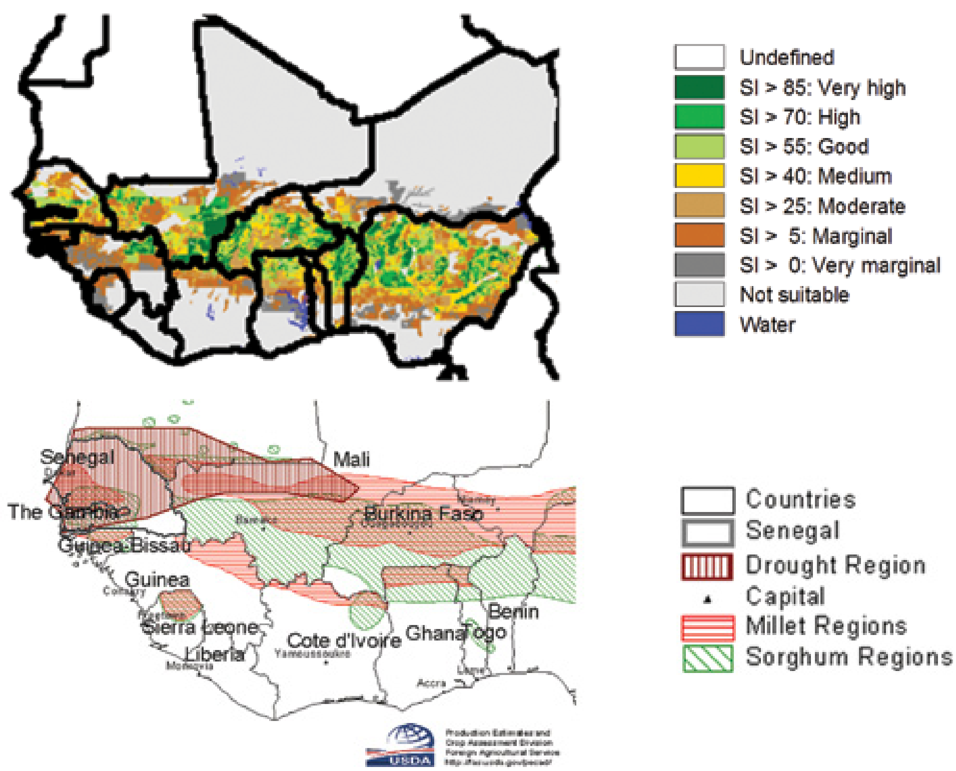


Figure 25: Top: IIASA suitability map of Grain Sorghum based on actual yields in the region. Bottom: crop belts depicting the sorghum growing regions

3.3. GIS-based land issue related maps for ECOWAS region countries

A per country inventory is being made of maps that give the current ground cover, biodiversity hot spots, erosion and flooding sensitive areas, main food producing regions and population densities. On top of that, data are collected on land ownerships issues, land use changes in the last ten years and infrastructure development. This part of the research is work in progress. In this first report we will give some information and the results of a preliminary analysis.

In first instance we looked at the surface area, population density and amount of arable land available in each country. The data were obtained from the FAO-website and summarized in table 3.

Country	Area (km^2)	Pop. Dens (#/km^2)	Arable land/capita (ha)	Potential arable land in use (%)
Benin	112.620	60,0	0,36	19,3
Burkina Faso	274.200	46,0	0,35	17,5
Cabo Verde	4.033	101,0	0,09	nd
Cote d'Ivoire	322.460	52,0	0,28	14,1
Ghana	239.460	85,0	0,16	23,6
Guinea	245.857	32,0	0,26	5,5
Guinea-Bissau	36.120	37,0	0,10	14,7
Liberia	111.370	30,0	0,16	6,0
Mali	1.240.000	9,1	0,18	9,4
Niger	1.267.000	8,4	0,44	35,1
Nigeria	923.768	141,0	0,41	49,4
Senegal	196.190	54,0	0,22	17,7
Sierra Leone	71.740	78,0	0,29	13,7
The Gambia	11.300	129,0	0,12	21,9
Togo	56.785	93,0	0,61	56,6

Table 3: Surface area, population density, arable land per capita and potential arable land in use for the ECOWAS countries.

For Cape Verde no data on the use of the arable land was available. The conclusion from this table is, that countries like Togo and Nigeria already have a very extended agriculture that encompass a large part of the total arable land that is available in the country. The next step was to investigate where agriculture took place. The current ground cover, population density and potential for rain-fed agriculture in the ECOWAS region are given in figures 26, 27 and 28.

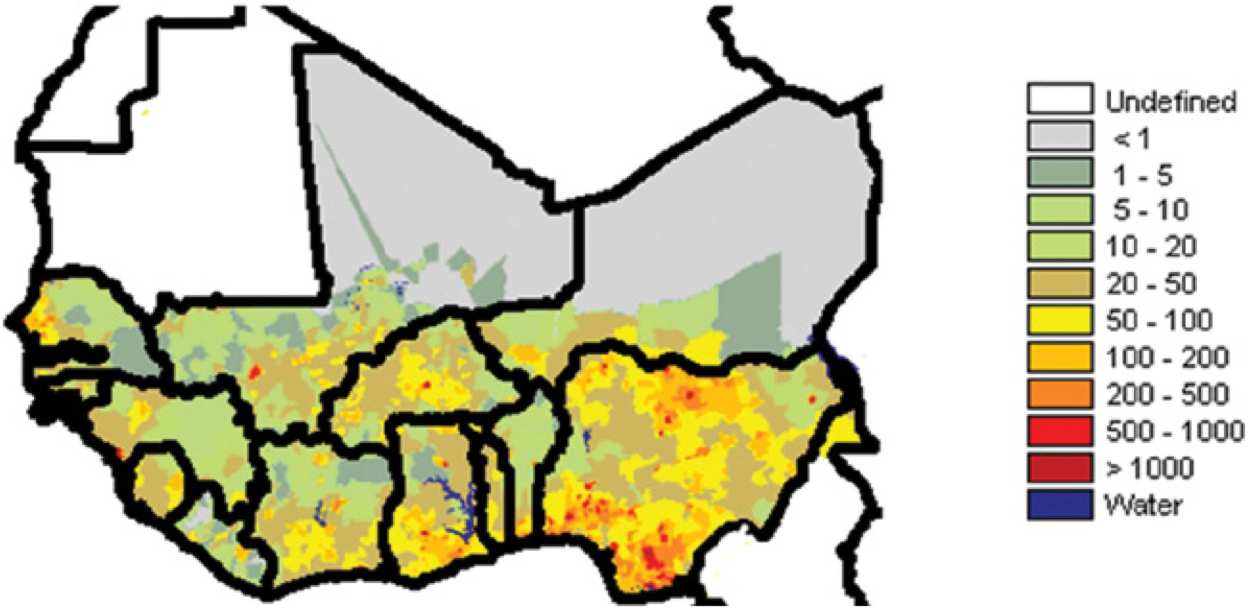


Figure 26: Population density in the ECOWAS region (IIASA).

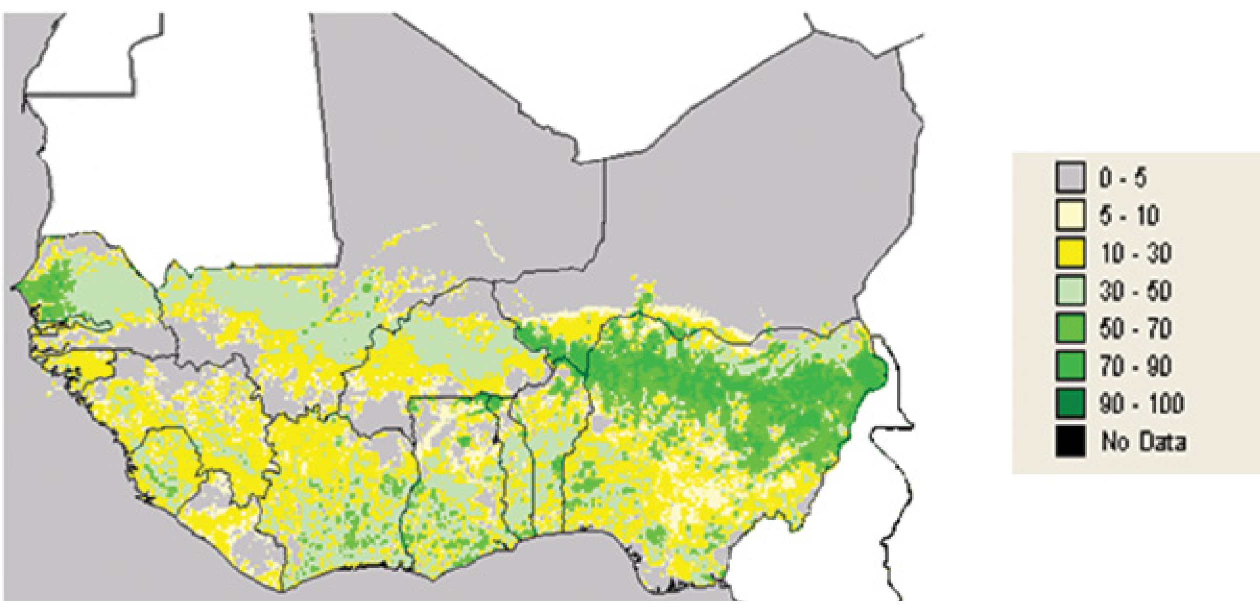


Figure 27: Percentage cultivated land and suitability for rain-fed crops excluding forest ecosystems (IIASA).

Figure 27 makes clear that a large part of the ECOWAS region is very suited for rain-fed agriculture. With the exception of the northern parts of Mali and Niger and the forest areas, the rain-fed agriculture is broadly dispersed over the region.

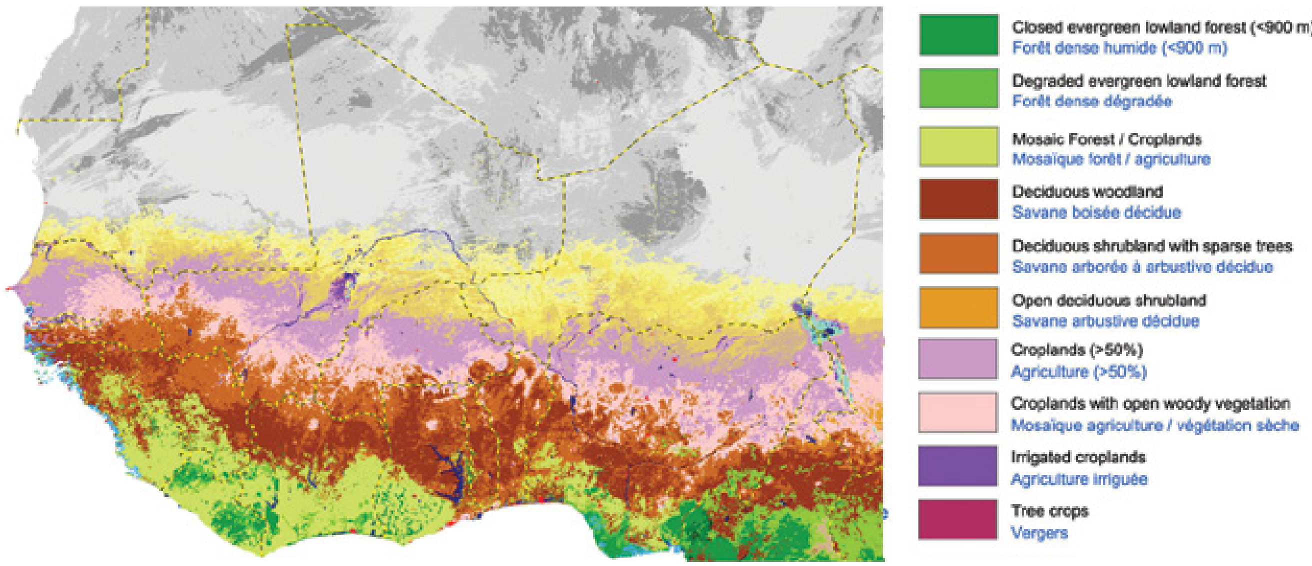


Figure 28: Ground cover in the ECOWAS region in 2000 and part of the legend (source European commission). For the complete legend see appendix 2.

