Regional Centre for Renewable Energy and Energy Efficiency
Centre Régional pour les Energies Renouvelables et l'Efficacité Energétique
Centro Regional de Energias Renováveis e de Eficiência Energética

Regional potential assessment of novel bio energy crops in fifteen ECOWAS countries

Source: Sahel and West Africa Club (2005)

3rd progress report to ECREEE (and IIBN/UNIDO)

December 2012

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 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 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.

1.3 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 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. This will be another important subject of focus in the second phase of the project.

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. 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 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. Based on these observations, 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 1).

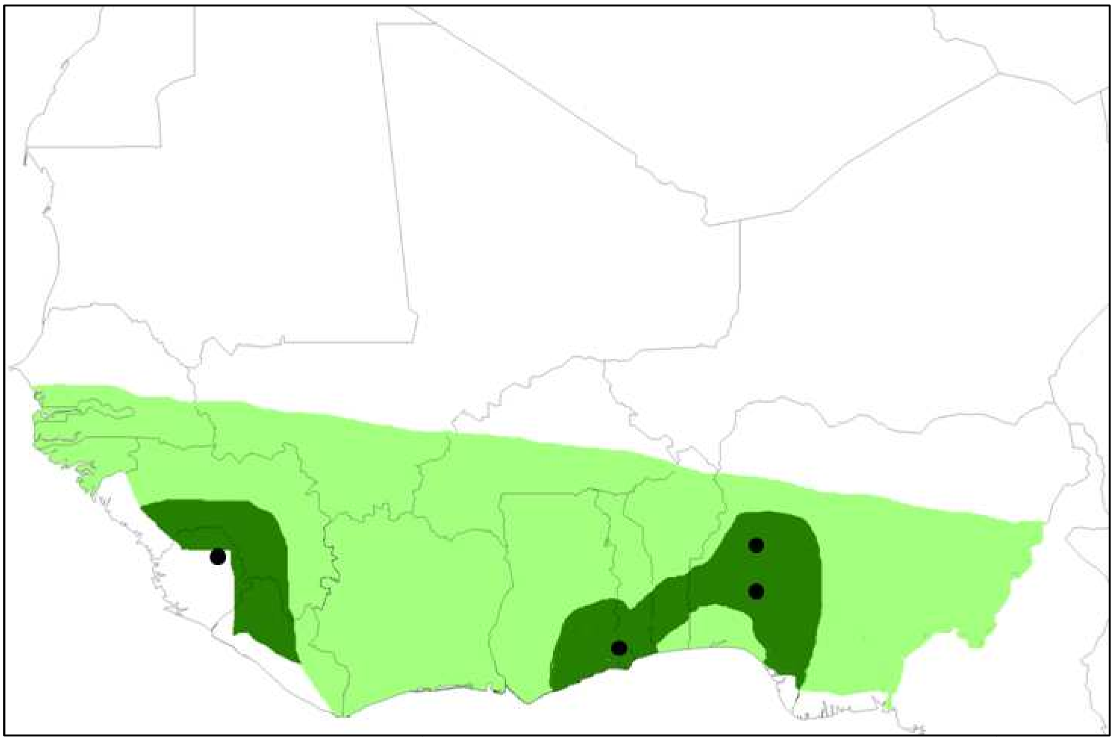


Figure 1: target area for further Sweet Sorghum study. Dark green: primary focus area; light green: secondary focus area. Black dots show existing ethanol plants processing sugarcane or cassava

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. 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.

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 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 plantation projects projected for Ghana and Senegal were less successful so far and were 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 Jatropha's suitability 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 and Burkina Faso as examples to build on. 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 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.

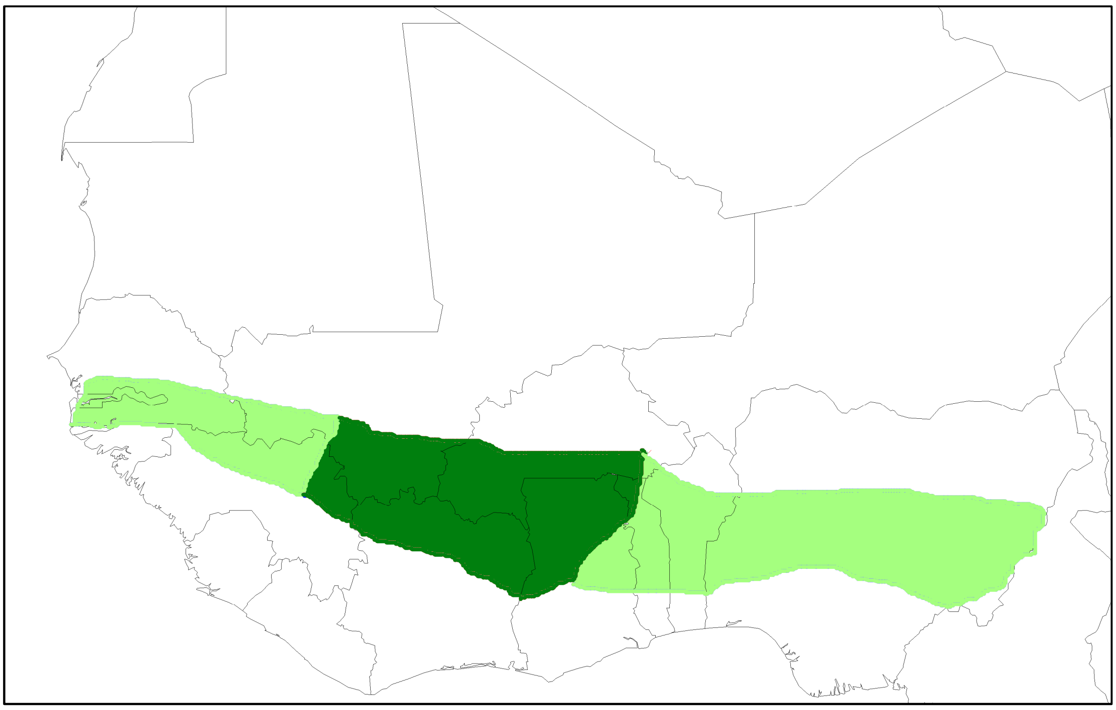


Figure 2: target area for further Jatropha study. Dark green: primary focus area; light green: secondary focus area

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 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 (km^2)	Pop. Dens (#/km^2)	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	5.780	-1.813
Cape 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-Bissa	36.120	37,0	0,10	14,7	45.000	43.397	1.603
Ivory Coast	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 these 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.

