Institut International d'Ingénierie de l'Eau et de l'Environnement
International Institute for Water and Environmental Engineering
Fondation 2iE

cirad
LA RECHERCHE AGRONOMIQUE POUR LE DÉVELOPPEMENT

EVALUATION OF THE AVAILABILITY OF AGROALIMENTARY AND FORESTRY BIOMASS RESIDUES IN WEST AFRICA

FINAL YEAR REPORT FOR OBTAINING THE MASTER IN ENGINEERING WATER AND ENVIRONMENT

OPTION: ENERGY AND INDUSTRIAL PROCESSES

Presented and publicly defended June 10, 2011 by: Daouda ZOURE

Directed by : Mr.Michael MELZER
(engineering degree)
UTER GEI

Members of the Jury :

Président : **Dr. Joël BLIN**

Members : **Ms.Sarah AUDOUIN**
Mr. Arnaud CHAPUIS
Mr. Michael MELZER

Class of 2010/2011

DEDICATION

This work is dedicated to my late Father Zoure Tenin Moussa, my moms, my Family, and my Friends.

Don't worry be happy

ACKNOWLEDGEMENT

First and foremost my sincere gratitude goes to Michael MELZER and Dr. Joël BLIN for accepting to supervise this work and

I also wish to acknowledge the peer support and encouragement of the workers of LBEB 2iE and CIRAD Ouaga.

I am indebted to the following people and institutions for the various support during the study:

Omar Zampaligre, Dembele Issiaka, 2iE, the CIRAD, and the Burkina Faso public schools system.

I am also grateful to all my teachers from High school to 2iE, my classmates, and friends.

Résumé

La biomasse devient incontestablement une source d'énergie renouvelable pouvant remplacer les combustibles fossiles. Dans les pays de l’Afrique occidentale certaines quantités de résidus agroalimentaires, jusqu'ici inexploités, sont produites. Le but de ce rapport est d’évaluer la production de résidus dans les unités semi-industrielles et industrielles de noix d’arachides, de noix de cajou, de noix de karité, d’huile de palme, d’huile de jatropha, et le bois d’hévéa au Burkina Faso et ses pays voisins. Les données sur les résidus n’étant pas disponibles un ratio du Résidu sur le-Produit est déterminé et appliqué à la production de la partie noble, sur laquelle les données sont disponibles.

Les résultats sont présentés de trois manières, une première approche suppose que la quantité entière de biomasses produites est transformée dans le pays d'origine, la deuxième approche suppose que les unités de transformation fonctionnent à 100% de leur capacité, finalement des résultats sont basés sur la transformation réelle de ces dernières années. La Côte d’Ivoire produit la plus grande quantité de coque de cajou (4650 t/an), résidus d’huile de palme (399700 t/an), et de résidus de bois d’hévéa (43700 t/an). Aussi le mali produit la plus grande quantité de tourteaux de karité 6530 t/an, Niger produit 3780 t/an de coque d’arachide.

Mots Clés :

1 – Potentiel des résidus des biomasses en Afrique de l’Ouest

2 - Anacarde

3 – Palmier à huile

4 - Jatropha

5 – Karité

Abstract

Biomass is becoming increasingly important globally as a clean alternative source of energy to fossil fuel. In West African countries certain quantities of so far unexploited agro alimentary residues are produced. The aim of this report is an evaluation of the potential production of the residues of semi-industrial and industrial processing units of Cashew nuts, Ground nuts, oil palm, Shea nut, Jatropha and rubber wood in Burkina Faso and its neighbor countries. As data on residues are scarcely available Residue-to-Product ratios are determined and applied to the production of the noble part, on which data more easily available.

The results are presented in three ways, a first approach assumes that the whole quantity of fruits/biomasses harvested is transformed in the country of origin, the second approach assumes that the transformation units work at 100% of their capacity, finally results are based on actual transformation in recent years.

Ivory Coast produce the highest amount of cashew shells (4650 t/yr), oil palm wastes (399700 t/yr), and rubber wastes (43700 t/yr). Also Mali produce the highest amount of Shea cakes 6530 t/yr, Niger produce 3780 t/yr of groundnuts shells.

Key words:

1 – Biomass residue potential in West Africa

2 – Cashew nut

3 – Oil palm

4 – Jatropha

5 – Shea nut

List of abbreviations

ACA: African Cashew Alliance

CNSL: Cashew Nut Shell Liquid

FAO: Food and Agriculture Organisation of the United Nations

FAOSTAT: statistical Web site of the fore mentioned

GREL: Ghana Rubber Estates Ltd

GTZ: German Technical Cooperation

NGO: Non Governmental Organization

RCN: Raw Cashew Nuts

RPR: Residue-to-Product-Ratio

WP_{actual}: actual waste potential

WP_t: theoretic waste potential

$WP_{100\%}$: waste potential if transformation unities work at 100% of their capacity

Table of Content

List of Figures

List of Tables

1 Introduction

1.1 Setting the Scene

The increase of crude oil price (130 USD/barrel at New York in May, 2008) [1], the global warming (increase of surface temperature on land and water caused by Green House Gases), the augmentation of energy consumption along with the economic growth in India and China, have reactivated worldwide the interest in renewable energies [2-3] (e.g. biomass, wind energy, wave energy and swells, tidal energy, ocean thermal energy, hydraulic energy, geothermal energy, and solar energy).

Biomass accounted for roughly 10% (about 50 EJ/yr) of global primary energy consumption in 2007, making it the largest primary source of renewable energy. [4] In Sub-Saharan Africa, biomass represents 56.3% of the energy consumption (mostly used as charcoal and wood fuel) [5], but Africa still has the lowest per capita energy consumption (e.g. the electricity consumption is 542 kwh in Sub-Saharan countries versus 2678 kwh for the world [5]).

In Africa, to reduce poverty in rural areas, energy is needed to process food and produce electricity. [6] Biomass as agricultural residues, forestry or food processing waste, is an available resource that can be used as fuel to run engines for processing or electricity production. [3] However, these residues are not available all year long and most important they have physico-chemical variable properties (particle size, moisture content, ash, ...), so it is important to pre-condition the available biomass to a homogenous fuel of quality that can be used throughout the year. One way of preconditioning biomass is flash pyrolysis. It is a process which transforms lignocellulosic biomass into a biofuel liquid that can be used for various energy purposes, such as heat and electricity production, and after upgrading as a transportation fuel.

A thesis, conducted jointly by the Centre International de la Recherche Agronomique (CIRAD, Montpellier, France), the International Institute of Water and Environmental Engineering (2iE, Ouagadougou, Burkina Faso), and the Université de Technologie de Compiègne (UTC, Compiègne, France) aims to evaluate the feasibility of flash pyrolysis using agricultural by-products as feedstock in sub-Saharan Africa.

Objective of this study is to evaluate the availability of certain agro-alimentary residues in sub-Saharan Africa.

1.2 Sizing the Objectives

Since the collection of data concerning the agro-alimentary residues is very complicated and time-consuming it has been necessary to limit the study to a few countries.

A former study showed that some agricultural wastes are entirely valorized or not easy to mobilize e.g. the cotton (the seed are used to produce oil and the cake to feed animals whereas the unexploited stems are distributed in a very large area and collection would be too expensive).

As they are residues of the agro-alimentary industry and therefore easy to mobilize the following unexploited biomasses maybe interesting for advanced energetical valorization i.e. Jatropha seed cake, cashew nut shell, Shea nut cake, rubber tree, oil palm fruit wastes, and Groundnut shells. This works goal is to estimate the potential and the availability of the selected biomasses in semi-industrial and industrial production sites in some sub-Saharan countries (Benin, Burkina Faso, Ghana, Ivory Coast, Mali, Niger and Togo).

1.3 Outline of this study

This study consists of four parts. Part 1 contains biomass generalities, an overview on biomass transformation technologies, and a description of the pre-selected biomasses. This aims at giving the reader a general idea of the processes and knowledge of the biomasses studied. Part 2 describes the methodology used to get data and to calculate the quantity of wastes. In part 3 the results are presented in form of tables, and a discussion, will be made. Finally in part 4 a conclusion and perspectives are given.

2 Theorical Background

2.1 Biomass generalities

Biomass is a term used for all organic matter that is derived from plants as well as animals. Its resources include wood and wood wastes, agricultural crops and their waste by-products, municipal solid waste, animal wastes, wastes from food processing, aquatic plants and algae. [7] Woody biomass is mainly composed (38-50% by weight) of cellulose $(C_6H_{10}O_5)_x$, hemicelluloses (20-40% weight) such as xylan $(C_5H_8O_4)_m$, and lignin $[C_9H_{10}O_3\,(OCH_3)_{0.9-1.7}]_n$ (n,m,x are positive integer) that constitutes about 15-25% of the composition of lignocellulosic material. [7-8]

There are three main routes of converting biomass into biofuels: physical, biological and thermochemical processes.

Physical processes like grinding, drying, filtration, pressing, extracting, and briquetting, are used for oleaginous biomass. Biological processes, as anaerobic digestion and fermentation, are most suitable for high moisture herbaceous plants (e.g. vegetables, sugar cane, sugar beet, corn, sorghum, …), marine crops and manure. Thermochemical processes are: combustion, carbonization, flash pyrolysis, gasification. [3]

2.2 Flash pyrolysis

2.2.1 Definition

Pyrolysis is the thermochemical transformation of organic matter in a heated enclosure, usually in an oxygen-absent or very low oxygen level environment. The temperature increase leads to complex chemical reactions that degrade the major constituents of biomass into three main products: a solid (charcoal), condensable vapors (organic oil and water) and permanent gases ($CO, CO_2, H_{2,} CH_4$ and other light hydrocarbons $C_2 - C_3$). [8]

The goal of flash pyrolysis is to convert solid biomass into a liquid, the so called bio-oil with, a yield of 40-70%, on dry base. The by-products are char (10 -20%), and incondensable gases (10 -30%). [8]

2.2.1 Characteristics

The essential features of a fast pyrolysis process are:

- Very high heating and heat transfer ($> 10^3 °Cs^{-1}$) rates at the reaction interface, which usually requires either a finely ground biomass feed or the fast removal of primary products,
- Carefully controlled pyrolysis reaction temperature of around 500°C and vapor phase temperature of 400-450°C,
- Short vapor residence times of typically less than 2 seconds,
- Rapid cooling of the pyrolysis vapors to give the bio-oil product. [9]

2.2.2 Overview of fast pyrolysis technologies

There are three different processes of fast pyrolysis:

- Ablative pyrolysis: The biomass is pressed against a heated surface that rapidly turns, which leads to the effect that the organic components are "molten" leaving an oil film that evaporates;
- Fluid-bed and circulating fluid-bed pyrolysis, which transfers heat to biomass by a mixture of convection and conduction;
- Vacuum pyrolysis reactors: The principle is to maintain the atmosphere of the reactor at a very low pressure (about 15 kPa). The heating rates are relatively low and correspond to those encountered in slow pyrolysis systems. [9]

2.2.3 Advantage and Disadvantages

This process has the potential to transform all types of biomass (e.g. root, leaves, trunk, fiber,). The bio-oil produced is (in limits) storable, transportable, and can be, after upgrading, used as fuel in engines or burnt to produce electricity. On the other hand this technology is still in research and development state, there is no bio-oil in sell on the market yet. [4]

Additionally it is a high technology process which needs a lot of automation and monitoring. For rural communities in Africa that just need cheap fuels to run small processes, e.g. presses or mills, this process might not yet be adapted.