The croplands (light pink, light purple, light green in figure 28) form 2 belts in the central and southern part of the region, separated by a belt of closed to open shrub-grassland-forest mixed with agriculture (light and dark brown). The small dark green areas are the remainder of broad-leaved forests, still present in the Niger delta and the highlands of the west and south-western part of the region. These parts and the regularly flooded forests near the coast also contain the biodiversity hotspots (Figure 29).

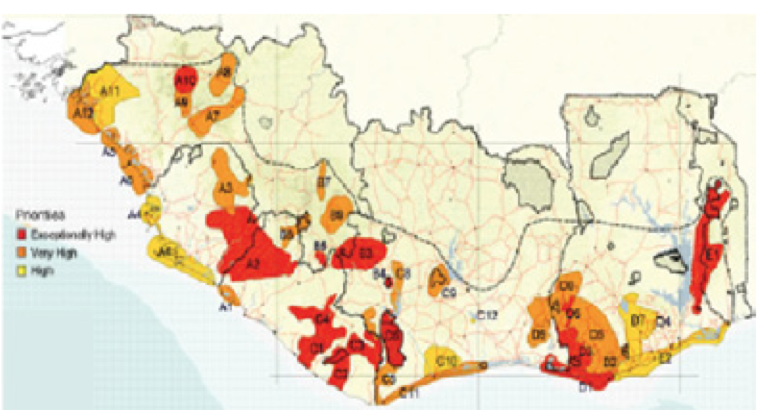


Figure 29: Biodiversity hotspots in the south-western part of the ECOWAS region.

The south-western parts of the region also suffer the most from climate and soil constraints for rain-fed agriculture. The IIASA map for these characteristics almost coincides with the greyish-green belt located in the southwest of figure 17 (not shown). This affects primarily countries like Liberia, Sierra Leone and the southern part of Ivory Coast and Ghana.

For determining which of the novel bio-energy crops mentioned in table 1 is suited for which country, we decided to use the following criteria:

- At least part of the agricultural land is green to dark green on the climate suitability maps for the bio-energy crop in question.

- Enough arable land available to extend rain-fed agriculture with (a) bio-energy crop(s).
- A net exporter of food.
- Current production volumes of the crop or a similar crop.
- The presence of bio-energy policies and regulations.
- The presence of projects on bio-energy crops in development and/or research.
- The presence of down-stream processing capacity for bio-energy crops and products.

Not all these parameters have been evaluated already extensively. This is part of the on-going work in phase 1 and 2 of the project. Nevertheless, we would want to present already the first results of our analysis, but future insights may still change this point of view. Our current opinion is summarized in table 4, in which we gave each crop a colour reflecting the opportunity as a bio-energy crop for the specific country.

Country	Camelina	Cashew	Cassava	Castor	Crambe	Ground-nut	Jatropha	Sweet Sorghum
Benin	Red	Light green	Green	Orange	Red	Light green	Green	Light green
Burkina Faso	Red	Orange	Red	Yellow	Red	Light green	Green	Green
Cabo Verde	Red	Red	Red	Red	Red	Red	Red	Red
Ghana	Red	Light green	Green	Light green	Red	Green	Green	Light green
Guinea	Red	Orange	Light green	Yellow	Red	Light green	Yellow	Light green
Guinea Bissau	Red	Light green	Yellow	Red	Red	Orange	Yellow	Yellow
Ivory Coast	Red	Green	Green	Red	Red	Light green	Light green	Light green
Liberia	Red	Red	Light green	Red	Red	Red	Red	Red
Mali	Red	Orange	Yellow	Yellow	Red	Light green	Green	Green
Niger	Red	Red	Orange	Light green	Red	Light green	Orange	Yellow
Nigeria	Red	Green	Green	Light green	Red	Green	Green	Green
Senegal	Red	Orange	Yellow	Light green	Red	Green	Light green	Light green
Sierra Leone	Red	Red	Light green	Red	Red	Yellow	Red	Yellow
The Gambia	Red	Red	Orange	Yellow	Red	Yellow	Light green	Yellow
Togo	Red	Orange	Light green	Orange	Red	Orange	Light green	Green

Table 4: Present point of view on the opportunity of the selected bio-energy crops for ECOWAS countries. Green: great opportunity, Light green: opportunity, Yellow: less opportunity, Orange: limited opportunity, Red: no opportunity.

Table 4 clearly reflects differences in the opportunities of the various countries for specific crops. As already stated in section 3.2; Camelina and Crambe are not suited for this region and Cape Verde is not suited for rain-fed agriculture.

Benin has a good potential for several of the crops we have analyzed. Cassava, Cashew and Groundnut are already grown in the country and a number of initiatives have been taken around Jatropha and early stage exploration of Sweet sorghum projects. Several points have to be watched with vigilance:

- The southern part of the country is growing oil palm. In these areas, it will be very difficult to compete with other (oil) crops.
- The country is a net exporter of Cassava products and is well placed to turn a portion of this stream, based on example projects in Nigeria into ethanol.
- The country probably has the luxury of choice and can afford not to consider castor beans as an industrial crop; however, this should not be excluded if a market exists for the end product use especially in the somewhat dryer growing areas in the very north of the country.

• The country has good conditions to grow Jatropha curcas successfully on condition these projects are managed professionally.

Burkina Faso is like all of the countries in the Northern part of the region very polarized, due to the gradient of rainfall from south to north. This makes most of the country suboptimal for production of Cassava and Cashew. Groundnut and Grain sorghum are grown in the country. The project team believes though that optimal production of Bio-energy crops like Jatropha and Sweet sorghum will need the rainfall patterns of the southern part of the country to produce significant quantities of oil and sweet biomass respectively. In the cotton growing belts of the country, synergies with Jatropha cultivation can be exploited. In the central dryer parts of the country, there is definitively a potential for Castor beans, although very little experience exists with the crop today. Jatropha projects grown the dryer northern part of the country for erosion control reasons will unlikely be significant sources of oil for energy applications of any sort.

Ghana has already a wide range of existing Bio-energy projects running today with mixed success. The country is blessed with rainfall patterns that are conducive to most of the crops we analyzed. The major challenge is the optimal conditioning of the right projects in the right area. This will be analyzed in more detail in the next phase of the project. Areas where industrial palm plantations can be grown will not allow competitive production of other crops; on the other hand, the extensive plantation experience in the country can help with the successful introduction of new crops like Jatropha on condition they are not co-cultivated with palm on marginal parts of the plantation but rather in the central areas of the country, which are better adapted to the crop. The presence of sugarcane to ethanol operations can form and excellent strategic synergy for the development of sweet sorghum in the country.

Guinea is producing significant quantities of groundnut and cassava but needs these entirely or primarily for food use today. The country is likely too wet for optimal castor production. The higher precipitation, during certain parts of the year also forms a serious risk for productivity reduction in potential Jatropha projects. We believe the crop may have limited potential in the North Eastern part of the country. Sweet Sorghum, especially grown as dedicated energy crops will likely have a clear potential in the country, especially in conjunction with existing ethanol plants operating in the area.

Guinea Bissau has a limited potential for cassava and needs all the production for food purposes. The rainfall patterns in the country are also not conducive for optimal production of Castor Bean, Groundnut and Jatropha. Some groundnut is produced today in specific parts of the country. Dedicated Energy Sweet Sorghum may have potential, although the rainfall patterns may be more conducive for successful sugarcane production. Cashew nuts are the major export crops and the country can develop at least a portion of its bio-energy strategy on the surplus fruit production and conversion technology that can exploit this.

Ivory Coast has the same luxury and challenges like Ghana, in that is has a wide rainfall spectrum and has choices for Novel Bio-energy projects to be developed. Again, the key objective should be to position the right crops in the right areas. Jatropha should be grown in the northern parts of the country and not in the south where it is too wet. The country is probably too wet for Castor cultivation. It is in very good position to further develop a successful ethanol business on the basis of cassava surpluses, sugarcane and sweet sorghum synergies and cashew fruits. Liberia is today growing palm plantations due to its high precipitation climate. It is also a relatively high producer of Cassava but needs this entire production for food uses. If in the future cassava productivity can be enhanced this may open further opportunities for bio-energy uses. The climate of the country is too wet for optimal Jatropha, sweet sorghum or castor production.

Mali is like Burkina Faso a country with strong rainfall gradients with a very dry northern part and a southern part conducive for cultivation of several of the analyzed bio-energy crops. The country is limited in cassava production but has significant efforts in Jatropha project development and has significant groundnut production. In the dryer central areas like in Burkina Faso, castor production has likely some potential and Jatropha projects grown for erosion control will again have limited bio-energy potential. If a sweet grain sorghum strategy can be developed, this could become a significant opportunity for the country.

Niger has the overall limiting factor of relatively low rainfall in the majority of its territory, limiting the potential for crop cultivation overall. Castor can have a clear potential as a crop under these conditions. The project team believes that the potential of Jatropha and Sweet sorghum as bio-energy crops will be limited due to too low precipitation levels. The country has limited cassava production and needs the entire production for food use. The groundnut production is significant but again food oriented.

Nigeria like Gambia and Ivory Coast has also a very wide rainfall pattern allowing the positioning of all the analyzed crops in its territory. The challenge for the country is to correctly position the correct projects in the right area. Jatropha and Sweet sorghum will have a limited potential as bio-energy crops in the northern part of the country limited by precipitation levels. In the south, bio-energy production will continue to be dominated by traditional crops like oil palm and sugarcane.

Senegal has a double gradient system in its agro-climatological zones: from south to north and from west to east. The country has limited cassava production and needs most of that for food purposes. In the central part of the country there will be a potential for the development of Castor as a crop. Contrary to what was believed before the potential for Jatropha and Sweet sorghum as bio energy crops will probably be restricted to the more southern and south western parts of the country, due to precipitation patterns. The majority of the groundnut production in Senegal has to our knowledge end uses in the food sector in Senegal and abroad.

Sierra Leone is located in area with in general high levels of precipitation and has attracted historically a number of oil palm and sugarcane projects. This climatic pattern is not conducive for the cultivation of Jatropha, castor and cashew. Quantities of groundnut production in the country are also limited and all directed towards food use. The cassava production in Sierra Leone is relatively important but the entire production is currently converted into food products. Sierra Leone can have some potential for the production of Sweet Sorghum as a dedicated energy crop in conjunction with sugarcane to ethanol projects. Especially the areas in the North East of the country adjacent to Guinea would be prime target areas for this opportunity.