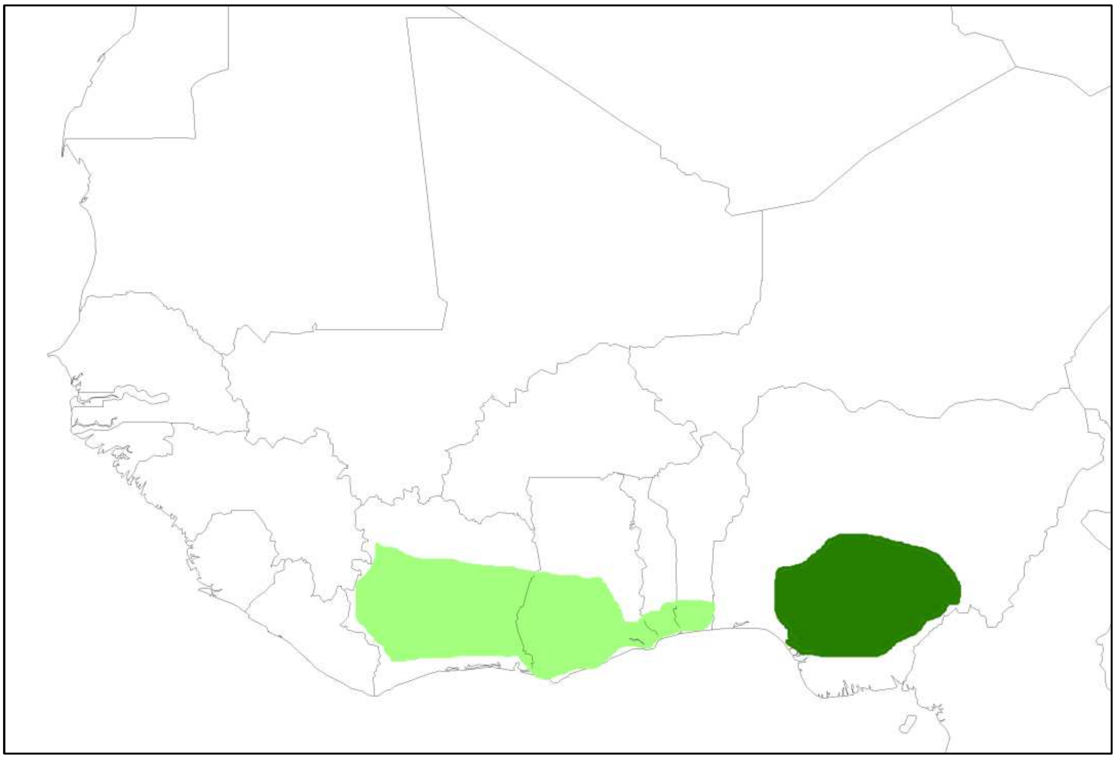


Figure 3: Target area for further Cassava study. Dark green: primary focus area; pale green secondary focus area

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.

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).

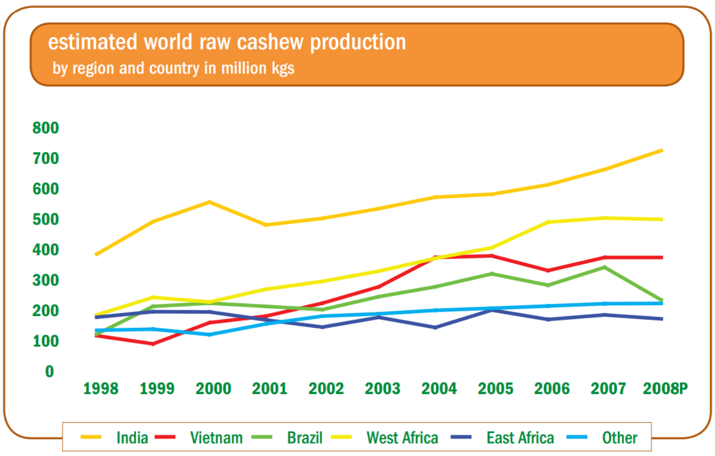


Figure 4: World Cashew production (source: Red River, Industry, FAO)

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. The question whether this industrial development 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.

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

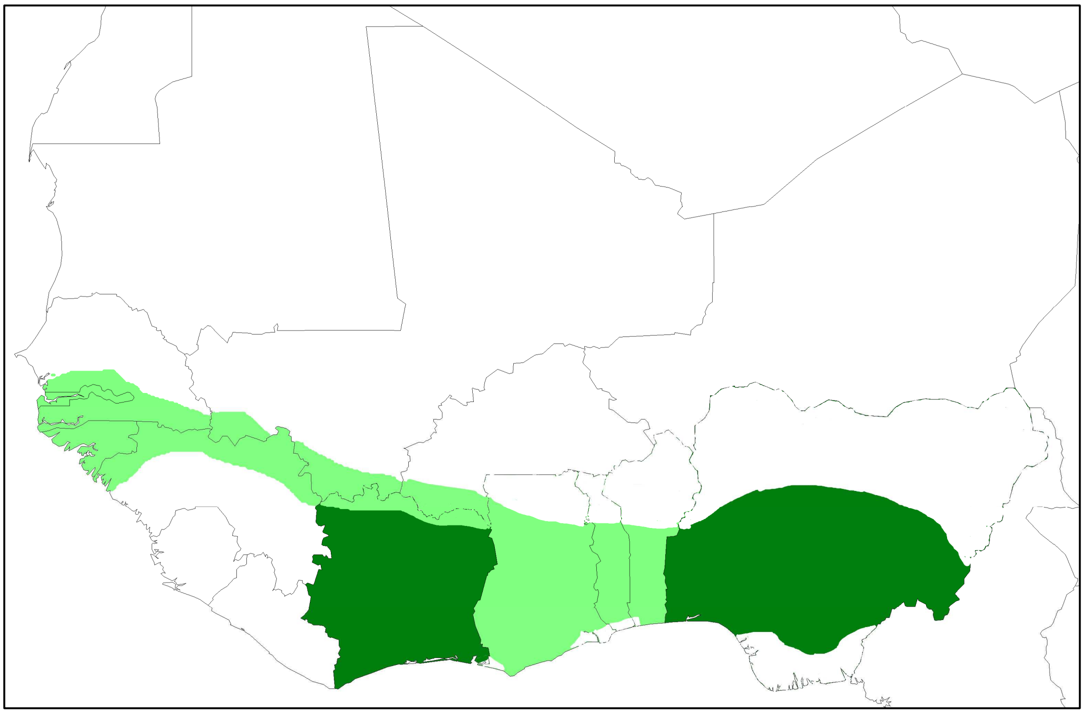


Figure 5: **Target area for further Cashew study. Dark green: primary focus area; pale green secondary focus area**

This report builds on the knowledge reported in previous reports and summarizes the current knowledge base and interim 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 in them 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. This process is currently being continued. The data in this interim report give a first indication and must be regarded as work in progress.