2.3 Description of the pre-selected biomasses

2.3.1 Cashew nut

2.3.1.1 Generality

The cashew tree (Anacardium occidentale), originated from Brazil, is an important tropical crop that has been brought to Africa to their colonies by the Portuguese. The cashew trees can survive with a minimum of 600 mm of rain per year, but below 1000 mm/yr the productivity is limited. [10] The tree reaches its period of high production in its seventh year, and can maintain it up to 20-25 years. After that age, the production and the quality of the nuts decrease gradually. [10] The harvest campaign of nuts lasts 4 months (January-May). [11] India is the largest processor and exporter of cashew nuts (India annually processes about 1.18 million tons of raw cashew through 3650 cashew processing industries) [12], and Africa produces about 40% of Raw Cashew Nuts (RCN) (Figure 1).

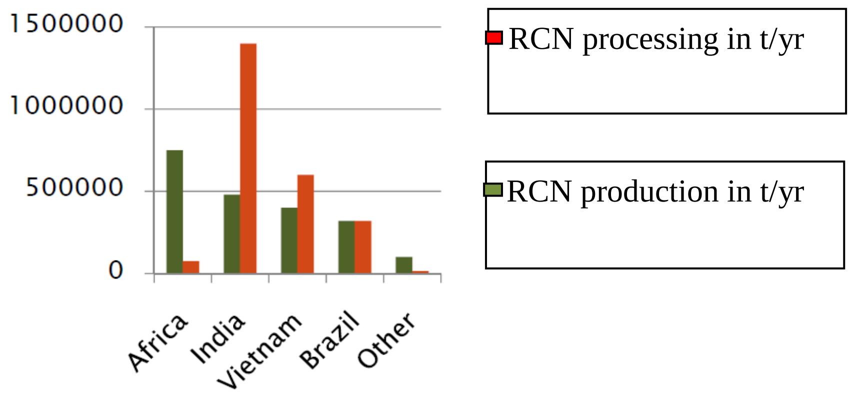

Figure 1: Cashew nut production and processing in the world [14]

The different parts of the cashew nut are (Figure 2):

- 1. Cashew kernel: It is mainly consumed roasted and salted, also it is used in confectionery and bakery products, for example, finely chopped kernels are used in the production of sweets, ice creams, cakes and chocolates, and as paste to spread on bread. [13]
- 2. Cashew Nut Schell Liquid (CNSL): It is highly hazardous in nature as it contains 90 % anacardinol and 10% cardol acid [12] and should not be handled with bare hands. Because it can irritate the skin. [13]

- 3. Cashew Apple (or false fruit): It is an edible food rich in vitamin C. It can be dried, canned, or eaten fresh from the tree. It can also be squeezed for fresh juice, which can then be fermented into cashew wine. [14]
- 4. Cashew nut shell: It is the major waste produced during the processing of the cashew nuts.
- 5. Testa Skin: It is sometimes as a supplement to livestock feed. It can be used to make dyes too. [13]

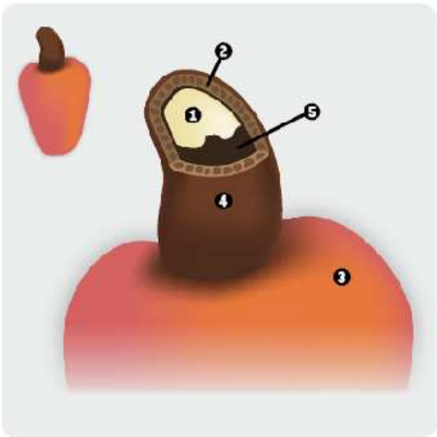

Figure 2: Cashew fruit [13]

2.3.1.2 Growing areas of Cashew trees

The growing areas in the countries studied are:

- Benin: The geographical area of production of cashew spans three regions: the center (including the departments of Zou and Collines), the north-east (including Borgou and Alibori) and the north-west (including Atacora and Donga). [15]
- Burkina Faso: According to data from the RGA (General Agricultural Census), approximately 45 000 households have over 10 cashew nut trees in Burkina Faso and 97% of them are located in the regions of the Cascades, Southwest, Hauts-basin and Central-west. [11]
- Ghana: Cashew is grown in all regions of Ghana except the Western region. The major regions for cashew cultivation are: coastal Savanna, Brong-Ahofo/Afram Plains, Upper East region, northern Region ,and the Upper West Region. [16]

- Ivory Coast: The center and the North of the country are the major regions of cashew trees. [17]
- Mali: The major production areas are the circles of Kadiolo, Kolondièba, Bougouni Yanfolila Garalo and Manakoro. Sikasso is considered as the capital of cashew nuts in Mali. The secondary zones of production are Koutiala, Kati, Koulikoro, and Kita. [10]

No data were found for Niger and Benin.

2.3.1.3 Cashew nuts process by-products

Cashew nuts shells are the main by-product of cashew almonds production. They have low combustion efficiency. Cashew nuts shells are used as fuel by the women to roast the nuts. But the combustion creates a smoke strongly unpleasant and suspected of being carcinogen. [18]

2.3.2 Groundnut

2.3.2.1 Generality

Groundnut or Peanut (Arachis hypogae) was first domesticated in the Valley of Peru. The Portuguese introduced peanut in West Africa in the late sixteenth century. Groundnut is a plant adapted to regions of tropical climates, and warm temperature. The plant requires at least 500 mm of rainfall well distributed during 3 to 5 months for its vegetative growth. In African countries, Groundnut production fluctuates a lot. The yield per hectare is low, due to irregular rainfall, traditional and small-scale mechanization, occurrence of pests and diseases. [19] Nigeria is the biggest producer in West Africa (2.97 million tons in 2009 [20]), Senegal is the second largest producer with 1.03 million tons in 2009. [20]

2.3.2.2 Growing Areas of Groundnut

Groundnuts are produced in all the studied countries. [20] Its growing areas:

- Benin: The Zou departemant produces more than 40% of Benin’s peanut production. [21]
- Burkina Faso: The provinces of Boulgou, Gnagna, Boulkiemde, Koulpelgo, Yatenga, Houet, Comoe, are the principle peanut producers. [22]
- Mali: Kayes area (Sikasso, Koulikoro, Mopti) is the principle peanut producer. [23]
- Niger: Maradi, Dosso, and Tahoua are peanut production regions.

No data were found for plantation locations in Ghana, Ivory Coast and Togo.

2.3.2.3 Groundnut process by-products

The Groundnut industry by-products are shells and press cakes. Press cakes are used to produce Groundnut paste, and the shells are used as a fuel to produce heat or electricity, animal feed, charcoal, fodder. [24]

2.3.3 Jatropha seeds

2.3.3.1 Generality

Jatropha Curcas is a small tree or large shrub, up to 5-7 m tall, belonging to the Euphorbiaceae family, with a life expectancy of up to 50 years. The plant has its native distribution in Mexico, Central America, Brazil, Bolivia, Peru, Argentina and Paraguay. Normally Jatropha flowers only once a year during the rainy season. In permanently humid regions or under irrigated conditions Jatropha flowers almost throughout the year. The seeds contain toxins, such as phorbol esters, curcin, trypsin inhibitors, lectins and phytates, up to such levels that the seeds, oil and seed cake are not edible without detoxification. The minimum annual average rainfall at which Jatropha is known to yield a considerable amount of seeds is 500-600 mm. [25]

Jatropha is used:

- To win the vegetable oil of its seeds for application as a direct fuel or for biodiesel production.
- As a medicinal plant, the seeds help against constipation; the sap is good for wound healing; the leaves help (in form of tea) to cure malaria; etc.
- Jatropha is planted in the form of hedges around gardens, fields, to protect the crops against roaming animals, and to reduce erosion caused by water or wind.
- Jatropha plants are used as a source of shade for coffee plants in Cuba; and to support plant for vanilla. [26]

2.3.3.2 Growing areas of Jatropha trees

Jatropha trees are cultivated in almost all tropical and subtropical countries. [27] The growing areas in the studied countries are:

- Burkina Faso: Jatropha is harvested in the region of Boni, Sawana, Dano, Kantchari, Gampela.
- Ghana: Jatropha plants are harvested in Central, Eastern, Volta, Brong-Ahafo, and Greater Accra regions. [27]
- Ivory Coast: The company “Jatropha Cote d’Ivoire JATROCI” has plantations in Toumodi, Taabo and Dimbokro [28], and Bio Pétrole renewable Africa (BPR AFRICA), in 2009, has set up experimental plantations in Daoukro, Gagnoa, Daloa, Ferké, Korhogo. [29]
- Mali: Jatropha in Mali is promoted by four projects (Mali Folke Center, Mali Biocarburant SA, Jatropha Mali Initiative (JMI), GERES Mali project); plantations are located in Commune de Garalo, Koulikoro Cercle, Kita Cercle, and Koutiala cercle. [30]
- Niger: Jatropha is harvested in Dosso and Tillabery.

No data were found for Benin and Togo.