The Gambia is after Cape Verde the country with the most limited arable land area in the region and the project team believes that this land base should in the first place be used for local food production. The production of Cassava is very limited today and all produce is directed towards food use. Crops that do have a potential as a bio-energy crop in The Gambia are Jatropha and Sweet Sorghum; for the latter it may be very helpful that in Senegal projects exist for the conversion of sugarcane to ethanol. In the case of Jatropha we believe there is a strong case to be made for projects integrating food and energy farming. These models are today already used in Mali and Burkina Faso. The project team will further analyze the critical success factors for these projects and make these available in follow on reports to the rest of the region.

Togo has again a relatively diverse rainfall pattern making it in principle suitable for a range of the bio-energy crops we have analyzed and/or selected. One factor to be taken into consideration is the relatively high degree of arable land use already today in Togo. This results in a necessity for Togo to focus very much on the development of integrated farming systems where food and energy are produced. There are today existing and successful co-operatives successful in the production of different food and industrial crops like corn and cotton. We believe it will be very important to involve these in the focused development in these integrated food, energy and fiber farming systems. Togo can in the region establish a lead role in the development of these kinds of models.

3.4. Overview of energy and fuel oil needs per country

The desk study by QUINVITA learned that a lot has been written on the energy use and needs of the ECOWAS countries in the last 5 years. To get a more accurate and up-to-date impression on the energy use and needs, ECREEE sent around a questionnaire and its staff to the ECOWAS member states. QUINVITA added a questionnaire specifically on bio-energy use, needs, projects, policies and legislation. The data received by these actions are available since June. The response to the QUINVITA questionnaire was 40%.

QUINVITA has drawn the following conclusions from this work:

• Data on energy use are only registered for energy sources that are being taxed or used for the generation of grid power. So, reliable information is present on the use of mineral fuels and power, but not for all countries. Use of biomass is recorded when it is used for co-firing in power plants. For the rest, the use and availability of biomass is based on the estimated numbers of households, people and yields.

• The generation of power depends for 80% on mineral energy sources. Although the WAPP has made a tremendous effort during the last years to connect the grid across country borders and to extend the grid to rural areas, the average electrification rate is low (<30%) with the exception of Cape Verde (95%). This means that the majority of communities on continental West Africa still depend on biomass for their daily energy need for cooking and heating.

• Up to 55% of the countries national budget is spent on the import and subsidy of mineral energy sources against hard currency. Even a big oil producer like Nigeria imports over 80% of its need for petrol, diesel, and aviation fuel, because the country lacks the petrochemical industry to convert their own crude oil resources.
Within this framework, it is not surprising to find that most of the renewable energy and energy efficiency actions of the last years have been dedicated to find energy sources that can be coupled to the grid and reduce the heavy burden of importing mineral energy sources: solar energy, wind energy and white power. The other major activities have been in the field of improving wood fuelled cooking stoves and the wood carbonization process. All the other applications of bio-energy only came into the picture after the 2010 publication of the UNDP-ECOWAS study on modern bio-energy.

3.5. Supportive framework

The use of biomass for energy production potentially may lead to many conflicts. To mention a few: the primary use of good agricultural land (food versus fuel debate), loss of biodiversity to excessive wood collection and/or plantation extension, disrespecting traditional land rights and small holders income by big plantation companies producing domestic products, export of bio-energy resources to please western markets instead of reducing the local dependency on mineral energy sources. For these reasons the use of bio-energy should be well regulated and be supported by a good policy and legislation framework.

However, only Cape Verde (2011), Senegal (2010) and Ghana (2011) have a renewable energy law. These are almost completely dedicated to the generation of power. Gambia has regulated a licensed collection of wood biomass in its forestry law, but did not implement any control system.

Draft laws and policies are more abundant in the ECOWAS region. Liberia recently set up a draft law on renewable energy and has published a national energy policy in 2009. Niger has a national strategy on renewable energy (2003) and on energy access (2006). Burkina Faso has a draft policy on biofuels. Mali has a national energy policy (2006) and a national strategy for the development of biofuels (2008). Nigeria has a renewable energy master plan (2005), a biofuels policy (2007) and even a biofuels agenda (2011). Senegal stressed the necessity to go back to agriculture in its plan REVA (2006) and has a biofuels policy trajectory (2007-2011). Most of these biofuel policies mention targets for blending gasoline with alcohol and diesel with biodiesel and sometimes also how to get there. Some of these stimulated the production of enormous ha of bio-energy crops; Jatropha, palm and cassava being the most prominent ones. If all these plans would have been realized, the region should now have over 2.5 million ha plantations of these crops fully dedicated to biofuel production. Evidently, this is not the case.

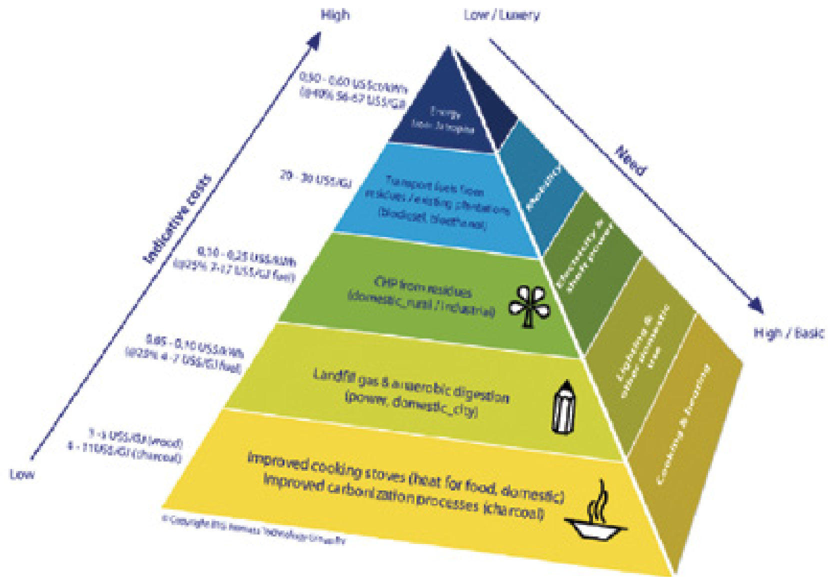


Figure 30: Maslow Bio-energy Pyramid for West Africa (UNDP)

The reason why bio-energy crops and biofuels get so little attention partly resides in the 2010 UNDP-ECOWAS study towards renewable energy. In this study the pyramid of Maslow (figure 19) is promoted as a guide for setting up renewable energy and energy efficiency policies. This pyramid emphasizes to give attention to the basal layers: improvements of cooking stoves and the carbonization process, the use of biogas from land fills and anaerobic digestion, combined heat and electricity generation from agricultural residues and waste streams. Only the top 2 layers are dedicated to transport fuels from residues of existing plantations and from specific bio-energy crops. The latter primarily being regarded as luxury, not to be invested in by the governments but only by private companies. This is pitiful, because it does not reflect the use of these crops for of-grid power generation for multifunctional platforms, especially in rural areas where grid extension is far too expensive, and for fuel in cleaner cooking stoves. It also does not take into consideration that growing these crops in an integrated system alongside food crops cannot only stimulate production of local energy, but also of food, feed and fiber crops. Recent examples that start to exploit these synergies have proven to be early success stories in Burkina Faso and in Tanzania. We believe that a balanced approach in this co-production system has a lot of merits; the more recent emphasis on a food versus fuel as opposed to a food AND fuels debate, have also not enhanced creative thinking in this respect. It is encouraging in this respect to see that international organizations like UNIDO, FAO and IFAD are more and more tackling the lack of food AND energy in integrated programs, with the overall goal of alleviating poverty in these areas through more agricultural and industrial developments. The findings in this study fully endorse this approach and can form additional bases for implementation of other success stories.

One thing is clear from the legislations and draft legislations published so far: primarily the in-country use of bio-energy is stimulated; export of that source to developed countries is discouraged by a.o. taxation schemes. In this way the West African governments try to stimulate using the bio-energy locally and thus making the country less dependent on import of expensive mineral fuels. It is going to be critical for future development that a balance can be found between necessary foreign investment and the application balance of the bio-energy produced. Schemes where initial volumes produced in a project are reserved for in–country use and where production of volumes above certain thresholds are allowed to be exported under agreed conditions will probably stimulate investment into the sector.

3.6. Overview of social and cultural parameters

3.6.1. Labour availability and prices

The ECOWAS region has one of the best GDP-growth figures of the developing countries with a decade average of ca. 6% per annum. However, this does not result in a decline in the figures for unemployment, underemployment and employment vulnerability. This is probably due to the even greater increase in labor productivity during the same period, which was ca. 12% per annum. This causes a real problem with youth unemployment, reaching 30% in some countries in the age 15-30. Most of this unemployment is faced in the urban areas. In some cases the rural areas show negative unemployment figures (ECOWAS, 2010). Combined with the strong population growth the high unemployment rates lead to a high poverty level. Over 80% of the people live from less than 2$ per day (UN, 2007). Although this seems very low, it is not low compared to other regions in Sub Saharan Africa, where labor and land productivity are even worse (figure 31). As much as 80% of the economically active people are

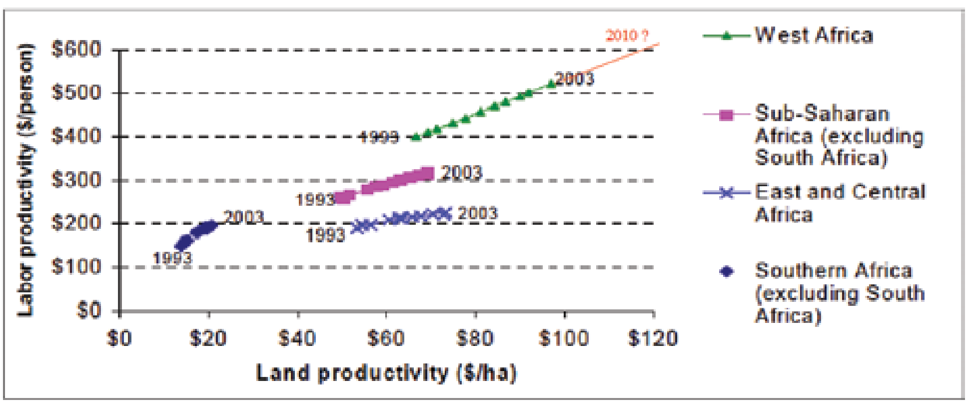


Figure 31: Labor productivity and Land Productivity in Africa. The red line is a projection. (UN, 2007)

underemployed or involved in non-decent work. Less than 12% is in jobs that have a decent remuneration. The informal private sector is 76.4% of the population, mostly active in agriculture. So, to stimulate employment, the governments set out plans to improve the living and working conditions in rural areas, to promote labor intensive economic activities, and to promote local processing of agricultural produce and mined minerals (ECOWAS, 2010). Co-production schemes of food and fuel can in many respects be one of the necessary mechanisms to combat poverty in these areas.

3.6.2. Existing farming systems

The basis of the farming systems in the ECOWAS region is given in figure 32.