3 Setting the boundaries for economical sustainability

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	Ethanol
Cashew	Nuts	Apples (food)	Biogas

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.

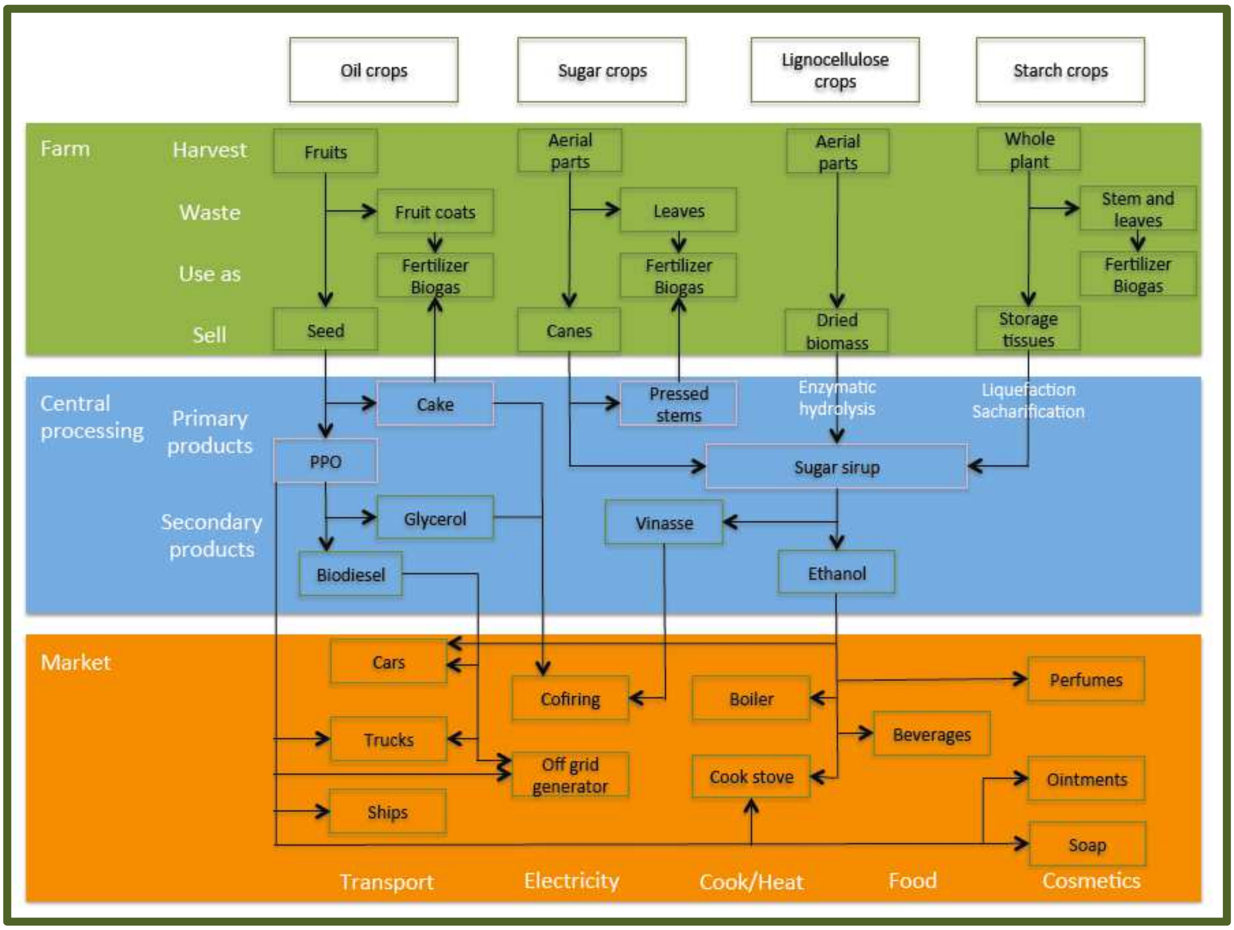


Figure 6: Overview of the way energy carriers are being obtained from various types of bio energy crops and how these carriers are utilized in the market

The costs for energy carriers, derived from renewable sources are determined by two major factors: the cost of the feedstock 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 costs (more than 80%) is feedstock production/acquisition costs. For ethanol from sugar cane the costs of feedstock are more than half of the production costs. 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).

Feedstock production costs are related strongly to 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. 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.

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. The areal parts of the plants can be used as animal feed or as fertilizer. In case they are used as animal feed, 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. 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.).

This opportunity needs to be weighed against the potential to use the large volumes of apples as a feedstock for decentralized biogas production.

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 the 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. We believe it is very critical that for all considered crops, one needs to creatively stimulate co-cultivation of food and energy 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.

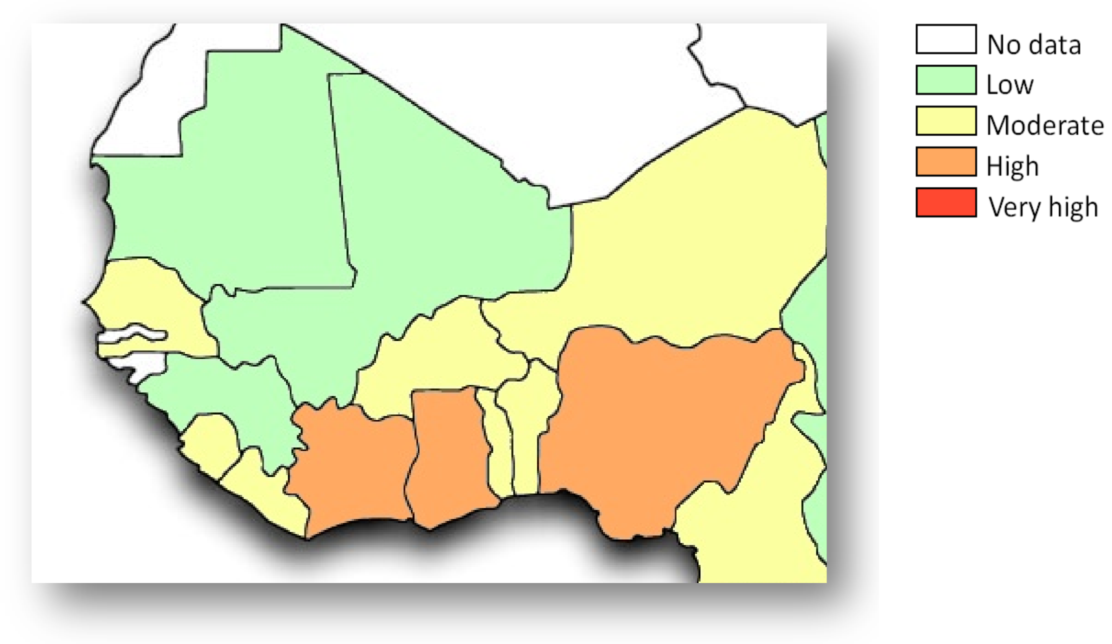


Figure 7: Status of mineral depletion of soils in West Africa (Bindraban 2009)

Energy carriers will have to compete 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).