2.3.3.3 Jatropha seeds transformation by-products

Jatropha seeds transformation produces two main by-products, the husks and the seed cakes. Seedcakes can have much utilization. They could serve as an organic fertilizer. The presence of the bio-degradable toxins, mainly phorbol esters, makes the fertilizing cake simultaneously serve as biopesticide/insecticide. Also, the cakes can serve as feedstock for biogas production through anaerobic digestion and the effluents are used for soil amendment as well. A study obtained 0.446 m^3 of biogas, containing 70% CH_4 per kg of dry seed press cakes (using pig manure as inoculum). The husks can be used for direct combustion and biogas production. In addition, it was shown that Jatropha seed husks are an excellent feedstock for gasification. [25]

2.3.4 Oil palm fruit

2.3.4.1 Generality

In Africa, the oil palm plant (Elaeis guineensis) is mostly cultivated in Central Africa and parts of West Africa. Nigeria is the largest producer of palm oil, with a global market share of 3%, followed by Ivory Coast, and the Democratic Republic of Congo, both having a market share of around 0.5%. [7] Malaysia and Indonesia produce 85% of world palm oil. [31] The tree production is maximal from 8 to 20 years of culture. Oil palm trees produce all year long. But they require 2 000 hours of annual sunning, more than 1 800 mm of rain well distributed all the year, and an average temperature of 28°C. Oil palm fruit is, by far, the oilseed that is most productive. It produces, cultivated on the same area, 7 to 10 times more than its direct competitors (soya, colza and sunflower). [31]

2.3.4.2 Growing areas of oil palm

Oil palm plantations are harvested in:

- Benin: Plantations are located in the South of the Country. [32]
- Ivory Coast: Oil Palm trees are cultivated in the southern part of the forest belt, from east to west. [33]
- Ghana: Oil palm plantations are located mostly in the zones of the Ashanti, Western and Eastern regions. [7]
- Togo: 70% of the plantations are located in the south of the country. [32]

2.3.4.3 Oil palm fruits transformation by-products

Oil palm fruits by-products are: empty fruit bunches fibers, kernels and shells. Empty fruits bunches, to replace their incineration, are spread all over the plantations to reduce pollution and to keep organic matter in the grounds. The empty fruit bunches can be used as feedstock for methanation and composting. [34]

2.3.5 Rubber wood

2.3.5.1 Generality

Rubber tree (*Hévéa brasiliensis* Muell. Arg) is used to produce latex. Cameroon, Ivory Coast (first producer of rubber in Africa with 188532 t of latex produced in 2007 and 2008 [20]) and Nigeria are major latex producer in Africa, and Indonesia is the world largest producer of latex. [35] Rubber Wood is available in the plantations when the latex yield decreases after 25 to 30 years of exploitation. [35-36] It is used by traditional carpenters, charcoal makers and in sawmills. [37]

2.3.5.2 Growing areas of rubber tree

Hevea brasiliensis is a plant originated from the Amazon Basin, but now it is mostly harvested in tropical countries. [35] Ghana and Ivory Coast are the only countries out of the studied ones that produce latex. [20] The growing areas are:

- Ivory Coast: Plantations are located in Moyen Cavally région, Grand-Bereby region, Anguedédou region, Béttié (Abengourou) région, and Grand-Lahou.
- Ghana: Ghana Rubber Estates Ltd (GREL) plantation is located in Western Region of Ghana, about 35 km from Takoradi. [37]

2.3.5.3 Rubber tree processing by-products

Sawmill residues are wood waste and sawdust. A part of the residues is used by the sawmills themselves to produce steam for timber drying purposes. Also sawdust is sometimes briquetted, carbonized, and sold as a quality fuel (charcoal). [38]

2.3.6 Shea nut

2.3.6.1 Generalities

The Shea tree, *Butyrospermum parkii,* grows spontaneously in the wooded savannah areas of West Africa. It produces its first fruit when it is about 25 years old and reaches its full production at the age of 40-50 years. The Shea tree usually sheds its fruits in the middle of May and continues for about 90 days. [27] Shea nut trees are located in 16 countries: Benin, Burkina Faso, Cameroon, République Centrafricaine, Ivory Coast, Gambia, Ghana, Guinea, Mali, Niger, Nigeria, Uganda, Senegal, Sudan, Chad, and Togo. Nigeria is the biggest producer of nuts with 60% of world production (estimated to 700000 t in 2005). [39] Shea butter is now highly valued in the cosmetic, biotechnology and agri-food sectors.

2.3.6.2 Growing areas of Shea tree

The growing areas of Shea tree are:

- Burkina Faso: Shea trees cover 70% of the countries territory (the West, the Center-south, the East, the South, and the Center-west). [17]
- Ghana: Shea trees are located in the North of the country. [27]
- Ivory Coast: Shea trees are located in the North part of the country.
- Mali: Shea trees are located in Sikasso région (Bougouni, Koutiala, Kadiolo, Yanfolila, Kolondièba, Sikasso), Ségou région (Ségou, Bla et San), Koulikoro région (Dioila, Kati, Kolokani), Kayes région (Kita), Mopti région (Bandiagara, Bankass et Koro). [17]
- Niger: Shea trees are located in Dosso and Tillabéry.

No data for special growning areas have been found for Benin and Togo.

2.3.6.3 Shea nut processing by-products

In industrial scale, the Shea butter by-product is Shea cake. The cake has been tried in vain to be used as animals' feed. With a volatile matter of more than 70%, the Shea cake is a good feedstock for thermochemical valorization. [40]

2.4 Description of transformation processes

The following section describes the different transformation processes and shows in which steps the by-products (residues) are generated.

2.4.1 The Cashew nut transformation processes

There are three types of cashew nut processes: industrial, semi industrial and traditional. [17]
The industrial technology used by the processors is in most cases Indian. It comprises: calibrators to sort raw nuts into categories; steam embrittlement; nut-shelling devices (hand or foot operated); drying chambers that dry shelled kernels before they are peeled; mechanical peeling conveyors (pre-peeling followed by hand-peeling, weighing devices (sorting); vacuum and carton packaging devices. Figure 3 shows the different steps of industrial and semi industrial processing. [41]

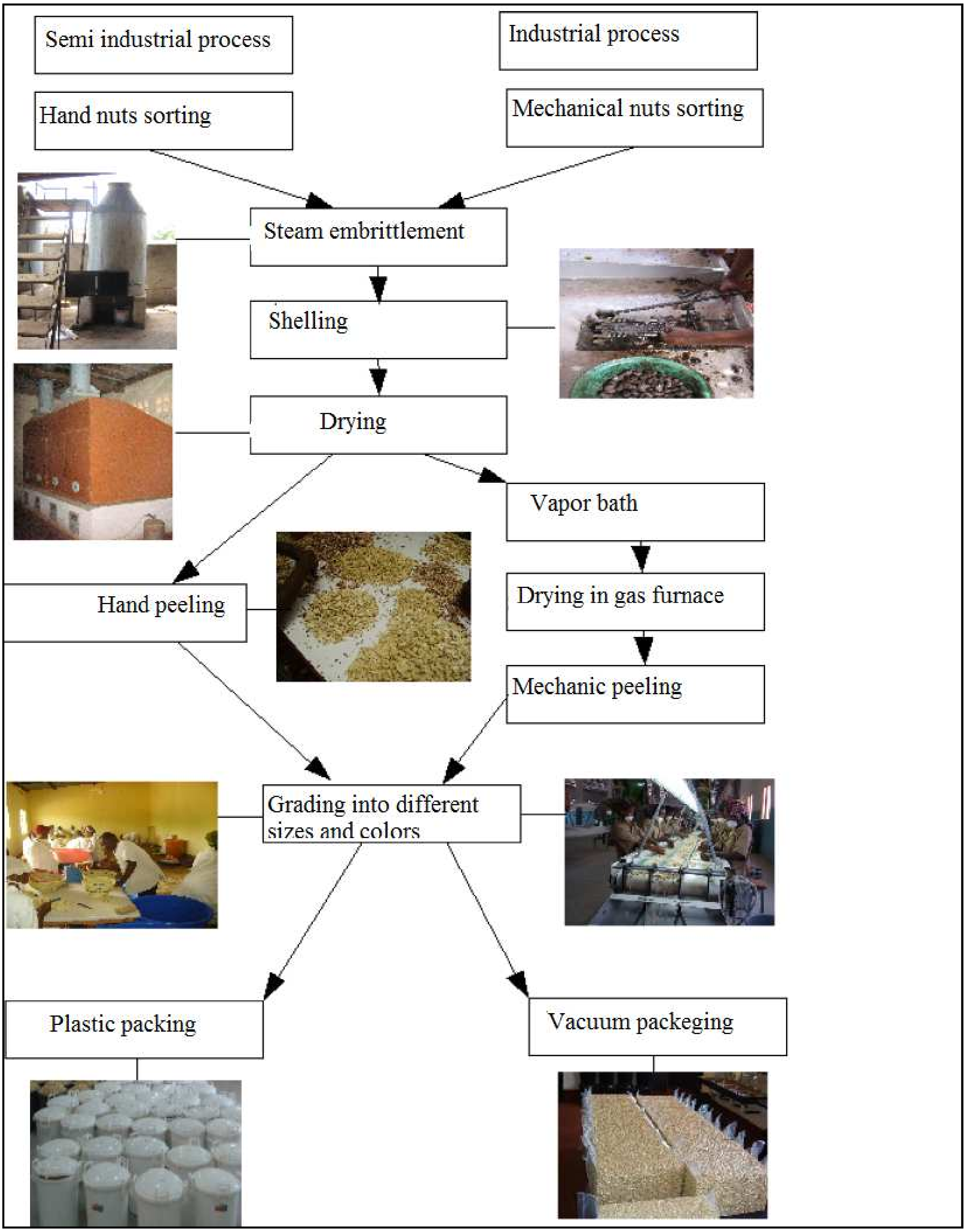

Figure 3: Semi-industrial process vs. industrial process [18]

2.4.2 Groundnut processing

The mechanical extraction of oil out of the seeds is most used (compared to the chemical extraction). In an oil unit, peanuts are shelled, dried, peeled, and pressed by mechanical expellers. [21] Figure 4 shows the stages of Groundnut oil production.