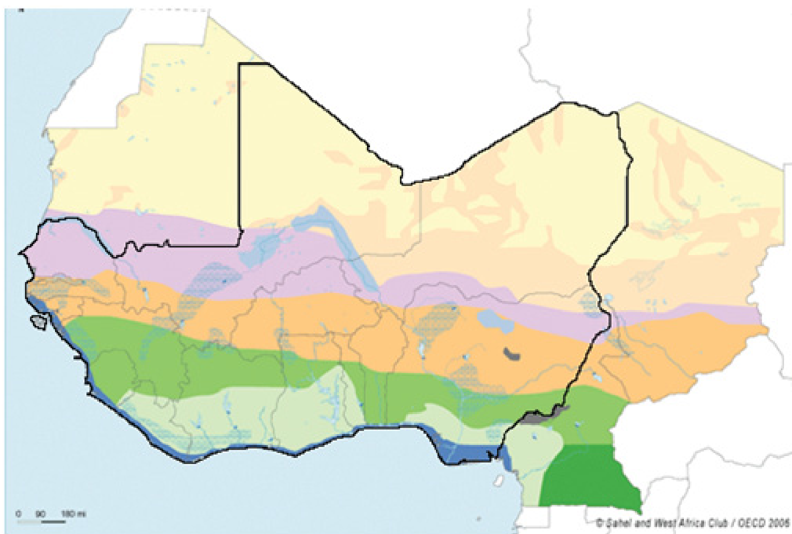
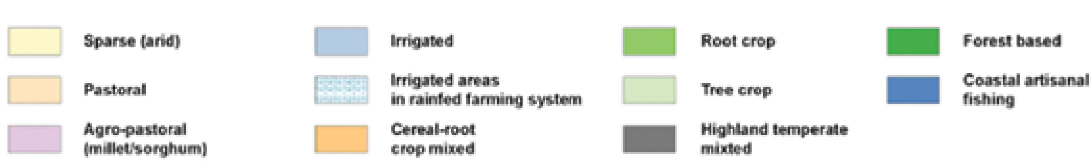


Figure 32: Farm production systems in West Africa (SWAC/OECD 2006)

This overview of the farming systems clearly reflects the crop-zones determined by the gradients in temperature, rainfall and the length of the growing season in the region from North to South. Although some big plantations exist in the area, the majority of the farmers are small-holders with a mixed cropping system on an ever decreasing average farm size (< 2 ha) due to the strong population growth and growth of urban areas. The key characteristics of these small holders are:



(Syngenta foundation, 2011)

The general agricultural practice level in Sub-Saharan Africa is quite low, resulting in a very low productivity per ha compared to the rest of the developing countries worldwide (figure 33). Fertilizer application depends on local

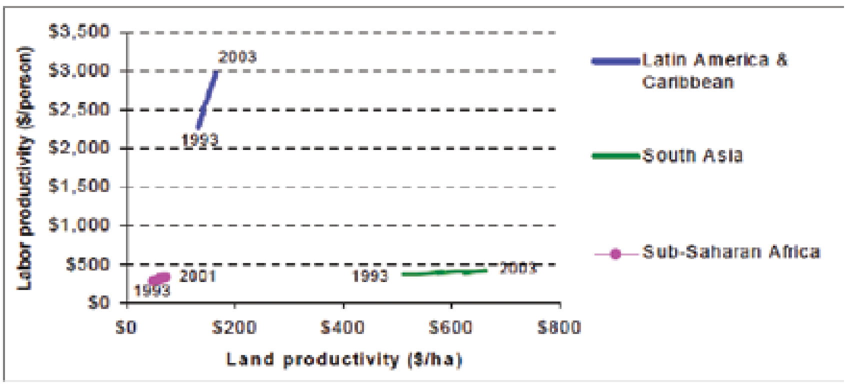


Figure 33: Labor and land productivity in the world (UN, 2007)

availability and financial resources. Irrigation can only be done in the neighborhood of rivers or water sources. In all other cases, it is too expensive. Productivity per ha strongly depends on rainfall, making harvest security vulnerable to longer spells of drought.

Women are particularly involved in growing and maintaining the crop, as well as in harvesting and post harvest processing. It is estimated that about 70-80% of the work on the farm is executed by women. Stimulation of good agricultural practice together with bio-energy crops and market diversification may give them a better entrepreneurial basis to work on.

3.7. Bio-energy crop projects and success/risks factors

Table 5 summarizes per country the various bio-energy crop projects initiated by governments or by private companies QUINVITA currently has been able to identify. The list needs to be reviewed in more detail in the next phase based on the current status of the projects.

Country	Bioenergy crop programs for novel crops	Public private initiatives
Benin	Cassava for transport, no data; Jc: for transport, no data; plan to convert 300,000 – 400,000 ha of wetlands to oil palm plantation;	Cassava 4800 ha for transport, Savé Nord du Benin; Jc for cooking, project JatroREF by GERES Benin and IRAM France; ALTERRE and GERES 150 Jv ha, NGO CERA Jc energy platform in Towe, Pobo city; “Our planet is a treasure”: Jc-based electrification of Okunfo; Altheo Solayon Jc program; 300,000 ha natural palm stands, 20,000 ha industrial palm plantations (Malaysian and South African investors); Green Waves, 250,000 ha for biofuel production

Country	Bioenergy crop programs for novel crops	Public private initiatives
Burkina Faso	Zianiaré: Cassava and Sweet Sorghum for ethanol cooking and other use;	JatroREF; Project in Dano (Dreyer Foundation) to replace wood with Jc oil; BELWET e.a.: Jc for transport, electricity and green fertilizer 50,000 ha; BELWET: Castor for non-specified use; DAGRIS and SN-CITEC: Cotton for cooking; Vivre au village; Jc for diesel generator; APROGER: Jc 3500 ha, Total-Suez, 20,500 ha Jc in Comoé;
Cabo Verde	Regarded as unsuitable for rain-fed agriculture	
Cote d'Ivoire	CNRA project on bioenergy: fast growing wood for cooking	I2T program bioenergy: use of cocoa and cassava residues for gas and electricity and cashew apple and cocoa for bioethanol and medical ethanol. Jatroci 10,000 ha at fètêhassou for biofuel; 21st Century Energy, 10,000 mt ethanol plant from cane, SS and maize; Badeco in Banandje, non-tox Jc for soap and biofuel; DekelOil, 68,000 ha of oil palm; ADERCI, 100,000 ha Jc for biofuel; 140,000 ha natural palm oil stands; 88,000 ha industrial palm oil (SIFCA, Wilmar International, Olam International, SIPEF)
Ghana	EU-funded italian Jc project with Ghana research institutes to build Jc processing plant at Walewale	Caltech Ventrures, cassava for ethanol, $ 6.5 million plant; Dumpong Biofuels at Aburi to turn Palm Oil into biodiesel; ScanFuel, 10,000 – 40,000 ha Jc plantations, Kumasi. Jatropha Africa, 50,000 ha; 300,000 ha industrial palm plantations (SITA, Unilver, Wilmar International, NORPALM) Abellon Clean Energy at Ashanti, 10,000 ha bamboo, palmarosa, sweet sorghum; Galten Global Alternative Energy, 100,000 ha Jc; SEKAB-Northern Sugar Resources and Constran S/A, 30,000 ha of sugar cane north side of Volta Lake; BioFuel Africa 23,762 ha Jc, Jatropha Africa 120,000 ha Jc;
Guinea		Crest Global Energy 900,000 ha of ?; 2,000,000 ha natural palm stands, 9,000 ha industrial palm plantations.
Guinea-Bissau	Gaia Movement Trust, 200 ha Jc.; ADPP project in training 1500 farmers to grow Jc and produce oil	Cashew is the main export crop
Liberia		Equatorial biofuels 80,000 ha of palm 30 km east of Buchanan; 70,000 ha industrial palm plantations (Sime Darby, Equatorial Palm Oil Company 20,000 ha of intensive Pongamia
Mali	PRODAB: Jatropha for transport and electricity: € 6200	Mali Biocarburant: Jc 3000 ha; Sud-Agri Sikasso: Jc 5000 ha; JMI KITA; Jc 3200 ha; Socimex Sélingué: Jc 1500 ha; AEDR Teriya Buggu: Jc 300 ha; MFC: Jc 500 ha; ONG GRAT Sikasso: Jc 100 ha; ALTERRE Koutiala: Jc 750 ha; all for transport, electricity, soap and cooking; JatroREF; SUKALA cane 5000 ha; Crest Global Energy 900,000 ha of?; Agroenerbia 40,000 ha for agrofuels; HUICOMA 100,000 ha on oleaginous crops; Assil Meroueh, 5000 ha Jc; LONHRO 20,000 ha sugar cane; SNF 15,000 ha oleaginous plants; Soc. Petrotech, 10,000 ha Jc for export; SOCIMEX 10,000 ha Jc Smallholders. SuSuMarb165, 40,000 ha sugar cane
Niger	Start with Moringa, Neem, Jc, Sunflower, Balanites. Ground nut is tested but yield is low.	IBS-Agroindustry, 50,000 ha of Jc.

Country	Bioenergy crop programs for novel crops	Public private initiatives
Nigeria		Global Green Field Dev. Group, 10,000 ha Jc in Kogi State, Itobe; Green Shields of Nation, Jc for biodiesel and anti-desertification in Kebbi, Sokoto, Zamfara, Katsina, Kano, Jigawa, Bauchi, Yobe, Borno, Adamawa and Gombe states. Global biofuels, 15 biofuel plants using SS 30,000 ha; NNPC 20,000 ha sugar cane, 10,000 ha cassava, 20,000 ha palm oil; Tolao Energy, 3000 hc Jc; 2,500,000 ha natural palm stands, 360,000 ha Industrial palm plantations (SIAT, Fri-EL Green Power); T4M, 10,000 ha for biofuel crops
Senegal		Durabilis, 1ha Jc; SBE 56 ha Jc.; JatroREF, EESF in Foundiougne introducing Jc in 675 ha existing farmland; Sustainable Agroenergy? ha of?; Crest Global Energy 900,000 ha of? 50,000 ha natural palm stands; SOPREEF SARL 1000t/y Jc grain processing plant in Sokone; ANOC-SARL 10,000 ha oa Jc in Salguir; BBE SA 1000 ha Jc in Mbadakhou
Sierra Leone	None	Sugar cane: 20,000 ha (Addax); 32,000 ha natural palm stands, 18,000 ha industrial palm plantations (Sierra Leone Agriculture, Quifel group, Gold Tree)
The Gambia	Jc for cooking; Castor for other use; Cashew for cooking; Groundnut for cooking	Cassia siamea for wood cooking and 3 other species; Industrial palm plantations? ha (Mercatalonia)
Togo		Greenleaf Global 2,700 ha Jc; 600,000 ha natural palm stands, 2,000 ha industrial palm plantations

Table 5: Inventory of bio-energy crop programs and public-private initiatives.

Many of these projects have been abandoned at an early or later stage of development. For Jatropha primarily due to the lack of a good yield from existing hedges, lack of good agricultural practice, improper placement of new plantations, the high production costs compared to (subsidized) mineral diesel and problems with land grabbing, i.e. not respecting the traditional land ownership rights. For palm primarily due to opposition by small holders producing products from natural palm stands and biodiversity activists and traditional landowners opposing the forest concessions given initially to palm plantation companies. The main success stories are found in cassava to ethanol in Nigeria and sugar cane to ethanol in Sierra Leone and Senegal.

The following factors are important for successful implementation of biofuel projects (modified from von Maltitz 2009).

- The availability of land with regard to local food production and food security.
- The land rights and resource rights of indigenous people need to be protected.
- Improvement of good agricultural practice. There is no excuse why yields in Africa should be so low with current knowledge on yield improvements (figure 34).