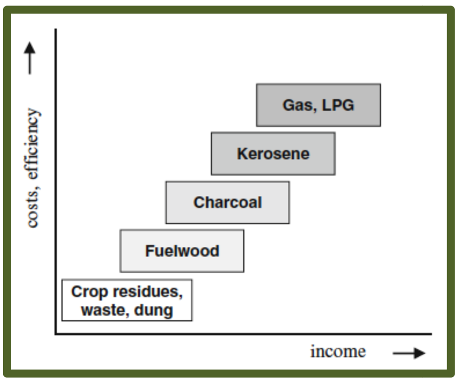
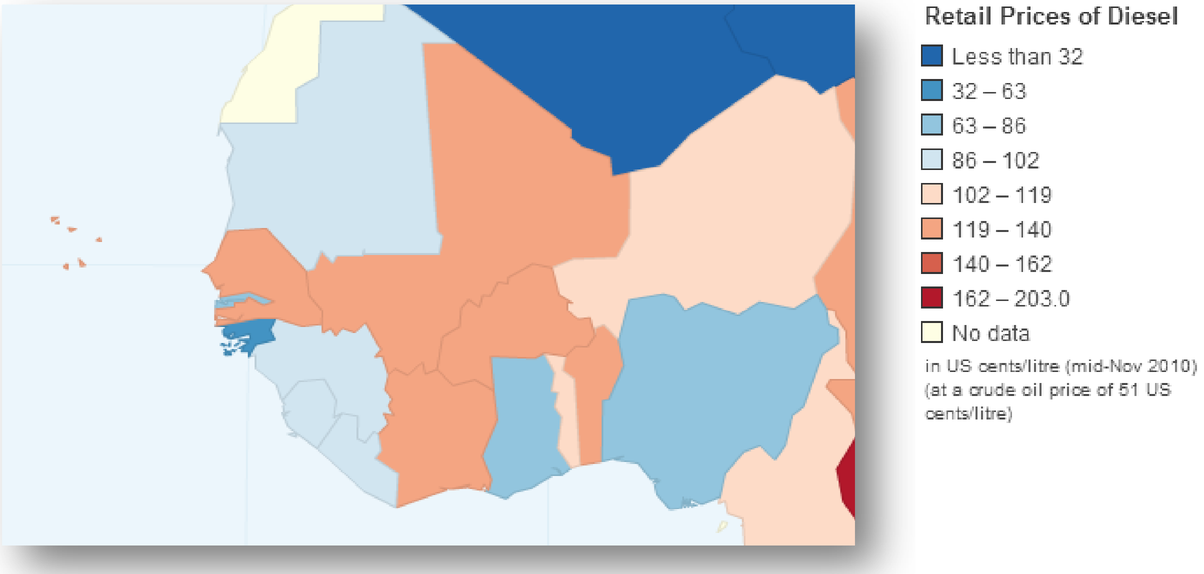


Figure 8: Fuel use is related to income in Africa (2011 Jansen)

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 two times: 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 on 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.



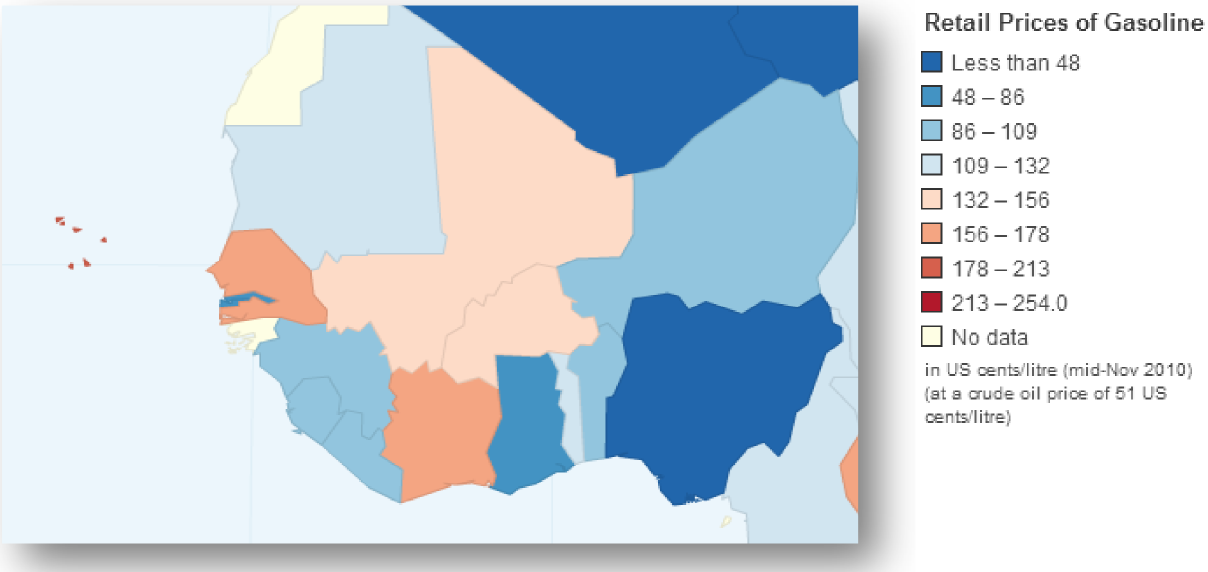


Figure 9: above: retail prices of diesel in US cents/litre, below: retail prices of gasoline in USD/litre (data.worldbank.org)

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 non-land-locked 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 directly have an effect 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 spend on import and subsidy of mineral energy sources. 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 regulation measures are abandoned in time and the dependence on mineral energy resources is decreased.

The pressure that high international mineral fuels prices put on national budgets also result regularly 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.

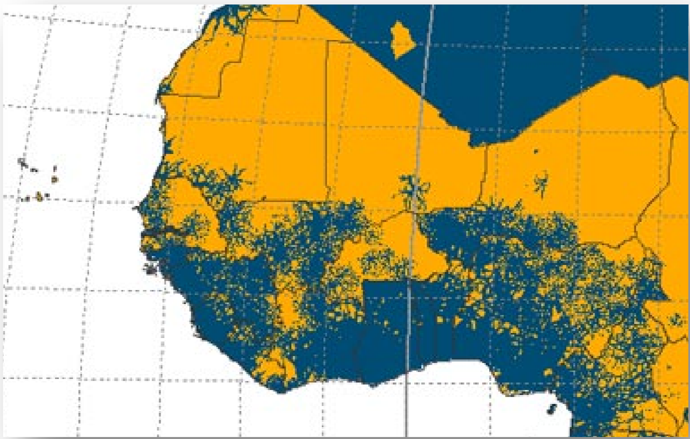


Figure 10: best economical options for off-grid electricity generations in the ECOWAS region: diesel generators (blue) versus photovoltaic (yellow) systems (S. Szabó 2011)

Besides the regulation of prices for mineral energy sources, one has to take into account that over 70% over 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 (2011 World Bank African Biomass Report). 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.