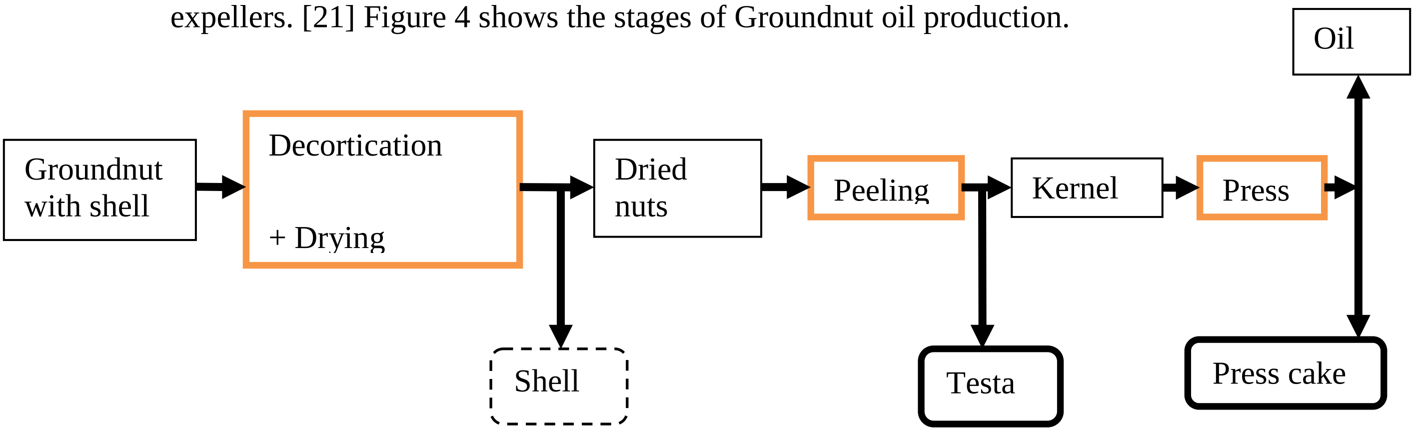

Figure 4: Different stages of Groundnut oil production

2.4.3 Jatropha oil production process

Jatropha oil can be extracted by two main methods:

Mechanical extraction (most used in West Africa) and chemical extraction. Prior to oil extraction the Jatropha seeds have to be dried, mechanical expelled (manual ram press, engine driven screw press). The presses can be fed with either whole seeds or kernels or a mix of both, but common practice is to use whole seeds. For chemical extraction only crushed Jatropha kernels are used as feed. The different operations of mechanical extraction of Jatropha seed oil are (Figure 5): cleaning, drying, pressing, filtering, and storage. [42]

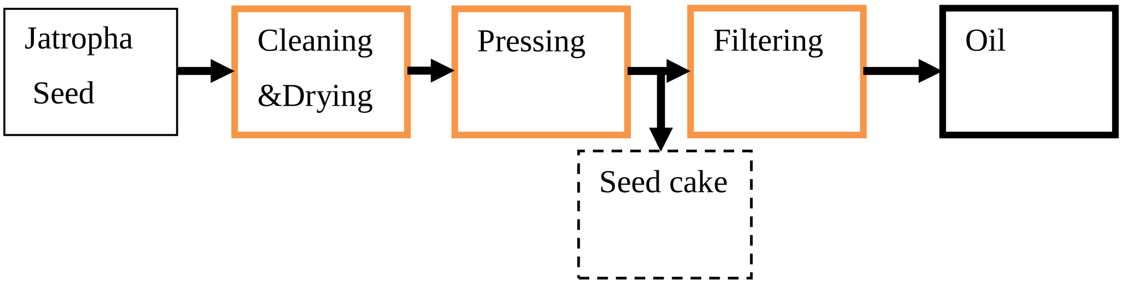

Figure 5: Jatropha oil extraction

2.4.4 Oil palm fruit processing

The oil winning process (shown in Figure 6) involves the reception of fresh fruit bunches from the plantations, sterilizing and threshing of the bunches to free the palm fruit, mashing the fruit and pressing out the crude palm oil. The crude oil is further treated to purify and dry it for storage and export.

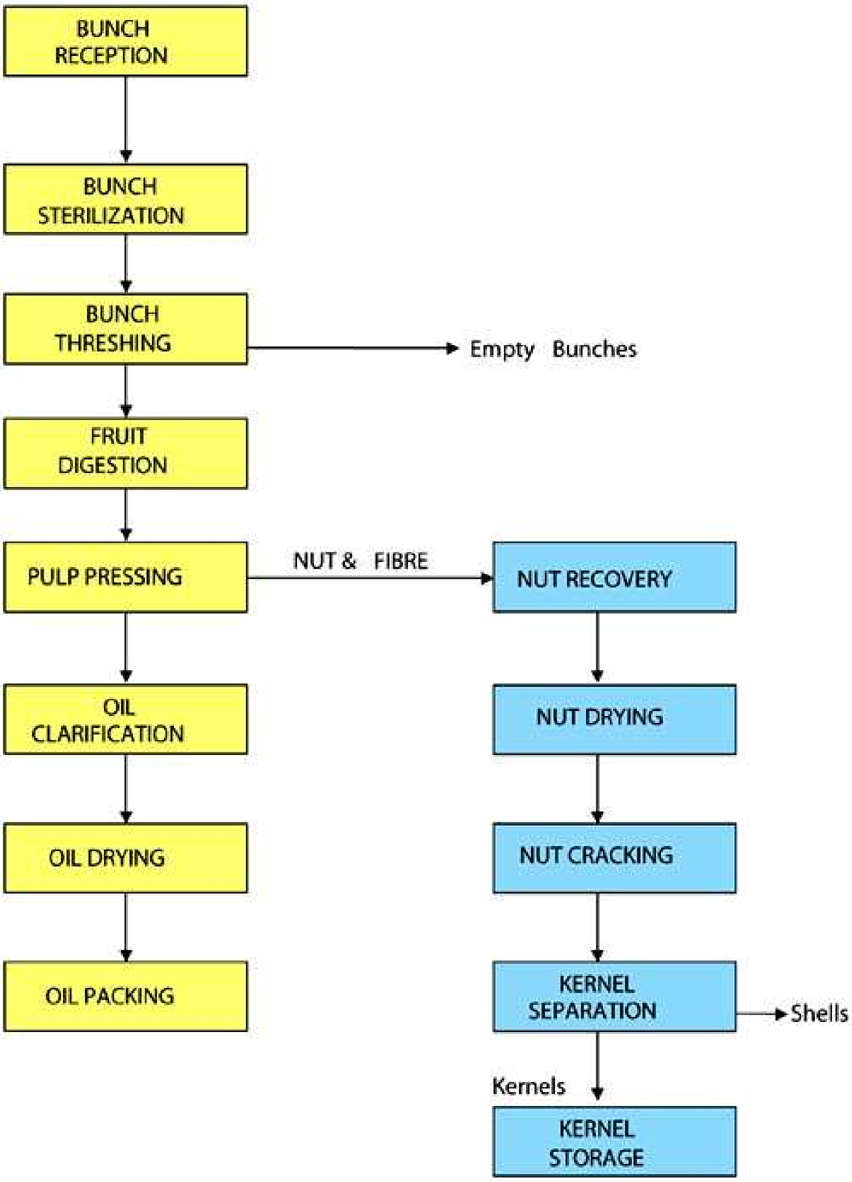

Figure 6: Processing of Oil palm fruit [43]

2.4.5 Rubber tree processing

The normal sawing line always consists of transport of logs, primary sawing with head rig band saw with carriage, secondary breakdown of cant with small band saw, and processing of flitch with small band saw. The techniques flow is shown in Figure 7.

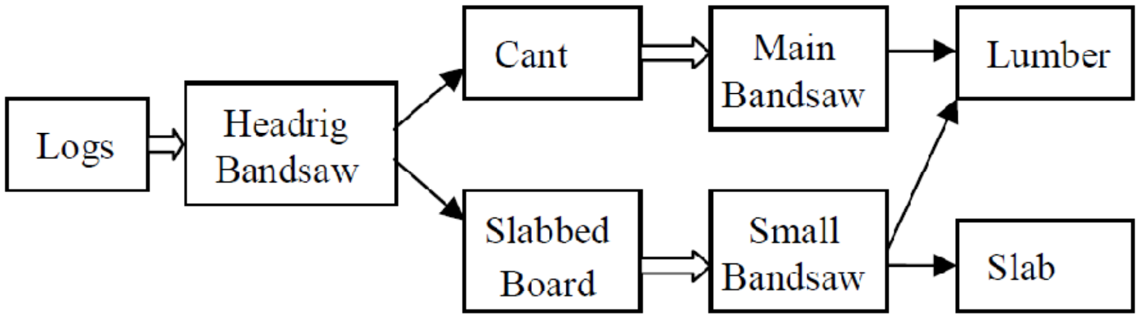

Figure 7: Wood processing in a saw mill [44]

2.4.6 Shea butter production

Shea butter is produced by traditional and industrial processes. There are two processes for obtaining Shea butter in the industrial level, mechanical pressing, and the use of an organic solvent. For mechanical extraction of butter, first, the Shea kernel is crushed in order to obtain a paste which will be directed towards the next stages of the extraction. Two processes are then used: either a cold pressing, or a hot pressing.

- During cold pressing, a press extracts oil at a temperature lower than 80°C. The disadvantage of this process is that the oil cakes content of grease is still very significant.
- During hot pressing, Shea almonds are preheated to a temperature of 90-100°C, are then introduced into a screw press. At the end of this stage, oil and Shea cake are obtained. The oil obtained by mechanical pressing must be refined (pass through neutralization, discoloration, deodorization, fractionation, hydrogenation, ungumming and the treatment against oxidation, …) in order to be usable. [45] Figure 8 resumes the main parts of industrial processing of Shea kernels.

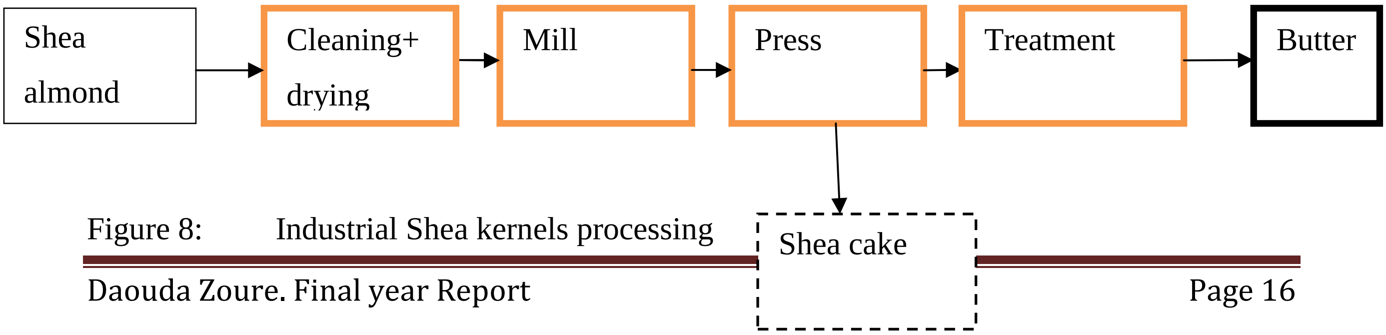

Figure 8: Industrial Shea kernels processing

3 Methodology

3.1 Collection of Data

As previous work efforts have shown data collection concerning the availability of agricultural and biomass wastes is not as easy as it may seem and stays very approximate.