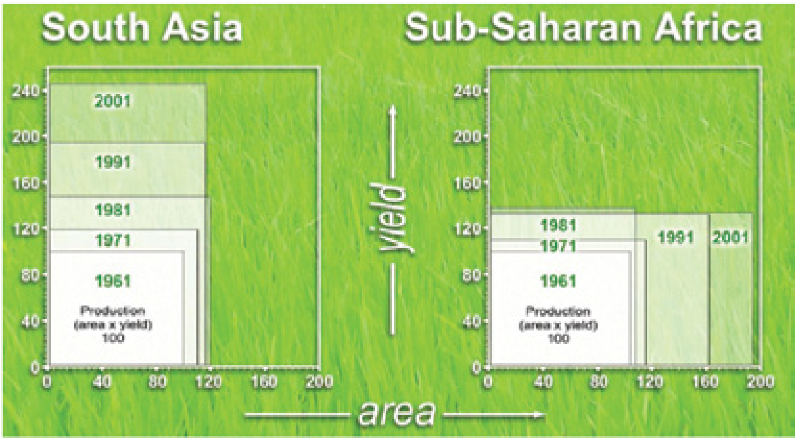


Figure 34: Development agricultural production area and yield in South East Asia and Sub Saharan Africa (Nijhoff, 2007).

• Biofuel production should benefit the West African country and not be used to meet global biofuel demands. The policies and legislation should support this.

• Biofuel projects must balance local and national benefits. Economic production efficiency might have to be forfeited to maximize local benefit.

• Deforestation and loss of biodiversity are key concerns. Protection is needed against both social and environmental bad practices.

• A cap on land available, a set of land allocation criteria, and monitoring systems to ensure these standards are respected need to be developed to limit food-fuel conflicts, ensure social sustainability, and keep biodiversity loss within acceptable limits.

• Maximize the value of the co-product stream coming from produce processing.

3.8. Short list of 3-4 crop-region combinations

In order to select 3-4 crop/region combinations a set of criteria was used.

3.8.1. Climate suitability

From the first report it is evident that from the 8 crops investigated in this project, 2 crops are absolutely not suited to grow in West Africa: Camelina and Crambe.

3.8.2. End market competition

Peanut, cashew and castor deliver products that are of high value for the food or special oils market. The current price of castor oil will never allow it to be transformed into biodiesel or straight energy oil bearing in mind that the current price of diesel from mineral oil is cheaper than the price of crude castor oil.

Peanut and cashew are high-value food components and important export products if produced with high quality. Many small holders have a lot of work in this sector. Mass production of nuts for processing to biodiesel and animal feed will not be competitive with the current food prices. The apples of cashew can be used for bio-energy production by turning their high sugar content either into ethanol by fermentation or into methane by anaerobic digestion. But this bio-energy path is regarded as added value to the food production chain. For these reasons, we will also disregard peanut and castor.

In the case of cashew, there is evidence that in several areas, large volumes of not utilized fruit are available for food applications and where left-overs could be used as a feedstock for ethanol or biogas production. We therefore have decided to also include cashew in our further analysis. One needs to do a gap analysis of the current state of this industry to explore the real potential.

Both criteria do not affect cassava (if correctly applied), Jatropha and sweet sorghum.

3.8.3. Presence of biofuel policies and legislation

As mentioned in paragraph 4, the supporting legal framework in most of the countries is still missing. The development of a correct, stimulating framework alongside the smart development of these crops can be very supportive and will be essential. But at this moment this criteria cannot be used to select for a specific crop or region.

3.8.4 Presence of biofuel projects

As listed in table 5, a lot of biofuel or bio-energy projects are known for the region. It seems that countries like Mali, Burkina Faso, and Nigeria have the longest and most successful experience with biofuel projects.

3.8.5 Selection of crop-region combinations

3.8.5.1 Sweet Sorghum

Based on the suitability maps we developed for sweet sorghum (figure 13), theoretically a large area of the ECOWAS countries can develop a sugar to ethanol business from sweet sorghum in the future. Sierra Leone and Nigeria have commercial sugar to ethanol plants running based on large-scale plantations of cassava or sugar cane. In coherence with the ethanol production, the end markets for ethanol (transport fuel, cooking stoves, heating water, oven) have also been developed and new applications for bio-ethanol are being created. Because Brazilian research has shown that sweet sorghum can be processed in sugar cane mills in times of low cane supply, it is interesting to investigate a potential role for sweet sorghum here as well. Then we have 2 regions of interest: the Northern part of Sierra Leone and central Senegal. Some parts of Nigeria with existing ethanol conversion technology from sugarcane and/or cassava can also be target areas for this application. We believe these are areas where dedicated sweet sorghum can be developed into a successful bio-energy crop and should be our primary areas of attention (figure 35).

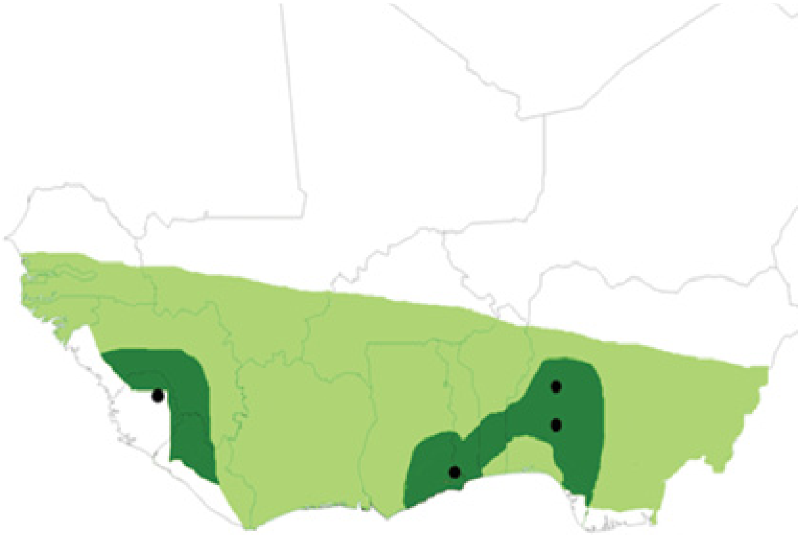


Figure 35: target area for further Sweet Sorghum study. Dark green: primary focus area; light green: secondary focus area. Black dots show existing ethanol plants processing sugarcane or cassava.

One school of thought also wants to develop a sweet version of grain sorghum (in general more resistant to drought). It remains to be seen if the additional income from the Sorghum grain can compensate for the lower biomass, and thus sugar production, to be anticipated in the traditional grain sorghum areas in West Africa. In addition, the crops grown in these areas will have to be the sole feedstock for ethanol conversion, as these areas do not allow the large-scale production of sugarcane or to a lesser extend cassava.

A phased approach, where dedicated sweet sorghum cultivation can benefit from existing cassava or sugarcane to ethanol know-how, followed by a smaller scale implementation of dedicated sweet sorghum plants moving to the northern growing areas, may be realistic. The map in figure 24 shows the selected target areas for further development.

3.8.5.2 Jatropha

Mali and Burkina Faso have the longest record in Jatropha projects. Most of these projects are located at the Southern part of the countries. In these areas there is Jatropha grain processing capacity and a market for the Jatropha oil, mainly used to power MFPs, to produce soap or to be turned into biodiesel on a small scale. Both countries are land-locked and diesel prices are relatively high. The large plantations projects projected for Ghana and Senegal were less successful so far and were not realised, although small experiments are on-going. In the case of Senegal, the primary reason was the fact that Jatropha was pushed in areas suboptimal for rainfall (too dry). In the case of Ghana, the project optimization is still ongoing. Recently major project intentions were also announced in Nigeria. Based on global experience QUINVITA has developed Jatropha's suitability to be grown as a sustainable oil crop, summarized in figures 19, 20, 21 and 21.

Based on the suitability maps and the ongoing and announced initiatives, a crop-region combination as shown on the map in figure 36 is suggested, using some of the more developed projects in Mali and Burkina Faso as examples to build on. Therefore we like to select the area shown on the map for a further Jatropha plantation evaluation. One of the important pre-judgements we will have to deal with upfront is the persisting belief in some countries that Jatropha is a miracle crop which can be developed into a successful oil crop in areas marginal for land quality and rainfall patterns. The reality is that in these areas (northern boundaries of the areas on the map), Jatropha can survive the harsh climatic conditions but will never become a significant source of energy oil. In these areas Jatropha can be evaluated as an anti-erosion crop with very limited potential as an oil feedstock crop.

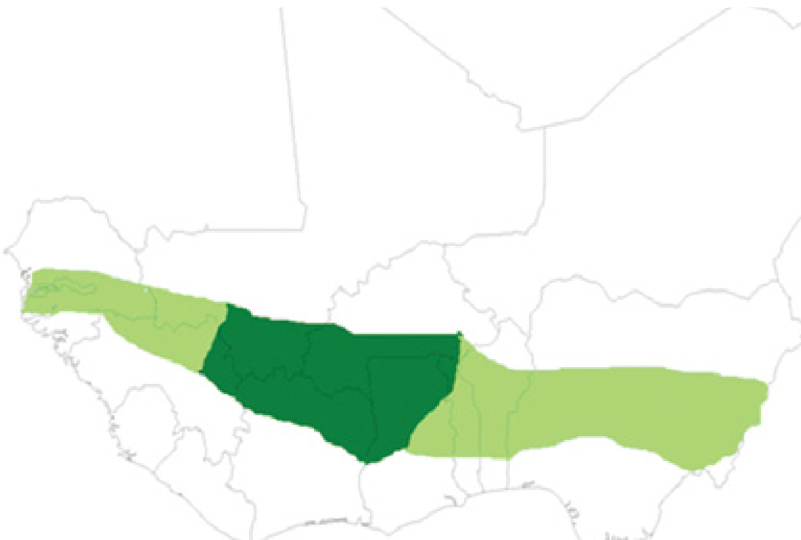


Figure 36: target area for further Jatropha study. Dark green: primary focus area; light green : secondary focus area.

3.8.5.3. Cassava

Based on climate suitability of cassava, a relatively large portion of the ECOWAS region can develop cassava into a bio-energy source. This is indicated on the suitability maps shown in Figure 6. However, it is very critical that in this case cassava is produced in first instance as a food crop and that supply for food applications is guaranteed. Table 6 summarizes the current supply demand situation for the different ECOWAS countries. Nigeria already has an extensive cassava for ethanol industry. This is the direct result of the fact that the country has a major surplus of production of cassava for food purposes. Very few other countries in West Africa are in a similar condition. Only Ghana, Benin and to a lesser extend Ivory Coast and Togo could consider the development of a cassava to ethanol industry based on a surplus production.

				FAOSTAT	Cassava		
					Tonnes roots		
Country	Area (km²)	Pop. Dens (#/km²)	Arable land/ capita (ha)	Potential arable land in use (%)	Production	Food supply	Surplus/ (shortage)
Benin	112.620	60,0	0,36	19,3	3.996.420	1.165.309	2.831.111
Burkina Faso	274.200	46,0	0,35	17,5	3.967	5.789	-1.813
Cabo Verde	4.033	101,0	0,09	nd	3.591	3.776	-185
Ghana	239.460	85,0	0,16	23,6	12.230.600	4.602.571	7.628.029
Guinea	245.857	32,0	0,26	5,5	989.326	982.551	6.775
Guinea-Bissau	36.120	37,0	0,10	14,7	45.000	43.397	1.603
Cote d'Ivoire	322.460	52,0	0,28	14,1	2.900.000	2.107.122	792.878
Liberia	111.370	30,0	0,16	6,0	493.706	550.000	-56.294
Mali	1.240.000	9,1	0,18	9,4	88.162	21.125	67.037
Niger	1.267.000	8.4	0,44	35,1	107.625	113.277	-5.652
Nigeria	923.768	141,0	0,41	49,4	36.804.300	16.890.305	19.913.995
Senegal	196.190	54,0	0,22	17,7	265.533	212.151	53.382
Sierra Leone	71.740	78,0	0,29	13,7	349.618	370.225	-20.607
The Gambia	11.300	129,0	0,12	21,9	7.370	8.199	-829
Togo	56.785	93,0	0,61	56,6	776.715	657.405	119.310
Total	5.112.903				59.061.933	27.733.193	31.328.740

Table 6: Production and consumption of Cassava in ECOWAS countries (FAOSTAT)

In countries where cassava suitability is good but current productivity is too low to supply local food needs, emphasis first needs to be put on the improvement of cassava productivity. In a later phase and only if a surplus production situation is reached, should these be a consideration for cassava to ethanol conversion. In our further study, these countries will at this point in time not be considered. On the map of figure 37, the target area for further study is indicated.