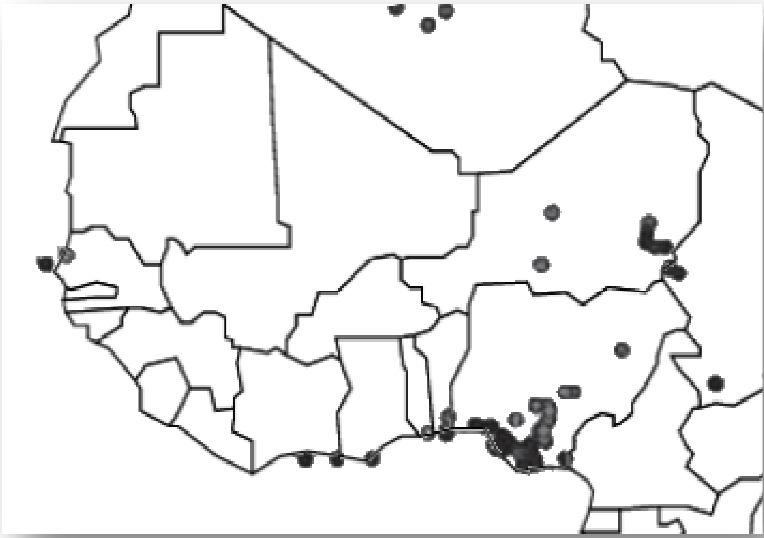


Figure 11: Oil (black dots) and coal (grey dots) reserves in West Africa (2009 oil and gas in Africa)

It is in this setting that renewable energy sources have to be evaluated on grounds of economic, 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.

4 *Jatropha curcas* in Mali and Burkina Faso

Jatropha curcas is already in the region for a very long time but it is only recently that the crop has been considered as a bio energy crop. The traditional uses and perceptions of the crop as a miracle crop, have 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. 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, much literature has been published to show that the grains of Jatropha indeed have a high oil content of a quality that is very versatile in use, but that the plant needs optimal climatic conditions (temperature AND rainfall) to produce economic quantities of grain and oil. In addition, in order to achieve this, 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 the planting of the crop in ‘’marginal areas with limited management practises’’ as a way to make quick money for farmers. With the current knowledge that has developed on the crop, this is very irresponsible.

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 to 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 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 short on term the fruit coats and the seed cake can and should be used as a fertiliser 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 about the biodegradability of phorbol esters in the soil when using Jatropha seed cake as a fertilizer and a soil conditioner. Srinophakan et al. (2012) have demonstrated that Jatropha seed cake can be used successfully for these purposes without any evidence for presence of phorbolesters in the food crops. Phorbol esters are readily degraded in soil (Devappa 2010).

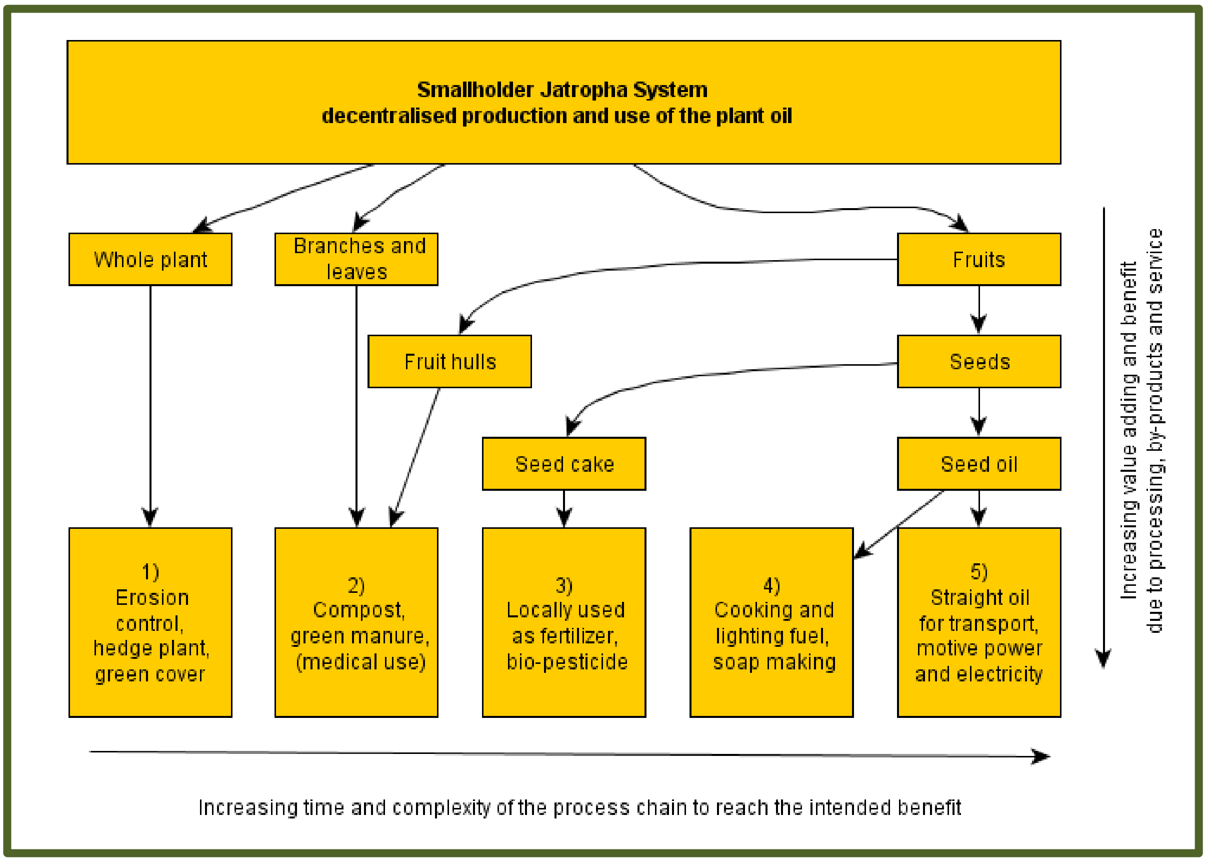


Figure 12: production and use of *Jatropha curcas* plant parts (F. Nielsen 2012)

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 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. 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 are given in figure 13. The estimate of the surface of the land 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. This does not take into consideration the plants in traditional hedges. Plants 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 seed 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 some instances Jatropha is grown as a distinct block on the farm but in most instances, the plants are planted in a hedge pattern. As indicated before experience teaches us that Jatropha plants that are planted too densely, are not resulting in economical yields of Jatropha fruits.