Official and semi official data can be obtained for the noble products, but little is available for the residues.

For this study the collection of data has been carried out in several steps:

- For getting a first idea of annual production of the noble part of the chosen biomasses in each country, data have been collected mainly from the Food and Agriculture Organisation of the United Nations FAOSTAT. For being capable to estimate an average production of the noble part, the production of the past years has been examined.
- Secondly data have been collected concerning the installed capacity on the different semi-industrial and industrial transformation facilities.
- The last step had the objective to get information about the actual production of these facilities.

With these data residue potentials have been calculated as described in the previous sections.

3.2 Estimation of the produced biomass waste quantity

To get a first idea of the quantities of waste produced, some companies were contacted.

The return on information of the enterprises and companies was very little.

As most of the sources give only data on the noble parts of the agricultural product and not the wastes, Residue to Product Ratios (RPR), used by the International Energy Agency and other authors [4], have been applied. These ratios are dimensionless as they are given in kg residue / kg main product.

The RPR is calculated using the percentage of the waste and the percentage of the noble part of a fruit.

$$RPR = \frac{percentage \quad of \quad waste}{percentage \quad of \quad noble \quad part} \qquad \text{Equation 1}$$

It should be noticed that these RPR's might depend on several factors, as plant age, water supply, growing region and climatic conditions, soil quality, transformation process (e.g.

press performance), which are interfering. In this study very average values have been chosen, and will be discussed later.

3.3 Availability of wastes from the biomasses studied

The availability of the different wastes will be presented in three ways.

First, a theoretic value WP_t (theoretic waste potential) should give the biomass waste potential in every country assuming that all the harvested biomass (fruits) are processed in the country of origin.

$$WP_t = noble \quad part \quad (national) \cdot RPR \qquad \text{Equation 2}$$

The second value should represent the waste potential only of the semi-industrial and industrial processing (small transformation unities should not be of interest here, as their waste production is assumed to be little and therefore difficult to mobilize) facilities assuming that they work at 100% of their installed capacities ($WP_{100\%}$).

$$WP_{100\%} = noble \quad part \quad (100\%) \cdot RPR \qquad \text{Equation 3}$$

Finally the actual waste production is calculated, depending on the actual charge of the fore mentioned units.

$$WP_{actual} = noble \quad part \quad (actual) \cdot RPR \qquad \text{Equation 4}$$

4 Results

4.1 Calculation on the Residues-to-Product ratios

4.1.1 Cashew nuts

The African Cashew Alliance (ACA) documents the yield of cashew nut processing units to be around 20%, which comprises waste almonds and testa. [46]

Moreover the German Technical Cooperation (GTZ) cashew nut advisor, Philippe CONSTANT, estimated that, in Ivory Coast, the processing yield of cashew nuts is between 20-22%, the outer shell waste represents 70-75% of the nuts weight, and the kernels waste is between 3-6%. [47] In Burkina Faso the processing units, named Unité de transformation de l'Anacarde de Bérégadougou (UTAB), shells yield is between 74-77% for the last nine months. [48]

Mohod et al. reported that the shelling operation generates waste which is about 70 % of the original raw nut weight. [12]

A personal discussion with Mister Shatki Pal (Regional Cashew Processing Expert), working for “TechnoServe – Business solutions to poverty” in Ghana, lead to the conclusion that the shell residue of the nuts is about 70% all over Africa. [49]

So, for this study the values taken are:

- The main product is the almonds and the wastes are shells
- Shells represent 70% of the cashew nuts mass
- The almonds produced weight 20% of the nuts mass

Hence the RPR. is:

$$RPR_{Cashew} = \frac{percentage\,of \quad waste \quad (shell)}{percentage\,of \quad noble \quad part \quad (almond)} = \frac{70\%}{20\%} = \underline{\underline{3,5}} \qquad \text{Equation 5}$$

4.1.2 Groundnut

Groundnut is composed of 20-30% of shells and 70% of kernel in mass, the kernels contain 47-50% of oil in mass. [19, 50] According to the type of press, 80 to 95% oil contained in seeds can be extracted. [42]

For this study it has been retained that:

- There are different noble parts of the ground nuts (the nut itself, the vegetable oil, and peanut paste); here the vegetable oil shall be taken as the main noble product (produced in oil mills) and the shells as residues.
- in average Groundnut is composed of 25% (in mass) of shells and 75% of kernel, the kernels contain should contain in average 48.5% of oil , and the press should have an average yield of 87.5%. Hence

  $$\%oil_{extracted} = press \quad yield \times \%oil \quad contained \quad in the \quad Biomass \qquad \text{Equation6}$$

  Then using Equation 6 the oil that can be extracted from the kernel represents.42% of the kernel mass. $\%oil_{extracted} = 87.5\% \cdot 48;5\% = 42\%$

Then the RPR is

$$RPR_{Groundnut} = \frac{percentage\,of \quad waste \quad (shell)}{percentage\,of \quad noble \quad part \quad (extracted \quad oil \quad from \quad entire \quad nut)} =$$

$$RPR_{Groundnut} = \frac{25\%}{42\% \times 75\%} = \underline{\underline{0.8}} \qquad \text{Equation 7}$$

4.1.3 Jatropha Curcas

In average 4 kg of Jatropha seed are needed to produce 1 l of oil. [51] The density of Jatropha oil is 0.92 kg/l [52], so the output of 4kg of seeds is 0.92 kg oil(23% of the seed mass), 3 kg seeds cakes(75%), and 0.08 kg of losses.

Here it will be considered that:

- the pressed oil represents 23% of the seed mass, and the seed cake represents 75% of the seed mass

Then the RPR is:

$$RPR_{Jatropha} = \frac{percentage\,of \quad waste \quad (cake)}{percentage\,of \quad noble \quad part \quad (oil)} = \frac{75}{23} = \underline{\underline{3.2}} \qquad \text{Equation 8}$$

N.B. As presented later the collected data on Jatropha are mainly plantations areas. The Jatropha plantations in West Africa are almost young, and as the plants begin to give fruits just 3-5 years after planting no viable data on fruit yields have been found yet.

The output of Jatropha oil per hectare was estimated in a preserving way to 300 l [53] which correspond to 0.276 t in Burkina Faso. As climatic conditions are almost similar this value shall be used for Burkina Faso, Mali, and Niger.
In contrast the average Jatropha oil production in Benin, according to a representant of the NGO Centre Songhai, is 1200 l/ha (the tree poduce all year long) which corresponds to 1.1 t/ha. [54] The same output of 1.1 t/ha is used for Ghana, and Ivory Coast that have preferable climatic condition (more rainfall), as Benin.

4.1.4 Oil palm fruit

A palm fruit bunch is composed of empty fruit bunch and the oil palm fruit. The oil palm production by-products are: empty fruits bunches that represent 23% of the fruit bunches mass (containing about 65% moisture), fibers represent 13% (with 40% moisture), pressed kernels and shell represent 7.5% of the fruit bunch mass (with 20% moisture). [34]

Therefore the total waste produced by the processing unit represents 43% of the fruit bunches mass (using equation 9)

$$\%Wastes \quad produces \quad = \quad \%empty\ fruit\,bunches + \%\,fibers + \%\,pressed\,\mathrm{ker}\,nel\ and\ shells \qquad \text{Equation 9}$$

. On the other hand palm oil extracted from the fruit represents 20 to 26% (press yield already considered) of the fresh fruit bunch weight. [55] Since empty fruit bunch represent 23% of the fruit bunch, it can be deduced that oil palm fruit represents 77% of the fruit bunch mass.

For this study the average palm oil extraction yield 23% will be used.

$$RPR_{Palm} = \frac{percentage\,of \quad waste \quad (empty\ fruit \quad bunch)}{percentage\,of \quad noble \quad part \quad (oil)}$$

$$RPR_{Palm} = \frac{43\%}{23\%} = 1.87 \qquad \text{Equation 10}$$

4.1.5 Rubber tree

When old rubber tree plantations are cut, in Ivory Coast, 190 m^3 of biomass in general and 80 m^3 of timber in particular can be won per hectare. [56] Rubber wood with a relatively good structure can be sawed easily and gives a satisfactory yield of around 44%. [56] The density of rubber 0.65t/m^3 (with a moisture content of 12%). [56]

It will be considered that:

- The residues are produced only in the sawmills, then only timber will be considered as source of waste
- The weight: $= Volume\ of\ biomass \times\ Density$ Equation 11

$$RPR = \frac{percentage\ of\ \ waste\ \ (wood)}{percentage\ of\ \ noble\ \ part\ \ wood} = \frac{56\%}{44\%} = \underline{\underline{1.27}}$$ Equation 12

However, in Ghana the sawmills do not process rubber wood, GREL (the biggest rubber company in Ghana) has a mobile processing factory which produces rubber wood chips with a capacity of 3 t/h. The rubber chips will be exported to the Europe for energy production. In the plantation it remains the stumps, and the leaves.that are hard to mobilized. Hence it will be supposed that the rubber wood in Ghana is already valorize.

4.1.6 Shea nut

The Shea kernels contain about 50% Shea butter in mass. One tree produces 15 to 20 kg of fresh fruit, which corresponds to 3 to 4 kg of kernel. [27] Burkarina, an industrial Shea nut processor in Burkina Faso, transforms 10 tons of kernels into 3,7 tons of butter (represent 37% of kernels mass); approximately 5 tons of oil cake (50% of kernels mass), 1,3 t are lost (probably evaporated water, impurities) per day [40]. The National Shea Project (PNK) estimated that the industrial processing yield of butter vary from 30 to 37% (depending on the technology used). [57]

It will be considered that:

- The main product is the butter and the waste is Shea cake
- The percentage of oil extracted is 34% (of the seed mass)
- The Shea cake produced represents 55% (of the seed mass).

Hence the RPR is:

$$RPR_{Shea} = \frac{percentage\,of \quad waste \quad (cake)}{percentage\,of \quad noble \quad part \quad (butter)} = \frac{55\%}{34\%} = \underline{\underline{1{,}6}} \qquad \text{Equation 13}$$

4.2 Biomass production in national scale

4.2.1 Cashew nut production

The African Cashew Alliance (ACA) reports that Africa only processes 10% of Cashew nuts harvested, the main part is exported predominately to India. [46]

Data on Cashew nut production vary depending on the source and the year.