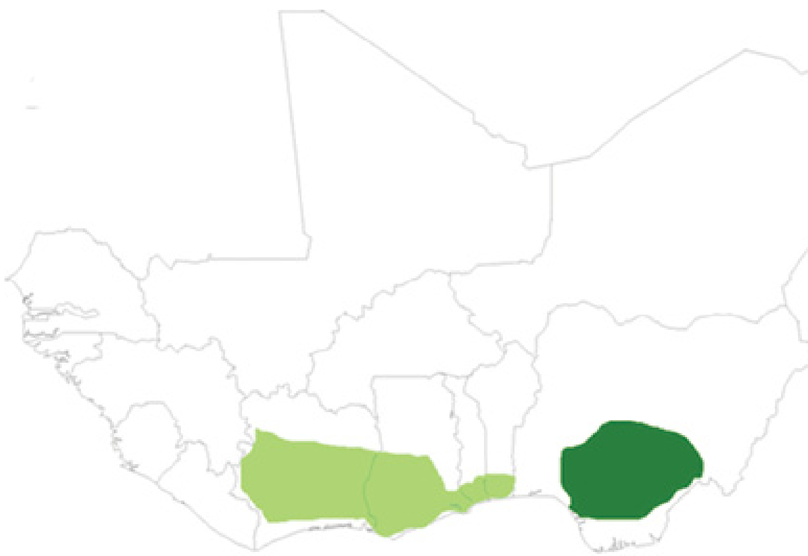


Figure 37: Target area for further Cassava study. Dark green: primary focus area; pale green secondary focus area.

The ethanol produced from cassava in Nigeria is not only used as transport fuel. It is also put on the market for cooking stove fuel, water heaters, and ovens. In Ghana, Caltech Ventures is planning to build a cassava to ethanol plant. Ghana is a major producer and exporter of various cassava products for food and feed. Cassava for the ethanol plant is ideally of the so-called high-sugar varieties. Learning from the Nigerian experience, it will be interesting to investigate the potential of these cassava varieties for ethanol production in Ghana and Benin and possibly in Ivory Coast and Togo in the future.

3.8.5.4. Cashew

Based on the analysis of the project team West Africa is the second most important producer of Cashew Nuts in the world (after India).

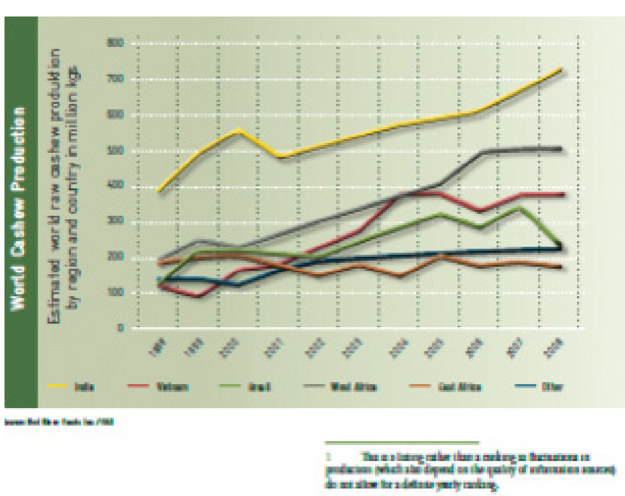


Figure 38: World Cashew production

During the Cashew production process in West Africa, today the major emphasis lies on the production of the cashew nuts and Nigeria (650K tons), Ivory Coast (350K tons), Guinea Bissau and Benin (100K tons) are the key producers in the area. In Mali, producing 3K tons of nuts, a small industry has been developed to also ''market'' cashew apples or fruits in analogy with Brazil where this is an important component of the value chain for Cashew farmers. In addition Brazil has also developed a major cashew apple processing industry with a range of end market applications in the food sector. We have not been able to find evidence that a similar development has started on a large scale in West Africa although this could also add significant value to the cashew value chain in the area. The question whether this industrial development can be accompanied by parallel value capture from the left-overs of the cashew apple processing (after delivery of the sap into a food application stream) into ethanol or biogas bio-energy applications is linked to the current state of affairs of the food processing industry from cashew apples.

Given the fact that today Nigeria and Ivory Coast are the primary producers of Cashew in the ECOWAS region, we suggest to focus our primary analysis on the state of affairs of the apple processing in these countries. Potential existing or emerging success stories can then be transposed to secondary target areas like Benin, Guinea Bissau and smaller producers like Ghana, Guinea, Mali, Senegal and Burkina Faso.

The focus map for the Cashew analysis derived from this analysis is shown below.

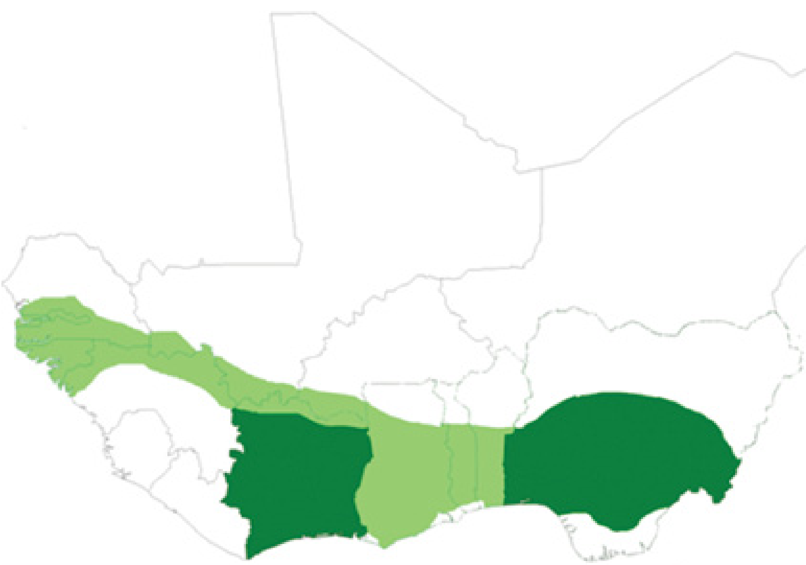


Figure 39: Target area for further Cashew study. Dark green: primary focus area; pale green secondary focus area

Appendix 1: List of figures and tables

Figures

Tables

Appendix 2: Legend to figure 28

Appendix 2: Project assessment of Jatropha projects in Mali, Burkina Faso and Ghana

Project assessment Tool Mali

General data	Company:	Mali BioCarburants	JMV Ecocarbone	IRAM-Geres	Sudagri	Mali Folke Center	AEDR
	Bioenergy crop:	Jatropha curcas	Jatropha curcas	Jatropha curcas	Jatropha curcas	Jatropha curcas	Jatropha curcas
	Location:	Koulikoro (transformation unit)	Kita, Sikasso	Sikasso	Sikasso	Garalo	Teriya Bugu
	Country:	Mali	Mali	Mali	Mali	Mali	Mali
	Start date:	2007; 2008 first planting		2007			2007
	Hectares planted:	1500 net ha Jatropha on 5000 ha farms	1500 net ha Jatropha on 5000 ha farms	250 net ha Jatropha	800 net ha Jatropha	<300 ha	<300 ha
	Type of project:	Outgrower network	Outgrower network	Outgrower network	Outgrower Network	Outgrowers	Outgrowers
	Nr of farmers in network:	2500-3000	2000	350		100-150	100-150
	Jatropha suitability risks:	total rainfall on the lower side	good	good	good	One part of the project is at high risk for low rainfall reasons	The project is in a high risk area for low rainfall reasons
Agricultural details	Crop rotation cycle:	with different cash and food crops	with different cash and food crops	with different cash and food crops	with different cash and food crops	with different cash and food crops	with different cash and food crops
	Mixed cropping:	Yes; Jatropha is grown as boundary crop for farms	Yes; Jatropha is grown as boundary crop for farms	Yes; Jatropha is grown as boundary crop for farms	Yes; Jatropha is grown as boundary crop for farms	Yes; Jatropha is grown as boundary crop for farms	Yes; Jatropha is grown as boundary crop for farms
	Average yield/ha for bioenergy crop:	less than 1 ton grain/ha	less than 1 ton grain/ha	less than 1 ton grain/ha	less than 1 ton grain/ha	less than 1 ton grain/ha	less than 1 ton grain/ha
	Irrigation:	No	No	No	No	No	No
	Type of soil:	varied	varied	varied	varied	varied	varied
	Use of fertilizer:	Very limited on cash crops/ food crops	Very limited on cash crops/ food crops	Very limited on cash crops/ food crops	Very limited on cash crops/ food crops	Very limited on cash crops/ food crops	Very limited on cash crops/ food crops
	Origin of fertilizer:	locally available/ manure	locally available/ manure	locally available/ manure	locally available/ manure	locally available/ manure	locally available/ manure
	Weed control:	hand labour; one of the challenges	hand labour; one of the challenges	hand labour; one of the challenges	hand labour; one of the challenges	hand labour; one of the challenges	hand labour; one of the challenges
	Pesticide use:	No	No	No	No	No	No
	Type of planting material:	Seedlings of local grain origin with no proven oil yield/ha	Seedlings of local grain origin and derived from selected QUINVITA cultivars	Seedlings of local grain origin with no proven oil yield/ha	Seedlings of local grain origin with no proven oil yield/ha	Seedlings of local grain origin with no proven oil yield/ha	Seedlings of local grain origin with no proven oil yield/ha
	Origin of planting material:	Wild grain	Wild grain; recently QUINVITA cultivars	Wild grain	Wild grain	Wild grain	Wild grain
	Specificity of planting material:	NA	QUINVITA cultivars selected for high oil yield/ha	NA	NA	NA	NA
	Way of planting:	Manual	Manual	Manual	Manual	Manual	Manual
	Way of harvesting:	Manual	Manual	Manual	Manual	Manual	Manual
	What is harvested:	Fruits	Fruits	Fruits	Fruits	Fruits	Fruits
	On-field processing:	sometimes husks	sometimes husks	sometimes husks	sometimes husks	sometimes husks	sometimes husks
	On farm processing:	dehusking	dehusking	dehusking	dehusking	dehusking	dehusking
	Left overs from on-farm processing:	husks	husks	husks	husks	husks	husks
	On farm storage facilities:	very limited	very limited	very limited	very limited	very limited	very limited
	Agricultural extention:	available; Jatropha field schools; level to be improved	available; Jatropha extension officers	very limited	very limited	very limited	very limited
Bio-energy carrier	Source:	Oil into Biodiesel, seedcake into biogas	Crude Jatropha Oil	Crude Jatropha Oil	Crude Jatropha Oil	Crude Jatropha Oil	Crude Jatropha Oil
project	Conversion:	Crushing of grain into oil; esterification into biodiesel	Crushing of grain into oil	Crushing of grain into oil	Crushing of grain into oil	Crushing of grain into oil	Crushing of grain into oil
	Distance:	1-50 km	1-50 km	1-50 km	1-50 km	1-50 km	1-50 km
	Type of roads:	dust/tarmac	dust/tarmac	dust/tarmac	dust/tarmac	dust/tarmac	dust/tarmac
	Yield of bio-energy carrier:	26% oil recovery from grains; 99% biodiesel recovery	26% oil recovery from grains	26% oil recovery from grains	26% oil recovery from grains	26% oil recovery from grains	26% oil recovery from grains
	By-products:	seedcake after crushing;	seedcake after crushing;	seedcake after crushing;	seedcake after crushing;	seedcake after crushing;	seedcake after crushing;
	Destination of bio-energy carrier:	Electricity generation; transport fuel	Electricity generation;	Electricity generation;	Electricity generation;	Electricity generation;	Electricity generation;
	Local use or export:	Local use	Local use	Local use	Local use	Local use	Local use
	Destination of by-products:	briquettes; fertilizer	fertilizer	briquettes; fertilizer	briquettes; fertilizer	briquettes; fertilizer	briquettes; fertilizer
	Inputs of the processing:	methanol for esterification					
	Electricity production:	575,819 kWh per year					