Based on the suitability maps presented in previous reports, half of the projects seem to be in the suitable Jatropha growing areas. The other half of the projects seem to be in areas too dry for optimal production of Jatropha fruit, a clear relict of the ''miracle crop syndrome''.

Most of the projects are based on out-grower models; some of them are plantations. Yields per ha per year vary a lot. Data were found to range between 100 kg/ha for hedges (confirming our observations above) to 3000 kg/ha for mature plantations. In this area Jatropha is co-cultivated with groundnut, sorghum, cotton, maize, soybean and sunflower.

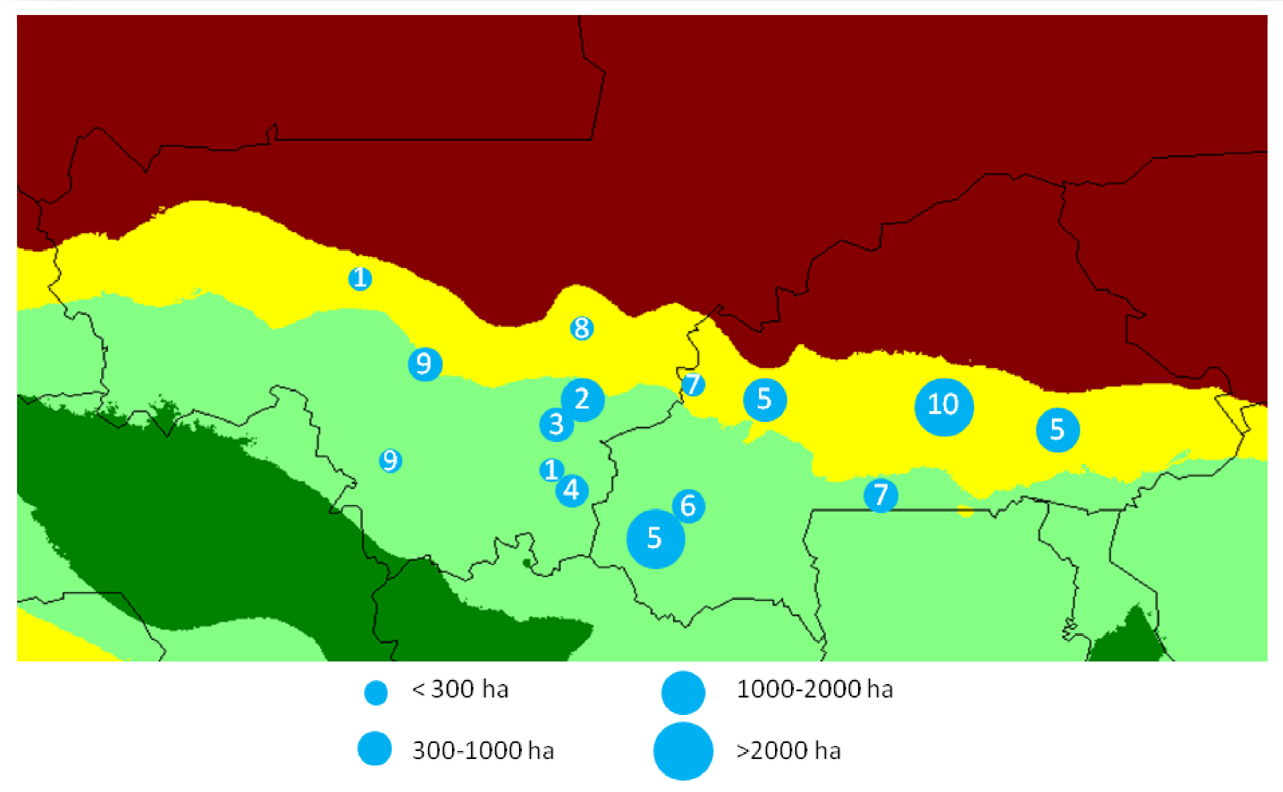


Figure 13: Location of *Jatropha curcas* projects in Mali and Burkina Faso. 1 = MFC, 2 = JMI, 3 = Geres, 4 = Sudagri, 5 = Aprojer, 6 = Fasogaz, 7 = Faso Biocarburant, 8 = AEDR, 9 = Mali Biocarburant, 10 = Belwet

Selling prices for harvested grain used to be 50-65 FCFA/kg but went up recently to 100-150 FCFA/kg. Assuming 4 kg grain is needed to expel 1 liter of oil, the feed stock costs for the oil is 400-600 FCFA/l before crushing costs. Knowing that the retail diesel price in this region varies between 600-650 FCFA/l, grain from Jatropha cannot 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.

Most of the oil today is being used for the production of soap that is sold at 1700 - 4000 FCFA/kg or in generators as CJO for ca 600 FCFA/l.

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

4.4 Intermediate 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 outgrower systems. With an average planting density of 1000 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 today primarily used for soap production (a smart way of incentivising the 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 3 tons of grain per ha (at maturity- 5-6 years after planting). The yield levels today are in most places below 1,5 tons of grain per ha.

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 periods 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 that this can represent 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. Many times bio-energy projects 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.

5 Sweet Sorghum in Sierra Leone and Nigeria

Sweet Sorghum is a high-sugar containing variant of Sorghum hybrids.

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 14).

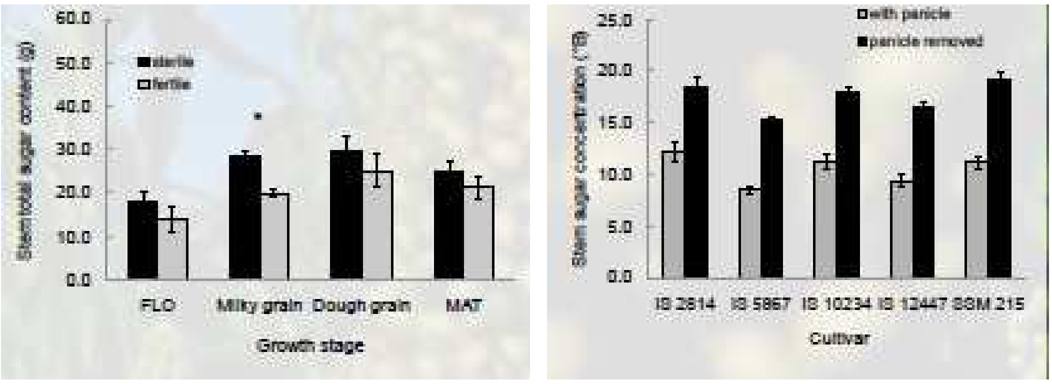


Figure 14: Left: sugar content in stems at various stages of panicle development and right: with or without panicles for various varieties (2010 Gutjar).