- In Benin FAOSTAT and ACA values show that the cashew nut production had increased from 2005 to 2008 (55000 to 100000) (see Table 1). However the 2008 production value given by FAOSTA is different (37% less) from the ACA value. Contrary to FAOSTAT where the values are calculated, ACA has got its values from the customs data in the port [41]. Furthermore, 2010 production was 30% less than 2009 because the harvest was poor and late. [58] The cashew production is assumed to be between 70000 t and 100000 t per year.

Table 1: Cashew nut production in Benin

Year	**Cashew nut production [t]**	**Source**
2005	55000	FAOSTAT [20] *
2007	60000	FAOSTAT [20] *
2008	62000	FAOSTAT [20] *
	99000	ACA[41]
2009	100000	ACA [58]
2010	70000	ACA [58]

*… FAO estimate

- In Burkina Faso the production was 25000 t in 2006 [11, 17], in 2010 a calculated value gives an average cashew nut production of 26000 t/yr. [59] Hence the annual cashew nut production lies between 25,000 t and 26000 t.

- In Ghana: the data given by FAOSTAT are calculated and lie between 34000 t and 44660 t (Table 2). In addition ACA production values for 2008 and 2010 are close (26454 t and 27000 t). Therefore the annual production of cashew nuts can be assumed to be between 26500 t and 34000 t.

Table 2: Cashew nut production in Ghana

Year	**Cashew nut production [t]**	**Source**
2006	34000	FAOSTAT [20] *
2007	40511	FAOSTAT [20] Im
2008	26454	ACA [16]
	44660	FAOSTAT [20] Im
2009	35647-	FAOSTAT [20] Im
2010	27000	ACA [58]

*… FAO estimate; Im=Amputation method

- In Ivory Coast the annual cashew nut production is between 280000 t and 336000 t (Table 3).

Table 3: Cashew nut production in Ivory Coast

Year	**Cashew nut production [t]**	**Source**
2007	280000	FAOSTAT [20]
2008	336000	ACA [60]
	308000	FAOSTAT [20] Im
2010	335000	ACA [58]

[ ] = Official data Im=Imputation method

- Mali: The annual cashew nut production is between 3500 t/yr [10] and 3600 t/yr [20]

Table **4** shows that the annual production of Cashew nuts in Togo. It lays between 550 and 700 t.

Table 4: Cashew nut production in Togo

Year	Cashew nut production [t]	Source
2004	550	FAOSTAT [20] *
2005	550	
2006	700	
2007	650	
2008	700	

*… FAO estimate

- No data were found for a production of cashew nuts in Niger.

The cashew nut production in the selected countries are summed up in Table 5.

Table 5: Annual cashew nut production in West Africa

Country	**Benin**	**Burkina Faso**	**Ghana**	**Ivory Coast**	**Mali**	**Togo**
Annual production [t]	70000-100000	25000-26000	26500-34000	280000-336000	3500-3600	550-700

4.2.2 Groundnut production

Groundnut production of the countries of interest here is given in **Table 6** for the period from 2000 to 2008.

- Benin: The production values are close to the average production (126570 t) except for 2002, 2004, and 2005 they are higher. As result the annual production of Groundnuts is between 110000 t (for the years 2000-01, 2003 and 2006-08) and 126570 t.

- Burkina Faso: The department of agriculture of Burkina Faso revealed that the average Groundnut production for the period 2005-2010 was 287476 t/yr. [22] FAOSTAT gives an average production of 264244 t/yr of Groundnuts for period 2000-2008 (Table 6). The production of Groundnuts is assumed to be between 264244-287476 t/yr following these two sources.

- Ghana: After a small production in 2000-01 the productions of ground nuts turned around 389649-520000 t from 2002 to 2008.

- Ivory Coast: Two years of intensive ground nut production 2000-01 were followed by an average production turning around 61207-69256 t from 2002 to 2007, 2008 was a year of relatively small production (Table 6).

- Mali: The production average 193000 t for the period 2000-2003, then drops in 2004 to 161044 t , and rises again in 2005 to maintain between 279503 t and 325000 t from 2005 to 2008(Table 6). Hence it will be retain that production turn around 279503 t-325000 t/yr.

- Niger: The average production is 100000 t/yr (in 2007) [61]. In Table 6 the production is around 113216-149600 t/yr. For this study the production is considered to be between 100000-149600 t/yr.

- Togo: The production turn between 33448-41428 t/yr from 2002-2008 (Table 6).

Table 7 resumes Groundnut production in each country.

Table 6: FAOSTAT Groundnut production [51]

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	Average (t/yr)
Benin (t/yr)	121159	125377	146214	124979	151666	140329	99382	114460	115562	126570
Burkina Faso (t/yr)	169146	301092	323642	358121	245307	220525	215447	244922	300000*	264244
Ghana (t/yr)	209000	258000	520000	439000	389649	420000	520000	301770	470100	391947
Ivory Coast (t/yr)	71853	73394	61207	63226	65280	67239	69239	69256	49885	65620
Mali (t/yr)	193073	139832	191548	214727	161044	279503	265549	324187	325000 F	232718
Niger (t/yr)	113216	82000	149600	180000 F	159000	113216	139100	152600*	147676*	132051
Togo (t/yr)	25976	38248	35680	38248	34870	33448	39285	35950	41428	35904

[*] = Official data | F = FAO estimate

Table 7: Groundnut production in West Africa

Country	Benin	Burkina Faso	Ghana	Ivory Coast	Mali	Niger	Togo
Average production t/yr	110000-126570	264244-287476	389649-520000	61207-69256	279503 -325000	100000-149600	33448-41428

4.2.3 Jatropha Plantations

The area of Jatropha plantations is around 5160 ha in Benin, 70000 ha in Burkina Faso, 1534 ha in Ghana, 18148 ha in Ivory Coast, 3830 ha in Mali and 100 ha in Niger (Table 8), no data was found for Togo.

Table 8: Jatropha plantations in West Africa

Country	Project Owner or regions name	Area planted (ha)	Source
Benin	SONGHAI CENTER	5000	[54]
	ALTERRE Bénin & GERES Benin	160	
Total		5160	
Burkina Faso		70000	[53]
Ghana:		1,534	[7, 27]
Ivory Coast	JATROCI	5.000	[28]
	BPR AFRICA	3.148	[29]
	Aderci	10.000	[62]
Total		18148	
Mali	Garalo	530	[30]
	Kita	1300	
	Koulikoro	1300	
	Yorosso	700	
Total		3830	
Niger	Dosso and Tillabery	100	[61]

4.2.4 Oil palm fruit production

The production of palm oil fruit in Benin, Ghana, Ivory Coast and Togo from 2004 to 2009 are shown in Table 9.

- Benin: The production is between 244000-250000 t/yr.
- Ghana: the production is between 1955300-2103600 t/yr
- Ivory Coast: The production of palm oil fruits (from 2004-2009) is between 1200000-1359470 t/yr. [15] The department of agriculture of the country gives the average production around 1 300 000 t/yr of palm fruit and 300000 t/yr of crude palm oil. [33] For this study the annual production of fruits will be taken between 1200000 t and 1300000 t/yr.

- Togo: The production of palm fruit is between 115000-125000 t/yr. [15] World Rainforest Movement wrote that Togo's production of oil palm fruits is around 130000 t/yr. [32] So for this study the production is assumed to be between 115000-130000 t/yr.

Table 9: Oil palm fruit production in tons [15]

Year	2004	2005	2006	2007	2008	2009	Average
Benin	244000	245000F	245000	250000 F	250000 F	ND	246800
Ghana	1955300	2024600	2097400	1684500	1896800	2103600	196036
Ivory Coast	1311035	1231754	1328443	1359470	1200000 F	1300000 F	1288450
Togo	115000 F	115000F	120000 F	120000 F	125000F	ND	120000

[ ] = Official data | F = FAO estimate ND= No Data

Table 10 gives an overview of the assumed average palm oil fruit production in the examined countries.

Table 10: Annual oil palm fruit production by country

Country	Benin	Ghana	Ivory Coast	Togo
Average production [t/yr]	244000-250000	1953300-2103600	1200000-1300000	115000-130000

4.2.5 Old rubber tree plantations

- Ghana: GREL has an 8-year replanting program covering a total of 4,700 hectares of old rubber tree plantations that initially date from 1967. [37]
- Ivory Coast: The area of rubber trees cut from replanting programs from 2001 and beyond amounts to 1500 ha /year .[56]

4.2.6 Shea nut production

The Shea crop is unique to sub-Saharan Africa and in high demand on the world market. Of the estimated 600,000 tons (in 2009) of Shea nuts harvested in West Africa (Burkina Faso, Mali, Ghana, Nigeria, Côte d'Ivoire, Benin, Togo and Guinea), about 350,000 tons are exported, mostly as raw nuts. The remaining 250,000 tons are processed and consumed locally and effectively left out of the traded market. [63] Table 11 gives the production of Shea nuts by country. Hence the productions of Shea nut are between 14056 and 20000 t/yr for Benin, 70000 and 90000 t/yr for Burkina Faso, 50000 and 65000 t/yr for Ghana, 28000 and 40000 t/yr for Ivory Coast, 80000 and 85000 t/yr for the Mali, 15000 t/yr for the Niger, 14000 and 15000 t/yr for Togo.

Table 11: Production of Shea nuts by country

Country	**Year**	**Production**	**source**
Benin	2000-2008	14056-14971 t/yr	FAOSTAT [20] Im
	2005	14000t	CIRAD [39].
	2008	20000t	WATH [63]
Burkina Faso	2005	70000 t/	[20, 39].
	2008	90000 t	WATH [63]
	2010	72000 t	PNK[57]
Ghana	2004-2008	.65000 t/yr	FAOSTAT [20]
	2005	63000 t	[39]
	2008	50000 t	WATH.[63]
Ivory Coast	2005	28000 t	CIRAD [39]
	2006-2008	27951-28874 t/yr	FAOSTAT [20]
	2008	40000 t	WATH.[63]
Mali	2005	84000 t	[39]
	2008	182202 t	FAOSTAT[20]
	2009	190000 t	
Niger	2007	15000 t/yr	[61]
Togo	2008 2009	15000 14000 t/yr	WATH.[63] [17]

Im= imputation methodology

4.3 Processing units

4.3.1 Cashew nut processing units

Several cashew nut units are found in Benin, Burkina Faso, Ghana, and Ivory Coast. But no information was found for Togo.