Processing	Primary processing:	Crushing of grain into oil.	Crushing of grain into oil.	Crushing of grain into oil.	Crushing of grain into oil.	Crushing of grain into oil.	Crushing of grain into oil.
	Capacity:	15 ton grains/day	ton grains/day	ton grains/day	ton grains/day	ton grains/day	ton grains/day
	Current output:	25 ton CJO/year	ton CJO/year	ton CJO/year	ton CJO/year	ton CJO/year	ton CJO/year
	Secondary processing:	Esterification of CJO into Biodiesel	No	No	No	No	No
	Capacity:						
	Current output:						
Economy	Valuta:	CFA	CFA	CFA	CFA	CFA	CFA
	Crop establishment costs per ha:	ND	ND	ND	ND	ND	ND
	Crop maintenance costs per ha per year:	ND	ND	ND	ND	ND	ND
	Harvesting costs per ha per year:	ND	ND	ND	ND	ND	ND
	Cropping costs per ha per year:	ND	ND	ND	ND	ND	ND
	grain cost / kg						
	Transport costs per km per ton:	ND	ND	ND	ND	ND	ND
	Local price for fire-wood per kg:						
	Local pump gasoline price per liter:	NA	NA	NA	NA	NA	NA
	Local pump diesel price per liter:	610 CFA/l diesel	610 CFA/l diesel	610 CFA/l diesel	610 CFA/l diesel	610 CFA/l diesel	610 CFA/l diesel
	Local charcoal price per kg:						
	Local gas price per kg:	NA	NA	NA	NA	NA	NA
	Local electricity price per kWh:						
	Processing costs per ton of produce:	ND	ND	ND	ND	ND	ND
	Sales price per ton of produce of farm:	120 CFA/ kg					
	By-product sales price per ton of farm:	NA	NA	NA	NA	NA	NA
	Sales price of bio-energy carrier per unit:	550 CFA/l biodiesel					
	Sales price of by-product from processing:		soap				
	Revenu of carbon credits:	NA today	Yes; Novartis foundation; voluntary market				
Knowledge infrastructure	ntact with agronomy research centre:	Limited in house on farm trials	In house agronomy trials	Limited trials	Contacts with local university on agronomy research	Limited	Some research together with CIRAD (France)
	Contact with demonstration farm:	In house Jatropha field school concept	In house demonstration activities	Limited	Plans but not executed	Limited	Yes
	Contact with processing technology company/institute:	In house processing expertise	In house crushing expertise	Limited	No	Limited	Limited
	Contact with breeding research centre:	Contacts but no contract with Quinvita	Contract with Quinvita on testing and growing of improved Jatropha cultivars	No	Contacts but no contract with Quinvita	No	No
	Contact with by-product valorisation research:	Limited	In house soap production	Limited	No	Limited	Limited
	Overall assessment	Good project with potential economy of scale; project suitability risks, agronomy support needs to be further re-inforced and the current genetics basis for planting Jatropha represents a major risk for the project. Project yields/ha need to be increased urgently to maintain motivation of growers.	Good project with potential economy of scale; good project suitability, agronomy support needs to be further re-inforced. Project yields/ha need to be increased urgently in order to maintain motivation of growers.	Project with potential; good project suitability; agronomy support and current genetics represent major risks; will the project realize the necessary economy of scale.	Project with potential; good project suitability; agronomy support and current genetics represent major risks; will the project realize the necessary economy of scale. Synergies with cash/food crop production efforts is a plus	Project with limited potential; suboptimal project suitability; agronomy support and current genetics represent major risks; given the above risks, it is very unlikely the project will realize the necessary economy of scale.	Project with limited potential; suboptimal project suitability; agronomy support and current genetics represent major risks; given the above risks, it is very unlikely the project will realize the necessary economy of scale.

Project assessment Burkina Faso

General data	Company:	Aprojer	Belwet Agrocarburant	Faso Biocarburants	Fasogaz
	Bioenergy crop:	Jatropha curcas	Jatropha curcas	Jatropha curcas	Jatropha curcas
	Location:	Comoé, Kénédougou and Komplenga provinces	North east of Ouagadougou	2 productions circles (Leo and Toma)	2 major activity circles (Banfora, Bolo in West and Gawa, Dano in South)
	Country:	Burkina Faso	Burkina Faso	Burkina Faso	Burkina Faso
	Start date:	2007	2009	2007	2011
	Hectares planted:	7000 ha Net of Jatropha planting	10000 ha+ Net of Jatropha planting	600 ha	200 ha+
	Type of project:	Outgrower network	Outgrower network	Outgrower network	Outgrower network
	Nr of farmers in network:	10,000 +	50,000+	2000	10,000 +
	Jatropha suitability risks:	total rainfall on the lower side in two of the three target area's	The growing area is too dry for Jatropha cultivation	total rainfall on the lower side in one target area	Very good project suitability
Agricultural details	Crop rotation cycle:	with different cash and food crops	with different cash and food crops	with different cash and food crops	with different cash and food crops
	Mixed cropping:	Yes; Jatropha is grown as boundary crop for farms	Yes; Jatropha is grown as boundary crop for farms	Yes; Jatropha is grown as boundary crop for farms	Yes; Jatropha is grown as boundary crop for farms
	Average yield/ha for bioenergy crop:	less than 1 ton grain/ha	less than 1 ton grain/ha	less than 1 ton grain/ha	less than 1 ton grain/ha; recent planting
	Irrigation:	No	No	No	No
	Type of soil:	varied	varied	varied	varied
	Use of fertilizer:	Very limited on cash crops/ food crops	Very limited on cash crops/ food crops	Very limited on cash crops/ food crops	Very limited on cash crops/ food crops
	Origin of fertilizer:	locally available/ manure	locally available/ manure	locally available/ manure	locally available/ manure
	Weed control:	hand labour; one of the challenges	hand labour; one of the challenges	hand labour; one of the challenges	hand labour; one of the challenges
	Pesticide use:	No	No	No	No
	Type of planting material:	Seedlings of local grain origin and from India with no proven oil yield/ha; quality of seed from India was very bad.	Seedlings of local grain origin with no proven oil yield/ha;	Seedlings of local grain origin with no proven oil yield/ha	Seedlings of local grain origin with no proven oil yield/ha; contract with QUINVITA
	Origin of planting material:	Wild grain	Wild grain	Wild grain	Wild grain
	Specificity of planting material:	NA	NA	NA	NA
	Way of planting:	Manual	Manual	Manual	Manual
	Way of harvesting:	Manual	Manual	Manual	Manual
	What is harvested:	Fruits	Fruits	Fruits	Fruits
	On-field processing:	sometimes husks	sometimes husks	sometimes husks	sometimes husks
	On farm processing:	dehusking	dehusking	dehusking	dehusking
	Left overs from on-farm processing:	husks	husks	husks	husks
	On farm storage facilities:	very limited	very limited	very limited	very limited
	Agricultural extention:	good level agronomy support now under pressure for funding reasons	No agronomy support structure; a more commercial grain collection apporach	available; Jatropha field schools; level to be improved	agronomy support being implemented
Bio-energy carrier project	Source:	Crude Jatropha oil	Crude Jatropha oil and biodiesel	Oil into Biodiesel, seedcake into biogas	Crude Jatropha oil
	Conversion:	Crushing of grain into oil;	Crushing of grain into oil;	Crushing of grain into oil; esterification into biodiesel	Crushing of grain into oil; production of biogas from seedcake
	Distance:	1-50 km	1-50 km	1-50 km	1-50 km
	Type of roads:	dust/tarmac	dust/tarmac	dust/tarmac	dust/tarmac
	Yield of bio-energy carrier:	25% oil recovery from grains;	25% oil recovery from grains;	25% oil recovery from grains; 99% biodiesel recovery	25% oil recovery from grains;
	By-products:	seedcake after crushing;	seedcake after crushing;	seedcake after crushing;	seedcake after crushing;
	Destination of bio-energy carrier:	Electricity generation;	Electricity generation; transport fuel	Electricity generation; transport fuel	Electricity generation;
	Local use or export:	Local use	Local use	Local use	Local use
	Destination of by-products:	briquettes; fertilizer	briquettes; fertilizer	briquettes; fertilizer	briquettes; fertilizer
	Inputs of the processing:	methanol for esterification	methanol for esterification	methanol for esterification	methanol for esterification
	Electricity production:				

Processing	Primary processing:	Crushing of grain into oil.	Crushing of grain into oil. Biodiesel production	Crushing of grain into oil.	Crushing of grain into oil.
	Capacity:	4 ton grains/day	3000 ton/year	15 ton grains/day	3000 ton/year
	Current output:	- current plant is not operational	limited due to low yields	not operational	current plant used for cotton seed crushing
	Secondary processing:		Biodiesel production		NA
	Capacity:		500 ton/year		
	Current output:		limited		
Economy	Valuta:	CFA	CFA	CFA	CFA
	Crop establishment costs per ha:	ND	ND	ND	ND
	Crop maintenance costs per ha per year:	ND	ND	ND	ND
	Harvesting costs per ha per year:	ND	ND	ND	ND
	Cropping costs per ha per year:	ND	ND	ND	ND
	grain cost / kg				
	Transport costs per km per ton:	ND	ND	ND	ND
	Local price for fire-wood per kg:				
	Local pump gasoline price per liter:	NA	NA	NA	NA
	Local pump diesel price per liter:	610 CFA/l diesel	650-700 CFA/l diesel	650-700 CFA/l diesel	650-700 CFA/l diesel
	Local charcoal price per kg:				
	Local gas price per kg:	NA	NA	NA	NA
	Local electricity price per kWh:				
	Processing costs per ton of produce:	ND	ND	ND	ND
	Sales price per ton of produce of farm:	100 CFA/ kg	100 CFA/ kg	100 CFA/ kg	100 CFA/ kg
	By-product sales price per ton of farm:	NA	NA	NA	NA
	Sales price of bio-energy carrier per unit:		No biodiesel sale today; only in house use	NA	
	Sales price of by-product from processing:				
	Revenu of carbon credits:	NA today	NA today	NA today	NA today
Knowledge infrastructure	Contact with agronomy research centre:	part of the Adecia funded project in Mali and Burkina	part of the Adecia funded project in Mali and Burkina complemneted with in house agronomy research	part of the Adecia funded project in Mali and Burkina	collaboration with the dreyer foundation and QUINVITA
project	Contact with demonstration farm:	internal agronomy support, demonstration efforts and training	internal agronomy research; no agronomy support	internal agronomy support, demonstration efforts and training	internal agronomy support, demonstration efforts and training
	Contact with processing technology company/institute:	Yes (Irsat)	Limited	-	Limited
	Contact with breeding research centre:	Contacts with Quinvita; no contract today	Contacts with Quinvita; no contract today	Contacts with Quinvita; no contract today	Contract with Quinvita for seed and agronomy knowledge supply
	Contact with by-product valorisation research:	Yes (Inera)	Limited	-	No
	Overall assessment	Good project with potential economy of scale; some project suitability risks, agronomy support needs to be further re-inforced after funding and the current genetics basis for planting Jatropha represents a major risk for the project. Project yields/ha need to be increased urgently to maintain motivation of growers.	Project with potential economy of scale; serious project suitability risks, agronomy support needs to be established and the current genetics basis for planting Jatropha represents a major risk for the project. Project yields/ha need to be increased urgently to maintain motivation of growers.	Good project with potential economy of scale; some project suitability risks, agronomy support needs to be further re-inforced after funding and the current genetics basis for planting Jatropha represents a major risk for the project. Project yields/ha need to be increased urgently to maintain motivation of growers.	Recent project with potential if necessary resources are put into the project ; good project suitability risks, agronomy support needs to be further re-inforced after funding. Contract with Quinvita to test selected cultivars and for agronomy knowledge transfer. Like in all projects yields/ha are crucial to maintain motivation of growers.