In Brasil 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 down-time of sugar mills when sugar cane harvesting season is over. In this way, sugar- and ethanol plants can be more optimally used. We are investigating the potential to develop similar co-cultivation schemes in ECOWAS countries growing sugarcane and transforming it into ethanol.

5.1 Processing

The processing scheme of Sweet Sorghum is given in figure 15. The stems are harvested and have to be transported immediately to the processing plants. The stems can hardly be stored without significant loss in sugar content. In the plant 10% water is added and the sugar rich juice is squeezed from the stems. The juice is fermented to ethanol leaving a vinasse that can either be used to generate biogas or directly be used to generate electricity. The bagasse can be used as animal feed, as feed stock to generate electricity or be fermented to ethanol as well.

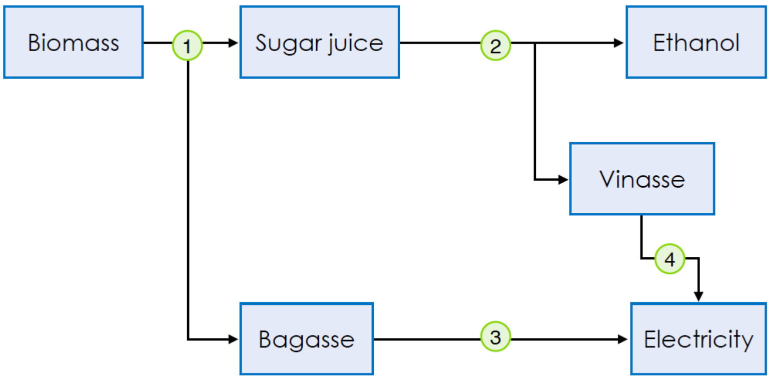


Figure 15: Mass stream in sweet sorghum processing (Sweethanol)

5.2 Mass balance

The mass balance of Sweet Sorghum processing is given in figure 16. 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 sugar cane. Only one crop per year is possible 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. 3500 l ethanol and vinasse. The bagasse can deliver another 2400 l ethanol. So, the yield per ha per year is close to 6000 l ethanol. The remaining dry plant parts can be used for the preparation of animal feed.

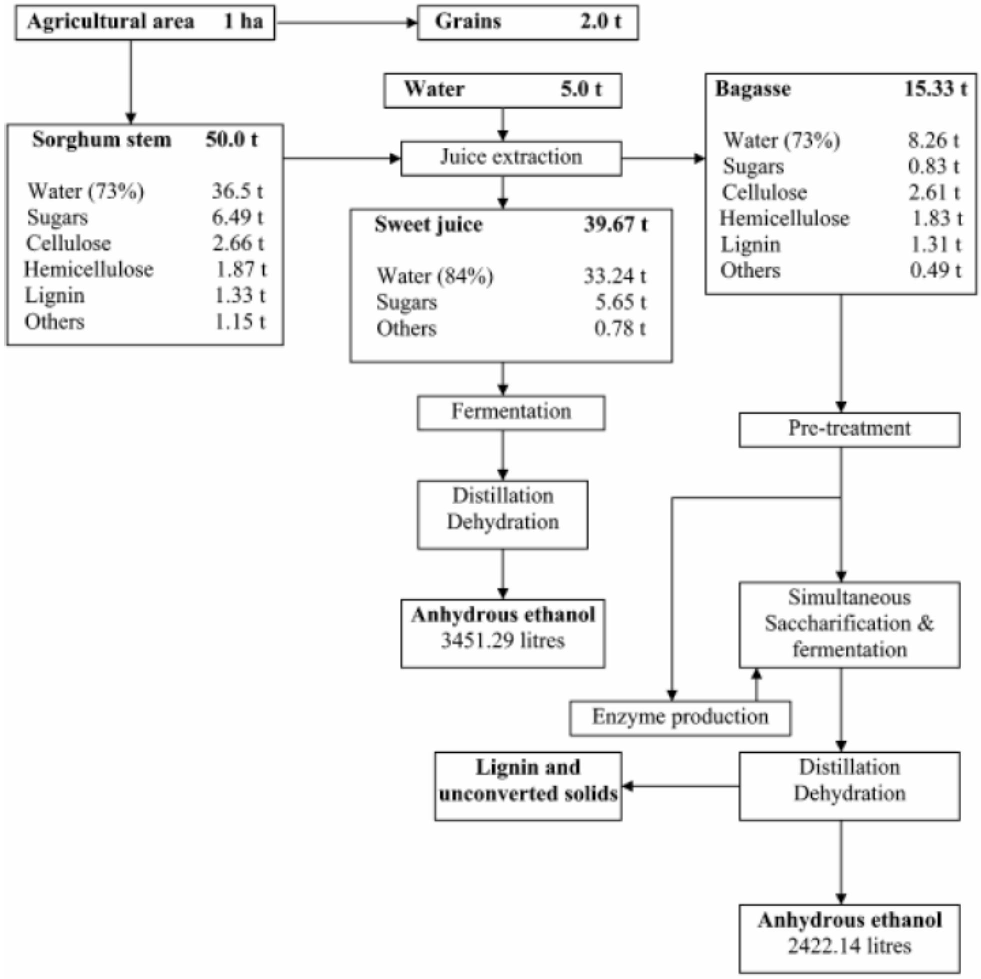


Figure 16: Mass balance of Sorghum processing to ethanol (Prasad 2007)

Although processing of the stems is a well-established procedure for sugar cane, for Sweet Sorghum little experience is at hand in the region. Due to the similarities of the process with sugar cane and the knowledge that Sweet Sorghum stems can be processed in sugar cane mills in Brasil, it is safe to assume that production costs of ethanol from Sweet Sorghum stems will be similar to the one for sugar cane. However, for the sugar cane 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 sugar cane 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 sugar cane 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 and experience an 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 illustrates the negative effect that transport fuel subsidies on mineral fuels have on the roll out of biofuels 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 more expensive than the commonly used wood fuel 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. Switching habits away from 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 endorsed also by GBEP is spending a lot of resources on possible promotion programs.

5.3 Intermediate observations and conclusions

In the project we are analyzing 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 one 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 very limited although a number of projects are being considered.

Experience from other parts of the world tells us that small projects with de-centralized growing and processing of the sugar into ethanol are challenging, primarily for logistical reasons (harvested sweet sorghum needs to be processed, just like sugarcane almost immediately).