- Benin: Artisanal processes are located near urban areas (Cotonou, Porto-Novo, Abomey, Parakou, Natitingou). They consist of several individual units or groups. Their processing capacity remains very low and they use rudimentary technology. Semi-industrial units (based on Indian technology but with more modest equipment) presented in Table 12 are: The Songhai Center in Porto Novo, the Association of women cashew processors (AFETRACA) in Cotonou, the Groupe KAKE 5 (GK5) in Savalou, the ZANCLAN in Cotonou, and GNICOBOU units. Their capacities are less than 150 t/year each, and their output is sold on local and regional markets. The company Afonkantan Benin Cashew (ABC), based in Tchaourou, is the only industrial processing unit in Benin, its processing capacity is 1,500 t of raw nuts per year. The country currently processes 1800 t/yr that represent less than 5% of the national production. [15, 41]

Table 12: RCN processing units in Benin [41]

Factory name	**Capacity of processing RCN (t/yr)**	**Processed RCN (t/yr)**	**Technology**
Songhai Centre	<150	500	Imported and local
AFETRACA	<150		
GK5	80		
ZANCLAN	<150		
GNICOBOU units	<150		
ABC	1500	Over 1000	
Total	1980-2180	1500	

- Burkina Faso: The activity of cashew nut processing is mainly conducted in the régions des Cascades and des Hauts-bassins [17]. The processing units capacities are given in Table 13.

Table 13: RCN processing units in Burkina Faso

Factory name	Capacity of processing RCN (t/yr)	Processed RCN (t/yr)	Technology	Source
ANATRANS	3500	1000	Imported	[59]
COOPAKE	200	50	Imported and local	[11]
ECLA	500	120-220	Local	[11, 59]
SOTRIAB	2500	1000-1080	Imported, local	[11, 64]
UNION YANTA	400	172-200	Local	[11, 64]
UTAB	600	400-600	Local	[11, 64]
UTAK	900	7.2	Local	[59]
UTASO	400	100	Local	[17]
Total	9000	2849-3257		

- Ghana: There are several RCN processing units.
- Table **14** shows the different processing units in Ghana. The only medium size processing company in Ghana is MIM Cashew Factory located in Brong-Ahafo Region, with a capacity of 1000 t/yr. The other processing units are small scale processing units with capacities that are less than 250 t/yr. In December 2010 ACA reported that the capacity of processing of RCN in Ghana was 3,112 t/yr. Also ACA announces that three new processing plants are in construction with processing capacities ranging between 1,000 t to 10,000 t in Ghana. [58]

Table 14: RCN processing units in Ghana in 2009 [14]

Factory name (location)	Capacity of processing RCN (t/yr)	Currently processing of RCN (t/year)	Technology
Kona Agro-Processing Ltd (Awisa)	250	58.48	Imported
Cash Nut Foods Ltd (Faaman)	250	5.5	
NASAKA (Kabile and Nsawkaw)	200	56.99	
CRIG (Bole)	120	18.04	
Winker Investments Ltd (Afienya)	100	31.31	

Dudasu (Dudasu)	90	12.93	
Latemu (Kabile)	72		
Shop Best Company Ltd (Accra)	25	11.42	
Jelana Company Ltd (Jamera)	20	1.56	
Nsuro (Accra)	10	1.8	
MIM Cashew Factory (Brong-Ahafo Region)	1000	150	
Latemu (Kabile)	72	15	
Total	2119	363	

- Ivory Coast: There are three types of Cashew processing facilities. The large industrial facilities (OLAM IVOIRE , SITA ,COSAMA), which have an average capacity of over 1,000 t/yr; semi-industrial facilities (GOOGES, CAJOU FASSOU), which have an average processing capacity of between 500 and 1,000 t/yr, and small facilities (COPABO, PAMON ,COOPRAMOVIT) which have an average capacity of less than 500 t/year and are generally artisanal operations. The major processing units are listed in
- Table 15 with their capacities. The total capacity of processing RCN in Ivory Coast is 20,354 t/yr, but only 6637 t/yr of cashew have been processed. [17]

Table 15: RCN processing units in Ivory Coast [40]

Factory name (location)	**Capacity of processing RCN (t/yr)**	**Technology**
OLAM IVOIRE(Dimbokro)	5000	Imported
SITA(Odienné)	2500	Imported
COSAMA(Touba)	5000	
CAJOU FASSOU(Yamoussoukro)	1500	Local
GOOGES(Sepingo)	540	Imported
COPABO(Bondoukou)	400	
PAMO(Bongouanou)	500	Imported
COOPRAMOVIT(Pokoutou Tiénigbé subprefecture)	50	Local and imported
CHONGAGNIGUI(Ferké)		
COCOPRAGED(Bouna)		
COOPRAK (Korhogo)		

CHONGAGNIGUI*(Karakoro)*		
KLOGNONMON(Ferké)		
OFED(Dabakala)		
Total	15740	

- Mali: Mali does not have a unit that transforms RCN in semi-industrial or industrial scale, the internal market of cashew kernel is satisfied by Burkina Faso, Ivory Coast and Guinea. [10]

No data for RCN processing units in Togo were found.

A summary of the processing units' capacities by country is presented in Table 16.

Table 16: Cashew nut processing units' capacities by country

Country	**Total Capacity(t/yr)**	**Capacity Used(t/yr)**
Benin	1980-2180	1500
Burkina Faso	9000	2849-3257
Ghana	2119-3112	363-712
Ivory Coast	15740-20354	6637
Mali	0	0
Niger	No data	
Togo	No data	

4.3.2 Groundnut processing units

- Benin: TPA (Transformation des Produits Agricoles) and WATRIC are small industrial units that have a peanut processing capacity of 3.5 t/day (1155 t/yr) each. The company ADEOSSI & FILS located in Zou departemant has a capacity that vary from 1500 to 3600 t/yr. [21]
- Burkina Faso: The Companies JOSSIRA, and SOFIB produce cotton oil and Groundnut oil. The production of Groundnut oil was around 7910 t/yr from 2000 to 2007. [65].
- Niger: Olga oil, located in Maradi, is the only Groundnut oil production unit with a capacity of 45000T/yr. [17]
- No Data were found for Ghana, Ivory Coast, Mali and Togo.

Groundnut processing units' capacities by country are shown in Table 17.

Table 17: Groundnut processing units' capacities by country

Country	**Total Capacity(t/yr)**	**Capacity Used(t/yr)**
Benin	3810-5910	No data
Burkina Faso	No data	7910
Ghana	No data	
Ivory Coast	No data	
Mali	No data	
Niger	45000	15000
Togo	No data	

4.3.3 Jatropha processing units

The processing units are:

- Benin: Songhai center in BENIN has a Jatropha oil unit and can produce 6 million liter a year. [54]
- Burkina Faso: Belwet S biocarburant sarl has the capacity to process 30 tons of seeds a day (9900 t/yr) [66] Also a unit in Barsalagho can process 100 kg/h (264 t/yr) of Jatropha seeds.
- Mali: Mali Biocarburant SA is the only industrial unit, located in Koulikoro, in Mali. Its capacity is 2000 t/yr. [67] There are small units, MJI has a unit that can process 400 kg of seed a day. [42]

No data for Jatropha processing units in Ghana, Ivory Coast, Niger, Togo.

Table 18 resumes the collected information on the Jatropha seed processing units.

Table 18: Jatropha seed processing units' capacity by country

Country	**Total Capacity(t/yr)**	**Capacity Used(t/yr)**
Benin	No data	
Burkina Faso	10164	No data
Ghana	No data	
Ivory Coast	No data	
Mali	2132	No data
Niger and Togo	No data	

4.3.4 Oil palm fruit processing units

- Benin: Oil palm fruit is mostly transformed manually in Benin. Palm oil production data from 2000 show this:
    - Small producer (artisans) produce 36 000 t of red palm oil harvested from an area of 300000 hectares.
    - Industrial units produce about 10000 t of oil palm in total. [32]

    It can be deduced that industrial units only produce about 22% of the crude palm oil in Benin. From FAOSTAT values of crude palm oil production in Benin (2006-2009) [20], the average production of palm oil in Benin is about 41000 t/yr. Since the average value is not too different from the 2000 value oil production, the percentage of industrial units production can be used to determine the average crude oil produced by the industry during the period 2006-2009. That value is 9020 t/yr.

- Ghana: The industry of oil palm in Ghana is run by three major companies: BENSO OIL PALM PLANTATION LIMITED (BOPP), GHANA OIL PALM DEVELOPMENT COMPANY LTD (GOPDC), and TWIFO Oil Palm Plantation Ltd (TOPP). Table 19 gives the location, the area exploited, and the production capacity of each company.

Table 19: Major oil palm producers in Ghana

Company	**Location**	**Area harvested (ha)**	**Processing capacity**	**Source**
BOPP	Adum Banso and Benso	6,799	ND	[68]
GOPDC	ND	21000	60 t/h fresh fruit bunch	[69]
TOPP	Twifo-Hemang	4234	20 t/h fresh fruit bunch	[70]
Total		25240		

ND no data

The calculation of the average crude palm oil production during the period 2007-2009, using FAOSTAT palm oil production in Ghana [20], gives 126000 t/yr.

- Ivory Coast: The crude palm oil industry in Ivory Coast consists of 18 processing units with a total capacity of about 560 t/hr (or 1850000 t/yr) [33, 71]. The largest producers of crude palm oil in Ivory Coast are: PALMAFRIQUE, PHCI, COSAVE, PALM-CI, SIPEF-CI, and ADAM AFRICA. They produced about 325000 tons of crude oil in 2009 (Table 20). In addition, referring to FAOSTAT the production of crude oil in 2007 and 2008 was around 290000 t/yr. [20] PALM-CI is the largest palm oil company. It has 36,024 hectares of industrial plantations (yield higher than 12.5t/ha) and 124318 hectares of village plantation. In 2009 the company had owned 9 processing units with a total capacity of processing fruits bunches equal to 1200000 t/yr. [72]

Table 20: Ivory Coast's major companies of crude palm oil production in 2009 [71]

Company	**Production (t)**
PALM-CI	220 000
PALMAFRIQUE	30 000
SIPEF-CI	40 000
PHCI	15 000
SOGB	20 000
TOTAL	325 000

- Togo: Agou oil processing unit is the only operating plant in the country with the capacity to produce 600 t/yr of crude palm oil, but runs only on 8% of its capacity. [73]

To transform the values of the production of few ghanaian industrial units, given in t/h, t/yr it is assumed that the units work 12 hours a day and 330 days a year.
The production of crude oil by country is presented in Table 21.