Project assessment of Ghana

General data *project*	Company:	Italian owned project
	Bioenergy crop:	Jatropha curcas
	Location:	Yeji
	Country:	Ghana
	Start date:	Very first tree planted in 2008, commercial plantation started in 2012
	Hectares planted:	ca. 730 ha
	Type of project:	plantation
	Hectares planned:	4500
	Completion date:	TBD
	Jatropha suitability	Excellent
Agricultural details *project*	Crop rotation cycle:	None
	Mixed cropping:	No (but approval also for food crops)
	Average yield/ha for bioenergy crop:	For commercial plantation only limited yield in season 1
	Irrigation:	No
	Type of soil:	sandy soil
	Use of fertilizer:	Yes
	Origin of fertilizer:	locally available
	Weed control:	Mechanical + chemical + hand labour
	Pesticide use:	yes: mealy bugs, mites, colletotrichum , flea beetle
	Type of planting material:	seedlings (polybags)
	Origin of planting material:	Other: wild seeds from Ghana; recently also seeds of QUINVITA cultivars
	Specificity of planting material:	no specificity
	Way of planting:	manual
	Way of harvesting:	manual
	What is harvested:	fruits
	On-field processing:	commercial large scale harvesting still needed to be organized as well as the processing afterwards
	On farm processing:	commercial large scale harvesting still needed to be organized as well as the processing afterwards
	Left overs from on-farm processing:	commercial large scale harvesting still needed to be organized as well as the processing afterwards
	On farm storage facilities:	limited for now
Bio-energy carrier *project*	Source:	Jatropha curcas- crude Jatropha oil
	Conversion:	Crushing
	Distance:	boat transport on river
	Type of roads:	tarmac + dust
	Yield of bio-energy carrier:	Early stage of project
	By-products:	Seedcake,
	Destination of bio-energy carrier:	TBD
	Amount of bio-energy carrier:	NA yet
	Local use or export:	Both considered
	Destination of by-products:	TBD
	Inputs of the processing:	TBD

Economy *project/country*	Valuta:	
	Crop establishment costs per ha:	Under evaluation
	Crop maintenance costs per ha per year:	Under evaluation
	Harvesting costs per ha per year:	Under evaluation
	Cropping costs per ha per year:	Under evaluation
	Transport costs per km per ton:	700 km
	Local price for fire-wood per kg:	NA
	Local pump gaseoline price per liter:	NA
	Local pump diesel price per liter:	NA
	Local charcoal price per kg:	NA
	Local gas price per kg:	NA
	Local electricity price per kWh:	NA
	Processing costs per ton of produce:	NA
	Sales price per ton of produce of farm:	TBD
	By-product sales price per ton of farm:	TBD
	Sales price of bio-energy carrier per unit:	TBD
	Sales price of by-product from processing:	TBD
	Revenu of carbon credits:	NA
Knowledge infrastructure	Contact with agronomy research centre:	Limited in house on farm trials; previous contract with Agroils; agronomy contract with Quinvita
	Contact with demonstration farm:	NA
	Contact with processing technology company/institute:	In house processing expertise
	Contact with breeding research centre:	Breeding knowledge contract with Quinvita
	Contact with by-product valorisation research:	In house expertise
	Overall assessment	Good project with potential economy of scale; excellent project suitability, good agronomy basis and contract with Quinvita; potential for food and energy farm concept

Appendix 3: List of research institutes in the ECOWAS region

Crop	Institute	Subjects
Cashew	Cocao Res. Inst. Ghana, New Tafo-Akim, Ghana	Agronomy Apple juice products Apple juice analysis Agronomy in mixed cropping systems
	Cocoa Res. Inst. Nigeria, Ibadan, Nigeria	Social aspects and awareness Apple juice preparation and analysis Reproduction biology, cytology, genetic diversity Agronomy Breeding, by-product development
	Dept. Crop Production, Univ. Ilorin, Nigeria	Reproduction biology and cytology
	Dept. Plant Science, Olabisi Onabanjo Univ. Ogun State, Nigeria	Seed storage
	Dept. Science & technol. Ecole Normale Supérieure d'Abidjan, Ivory Coast	Breeding and feed analysis
	Kwame Nkrumah Univ. Sc. & Technol., Ghana	Agronomy and economy
	Lab. Food Biochem. & Tropical Product Technology, Univ. Abobo-Adjame, Ivory Coast	Apple juice analysis
	West African Centre for Crop Improvement, Univ. Ghana, Legon	Breeding and selection
Cassava	Cassava Programme National Seed Service, Fed. Dept. Agriculture, Ijebu-Ife, Nigeria	Seed quality improvement
	Crops Res. Institute, Fumesua, Kumasi, Ghana	Clone selection and field performance
	Dept. Agricult. Economics, Michael Okpara Univ. Agricult., Umudike, Abia State, Nigeria	Production of food and food security
	Dept. Agricult. Economics & Fram Management, Univ. Ilorin, Nigeria	Farming systems
	Dept. Agricult. Economics, Univ. Agricult., Makurdi, Benue State, Nigeria	Economics of production
	Dept. Agricult. Engineering, Inst. Agricult. Research & Training, Ibadan, Nigeria	Conversion to ethanol
	Dept. Agricult. Engineering, Ladoke Univ. Technol., Ogbomoso, Oyo State, Nigeria	Energy use in processing to various products
	Dept. Animal Production & Health, Univ. Agricult. Abeokuta, Ogun State, Nigeria	Leaves for animal feed
	Dept. Home Economics & Food Science, Univ. Ilorin, Nigeria	Chemical composition during traditional storage
	Dept. Plant Physiol. & Crop Production, Univ. Agricult., Abeokuta, Nigeria	Farming systems across agro-ecological zones
	Forest and Horticultural Crops Res. Centre, Kade, Univ. Ghana, Legon, Ghana	Soil fertility and farming sustainability
	Internat. Institute of Tropical Agriculture, Ibadan, Nigeria	Economical impact of introduction of new varieties Economical analysis
	National Root Crops Res. Institute, Umudike, Nigeria	Breeding Agricultural economy
	Sierra Leone Agricult. Res. Inst./Natl. Agricult. Res. Centre, Sierra Leone	Value chain development
	University of Abidjan, Ivory Coast	Seed production agronomy
	West African Centre for Crop Improvement, Univ. Ghana, Legon	Breeding and selection
Jatropha	Biochem. & Nutrition Unit, Dept. Chem. Sci. Fiountain Univ. Osogbo, Nigeria	Analysis and anti-microbial activities of leaf extracts
	Centre Regional de la Recherche Agronomique, Institut d'Economie Rurale, Mali	Variety testing, agronomy
	Chem. Engin. Dept., Ahmadu Bello Univ., Zaria, Nigeria	Co-solvent transesterification of oil
	Chemistry Dept., Univ. Of Ado-Ekiti, Nigeria	Chemical analysis of cake and oil
	CSIR-Forestry Research Institute, Ghana	Development of improved seed and viability test Intercrop agronomy
	Dep. Chem. Sci., Redeemer's Univ. Redemption City, Ogun State, Nigeria	Chemical modification of oil via epoxidation
	Dept. Agricult. & Bioresources Engineer., Univ. Of Nigeria, Nsukka	Oil extraction
	Dept. Agricult. Engin., Univ. Agricult. Abeokuta, Ogun State, Nigeria	Production of biodiesel from the oil
	Dept. Appl. Chem. Biochem., Univ. For Dev. Studies, Navrongo, Ghana	Anti-microbial activity of extracts of various plant parts
	Dept. Biochem. Ahmadu Bello Univ. Zaria, Nigeria	Leaf biochemistry
	Dept. Biochem., Benjamin Carson School of Medicin, Babcock Univ., Ogun State, Nigeria	Anti-inflammatory properties of leaf extracts
	Dept. Biochem., Fed. Univ. Technol., Akure, Ondo State, Nigeria	Seed fermentation and properties
	Dept. Biochem., Kebbi State Univ. Of Sci. & Technol., Aliero, Nigeria	Cosmetic potential of oil
	Dept. Biol. Sci., Ibrahim Badamasi Babangida Univ. Lapai, Nigeria	Toxicity
	Dept. Biol. Sci., Usmanu Danfodiyo Univ., Sokoto, Nigeria	Phytoremediation of heavy metal contaminated soil
	Dept. Biotechn., Fac. Agric., Univ. For Developm. Studies, Tamale, Ghana	Physicochemical properties of seed and detoxification of cake
	Dept. Chem. & Ind. Chem., Adekunle Ajasin Univ., Akungba-Akoko, Ondo State, Nigeria	Oil properties
	Dept. Chem. Engin., Ladoke Akintole Univ.. Technol., Ogbomoso, Nigeria	Prospects of oil for Nigerian biodiesel Solvent extraction of oil and use as insecticide
	Dept. Chem. Engin., School of Eng.&Eng. Technol., Fed. Univ. Technol. Niger State, Nigeria	Production of diesel from the oil
	Dept. Chem. Sciences, Osun State University, Osogbo, Nigeria	Cellulosic ethanol from stems
	Dept. Chem. Univ. Ibadan, Nigeria	Toxicity of extracts
	Dept. Chem., Univ. Ado-Ekiti, Nigeria	Biochemical analysis of meal and oil
	Dept. Chem., Univ. Ilorin, Ilorin, Nigeria	Activated carbon from fruit hulls and seed coat
	Dept. Crop Prod., Fed. Univ. Technol., Minna, Nigeria	Seed germination vigour
	Dept. Crop Sci. & Horticult., Fed. Univ. Technol., Yola, Nigeria	Toxicity of leaf extracts to insects

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	Dept. Crop Sci. & Horticult., Fed. Univ. Technol., Yola, Nigeria	Toxicity of leaf extracts to insects

Appendix 4: List of figures and tables

Figures

Tables

Appendix 5: References

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Appendix 6: Project assessment tool for New Bio-energy projects

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