The first scientific reports indicate that optimal grain production and sugar production are not synchronized in the SWEET GRAIN SORGHUM model, adding economic pressure to this business model. In addition limited rainfall in traditional grain sorghum areas will limit the biomass production and thus the sugar production potential for the crop.

Based on similar models developed in Brazil, there is clear potential synergy between growing and processing sugarcane and sweet sorghum. We will explore this synergy more in detail also with existing sugarcane projects in the ECOWAS region.

6 Cassava in Nigeria and Ghana

Cassava is one of the staple food crops in the ECOWAS region. It is a special crop since it is toxic due to the presence of cyanogenic chemicals. Proper processing/preparation of the Cassava roots is of utmost importance to reduce the toxicity. The root tubers are processed to various products like starch, gari, 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, but Nigeria does not. The northern part of the country is an area vulnerable to regular droughts causing local food shortages in these periods.

Nigeria has embarked on a program to transform its agricultural production system after realizing that crop yields stay far behind in relation to other countries like Brazil, India and countries in South East Asia (Adesina 2011). In Nigeria and Ghana yields from local farming are closely to 10 t 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. There are many cassava varieties each having their own pattern in time for tuber production. Harvest time can be spread throughout the year by varying planting dates and choosing the right fast- and slow-tuberizing varieties. For the production of ethanol, special high sugar containing varieties have been bred.

6.1 Processing

Using modern farming techniques and new varieties the yield is around 20 t/ha per annum. Cassava roots once harvested cannot be stored and 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.

A typical ethanol production process is SLSF: slurry – liquefaction - sacharification – fermentation. Slurry is produced by grinding chips and mixing them with an equal weight of water. Liquefaction of the starch in the slurry takes place at 105 ^{o}C. Then alpha-amylase is added to saccharify the starch at 55 ^{o}C, yielding syrup that is fermented with yeast at 30 ^{o}C to produce an 8-10% ethanol containing slurry. The ethanol is distilled from the slurry and dehydrated. This way 6 kg of root tuber containing 25% starch delivers ca. 1 litre 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 sacharification 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 an access of 1.7 tons of water is added and mixed. The slurry is liquefied with steam at 120 ^{o}C, then cooled down to ca 50 ^{o}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 biogas production (Piyachomkwan, 2011). Using this process ca 90% of the original caloric value in the roots is retained in the ethanol. Processing takes about 2.7 MJ/t feedstock mainly for distillation and drying.

6.3 Current projects

Nigeria has an internal market demand of 5 billion liters 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 liters of crude ethanol mostly from Brazil. Dura Clean in Bacita and Allied Atlantic Distilleries in Sango-Ota produced only 15.3 million liters from molasses and cassava (Agbro 2012). The massive import of crude ethanol thus eludes Nigerian cassava farmers of additional business opportunities of feedstock supply. Atlantic Distilleries is producing 30,000 l from locally sourced cassava feedstock. Dura Clean has yet to begin full operations.

Evidently, $ 3.86 billion has already been committed to construct 19 ethanol biorefineries, 10,000 units of mini-refineries and feedstock plantations for the production of over 2.66 billion liters of fuel grade ethanol per year. Five companies already exist including the 2 mentioned above with a total installed capacity of 0.2 billion liters 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 sugar cane, 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).

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 roots/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 1000 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 (Caltech).

6.4 Intermediate observations and conclusions

There are very few countries in the region that have today 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 into ethanol operations. It remains to be seen if this also can form a basis for more de-centralized smaller scale processing units.

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. Cashew nut yield is about 1750 kg/ha since the new Brazilian varieties were introduced. Cashew nuts are sold nowadays for 650-830 USD/ton and deliver a revenue of USD 180/ha (GIZ 2010) for small holders. Over 80 % of the nuts are exported from the region, mostly to India were they are processed.

Processing nuts into shells and kernels is hardly done in the region although many small processing businesses exist. Kernels are sold for over 1000 USD/t depending on the quality and size. Processing the nuts gives a lot of employment and therefore the establishment of new processing companies is stimulated. The shells contain 20-30% liquid, which is called cashew nut shell liquid (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 de-carboxylates 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. It is sold for 480-550 USD/ton.

For every ton of nuts about 10 tons of apples is harvested as well. Apple is not the good word for it, because it is the swelling of the fruit stalk that produces this structure. The apple contains 85% moisture, but has a tremendous nutritious value. For 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 2012). 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 2011). 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, 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 to rot for fertilisation purposes. In a region with frequent food shortages that produces over 10 million tons cashew apple annually; not using these for human nutrition really looks like a big waste. Investigations are ongoing to use the apples for animal feed purposes as well.

7.1 Processing into bio energy

Cashew can be used for bio energy purposes via several ways. The CNSL can be used up to a 35% blend in diesel. The oil can be obtained simply by expelling the shells, which will deliver about 200 kg oil per ha. The 770 kg/ha 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. This will deliver about 273 kg oil per ha, bringing the total oil yield per ha to almost 500 kg. The 500 kg press cake produced per ha 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, which is ca 1260 kg ethanol per ha. These yields are reasonable, but the income and the social effect from selling apples and kernels for food and feed purposes will be much higher.

7.2 Mass balance

One ton of cashew apples produces around 660 kg juice. The remainder is cashew apple waste that is suitable for animal feed. Depending on the ripening stage of the apple the juice contains 50-200 g/l carbohydrates.

When cashew nuts are processed, the kernels are separated from the shells. In literature various data are obtained, depending on how the process is being performed. In general, nuts consist for 55% of shells, 2% of seed coat, 25% kernels, 3% dirt and 15% water. From 1 ton of shells circa 200 kg CNSL is obtained by pressing, leaving ca 800 kg of CNSL-press cake to be used as fertilizer or combustion. 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.

7.3 Intermediate observations and conclusions

For every ton of cashew nuts produced, about 9 tons of cashew apples are produced. This is a very large volume of potentially interesting biomass to be considered for further processing. One of the key problems will be that typically today, the cashew nuts and the apples are manually separated on farm immediately after harvesting. Organizing a collection system for the apples into larger processing units seems to be a logistical nightmare given the volumes and the texture of the apples.

One very important observation made by the project team is the very high vitamin C content measured in cashew apples, making it a very interesting target for further processing into vitamin C rich food products, rather than into the suggested biogas production stream.

The project team feels that this route needs to be fully explored and developed first and in a decentralized way. The further processing of cashew apples into food crops could lead into larger volumes of secondary biomass streams, which in turn can be used as feedstock for biogas production.

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.

In instances where larger scale plantations are being developed or considered for cashew production, a more integrated cashew nuts and apples processing unit can be considered from day 1. The project team will analyze this further.

Appendix 2: List of figures and tables

Figures

Tables