Table 21: Crude palm oil production by country

Country	**Crude oil production capacity (t/yr)**	**Actual crude oil production (t/yr)**
Benin	ND	9020
Ghana	72864*	126000
Ivory Coast	425500	290000-325000
Togo	600	48

ND= No Data *Just for the few capacities found

4.3.5 Rubber tree processing

In Ivory Coast no sawmills that process rubber wood have been found in the frame of this work.

GREL in Ghana has a Processing Factory that produces a crumb rubber with a Capacity 3 t/ h. Biomass will be wood chipped directly at the plantation.

4.3.6 Shea nut processing units

The Shea butter production is mainly carried out in small scale, manual facilities, but there are industrial Shea butter processing units shown as followed:

- Benin: Benin has two industrial units that process Shea almonds, Sinocog Bohicon and Sonocog Cotonou. Sinocog Bohicon has a capacity of 10000 t/yr of almond and used only 25% of his full capacity. The capacity of Sonocog Cotonou is 5000 t/yr only 20% are used. [74]
- Burkina Faso: Industrial units in Burkina Faso are Burkarina SARL, Karilor, Phycos, Savomi, Naturex, SNCITEC. [75] Further more there are unions of women that produce Shea butter: Association Songtaab Yalgré (ASY), Union des groupements de production de Karité (UGPPK), Association Ragussi, Association Burkinabé Action Solidarité (KARIBEL), Union de production du karité (UPROKA-BF). [76]
- Table **22** shows the capacity of these units.

Table 22: Shea butter units’ capacity in Burkina Faso

Industry or Union name	**Processing capacity (nut) [t/yr]**	**Production capacity (butter) [t/yr]**	**Source**
Burkarina SARL	3300		[40]
SNCITEC	15000		[74]
ASY		80	[76]
UGPPK		1000	
Association Ragussi		700	
KARIBEL		137	
UPROKA-BF	5000	1500	
Karikis International		550	
Total	23300	3967	

- Ivory Coast: Trituraf has a processing capacity of 10000 t/yr of almond. But in 2004 the unit run only with 2500 t/yr. [74]
- Ghana: In Ghana the complexes of transformation of Shea almond into Shea butter have a total capacity of approximately 70 000 tons of Shea nuts per year. [77]

Table 23 shows processing units in Ghana and their capacity.

Table 23: Capacity of Shea nut processing units in Ghana [74]

Company name	**Capacity (t/yr)**	**Capacity used in 2004**
West African Mills	10000	2500
Juaden oil mills	1200	600
The pure company	10000	0
Ed oil	5000	500
Bosbel	5000	500
Total	31200	4100

- Mali: In Mali around 80% of shelled almond is exported without transformation towards the European Union and Japan. For the transformation, there exist 10 large companies (6 % of the remaining 20%), 50 small and medium enterprise (31%) and 100 artisanal companies (63%). [17] In 2004 Huicoma and Sika have each a capacity of processing of 25000 t/yr of almond but processed only 6000 t/yr. [74]
- Niger: In Niger the production of Shea butter is artisanal. [61]
- Togo: The industrial transformation of almond in Togo is carried out by the company NIOTO (in Lome). This unit has a capacity of processing of 100 t/day. [17]

Table 24 resumes the processing units' total capacities, installed and used, by country.

Table 24: Shea nut processing capacities by country

Country	**Total capacity (t/yr)**	**Capacity used (t/yr)**
Benin	15000	3500
Burkina Faso	30348	No data

Ghana	31200	4100
Ivory Coast	25000	2500
Mali	50000	12000
Niger	0	0
Togo	33000	No data

4.4 Calculation of the agro-alimentary waste potential

Table 25 resumes the final results of the calculations carried out to determine the potential of agro-alimentary residues (WP_t, $WP_{100\%}$; WP_{actual}) in West Africa. The table sums up the essential values from Table 26 toTable 40 to be found in the Annexes (6 Annexe 1 – Cashew Nut, 7 Annexe 2 – Groundnut, 8 Annexe 3 - Jatropha, 9 Annexe 4 – Oil palm, 10 Annexe 5– Rubber wood, 11 Annexe 6- Shea nut).

Table 25: WP_t, $WP_{100\%}$ and WP_{actual} of all the studied biomasses by country

Country	Cashew shell 10^3t/yr			Groundnut shell 10^3t/yr			Jatropha cake 10^3t/yr			Oil Palm waste 10^3t/yr			Rubber Wood 10^3t/yr	Sheanut cake 10^3t/yr		
	WP_t	$WP_{100\%}$	WP_{act}	WP_t	$WP_{100\%}$	WP_{act}	WP_t	$WP_{100\%}$	WP_{act}	WP_t	WP_{100}	WP_{act}	WP_t	WP_t	$WP_{100\%}$	WP_{actual}
BN	59.5	1.456	1.05	17.3	1.22		18.2			147		16.87		9.26	8.16	1.9
BF	17.85	6.3	2.13	6.95		1.993	61.8	7.48						43.5	16.51	
GH	21.16	1.831	0.38	114			5.4			1210		235.6		31.28	16.97	2.23
IC	215.6	12.63	4.65	16.44			63.9			764.3	795.7	575	43.7	18.49	13.6	1.36
ML	2.485			76.2			3.4	1.57						44.88	27.2	6.53
N				31.4	11.3	3.780	0.1							8.16		
T	4.375			9.43			0			73.2	1.1	0.1		7.89	17.9	

BN=Benin BF=Burkina Faso GH=Ghana IC=Ivory Coas ML=Mali N=Niger T=Togot

The sum of the theoric Cashew nut shell potential WP_t is about 317031 t/yr. Ivory Coast has the highest share (68%) followed by Benin (19%). The sum of the $WP_{100\%}$ values for Cashew Nut shells is 22200 t/yr, which represents only 7% of the theoretic value WP_t. If all the industrial Cashew processing units wold work at 100% Ivory Coast would still be the major producer with 56% followed by Burkina Faso with 28%. Actually the total production of Cashew Nut shells is around 8209 t/yr, which refers only to 2.5% of WP_t. Ivory Coast produces still the biggest share with 56% of the total waste, followed Burkina Faso with 26 %.
The total theoric potential WP_t of Groundnut shells is about 335000 t/yr, where Ghana has the highest share (34%), followed by Mali (about 23%). The determined $WP_{100\%}$ is around 12564 t/yr, which represents (3,7% of WP_t). Niger covers almost the entire ground nut shell production, with a share of 90%. However the actual production of shells in industrial units is 5773 t/yr (1,3% of total potential) and of which Niger produces 65%.
The determined total potential of Jatropha seed cake is 152738 t/yr, Burkina Fasos percentage is 40%. If all the industrial capacities were used, the quantity of seed cake would be 9050 t/yr and Burkina Faso would produce 82%.
An actual Jatropha oil production cannot be given here, because no data on real production of the oil presses has been available.
The total potential of oil palm waste production is estimated to be 2184500 t/yr, where Ghana has the highest percentage (55%), followed by Ivory Coast (35%). The found $WP_{100\%}$ value here is around 796800 t/yr, which represents 85% of WP_t. Ivory Coast has the most important potential with 85% of total $WP_{100\%}$. However the actual production of waste has been calculated to be 827570 t/y. Ivory Coast produces about 69% of the actual oil palm wastes.
The potential production of rubber wood waste is 43680 t/yr.
At last, the total potential of Sheanut cake has been calculated to be around 163487 t/yr with the following main shares: Mali 27%, Burkina Faso 26,7%, Ghana 19%. If the units were running at full capacity, the quantity of Sheanut cake would be around 100394 t/yr (61% of WP_t), and Mali might produce 27%. The actual production of waste is 12022 t/yr, representing only 7% of WP_t. Mali produces about 54% of this quantity.

4.5 Discussion

The presented values should be regarded with care. They give only orders of magnitude because the data collection and the calculations are afficted with a row of incertitudes:

- First, the RPR values are influenced by several factors that might interfere (or not). The quantity of waste per noble part depends on the variety of the plant, climatic condition as rainfall and sunshine, soil conditions and the application of fertilizers. Addintionally, the effectivity of the transformation unit has an important influence of the waste production, eg pressure in oil presses. Nevertheless in this study constant RPR values (except for Jatropha) have been applied, because
- Second, the determination of the waste production potentials (WP_t, $WP_{100\%}$ and $\mathrm{WP}_{\mathrm{actual}}$) were based on data of several past years which fluctuate partially enorm. The error imported with this incertainities is much more important than the error due to a slightly different RPR value.
- Third, the humidity content in the biomass waste has not been taken into account. For example, humidity in press cakes depends largely on the applied technology (hot or cold pressing, pressure).
- Forth, the present study makes no claim to be complete. It is possible that transformation units have not been found or data on the capacities installed and used were not available.

5 Conclusion

The main objective of this study was to evaluate the quantity of agro-alimentary industries residues. Tables 25 presents the potential quantity of residues produced during the processing of cashew nuts, groundnuts, jatropha seed, oil palm fruit, rubber wood, and Sheanuts. Ivory coast produce the highest amount of cashew shells (4650 t/yr), oil palm wastes (575000 t/yr), and rubber wastes (43700 t/yr). Mali produces the highest amount of Shea cakes (6530 t/yr), Niger produces 3780 t/yr of groundnuts shells.

To obtain these values some simplifications and approximative approaches has been necessary.

Sufficiently large intervals for the annual production of the noble parts have been applied, so that the real values should lay in between these frontiers.

This study permits to have a preview of the availability of six biomasses in the sub_Saharan Africa, namely Burkina Faso and its neighboring states.

For values more precise some more effort should be made:

To be capable of calculating the residues of example transformation units they should be visited,

And the responsible person should be interviewed concerning installed capacity, used capacity, waste production etc.

The agro-alimentary economie in West Africa is growing. Cashew nut transformation units are under construction, the demand on Shea butter (cosmetic industry) is rising just as Jatropha oil (firt generation biofuels). So, perspectively the agro-alimentary waste production will rise in the near and far future.

It is to mention that most of the Jatropha plantation are still too young and the intensive Jatropha oil production in Burkina Faso is estimated to come soon (2011-2012).

6 Annexe 1

The following tables give the results of the calculation of Cashew Nut Shell production in the examined countries. Table 26 represents the theoritic waste production WP_t (Equation 5) of Cashew Nuts based on the values presented in

Table **5**. Table 27 the Cashew Nut Shell production if all semi-industrial and industrial transformation units in each country would work at 100% of their capacity ($WP_{100\%}$) based on the values presented in Table 16.

Table 28 finally gives the actual Cashew Nut Shell production potential (WP_{actual}) of the semi-industrial and industrial units by each country based on the values given in Table 16 as well.

The average values of the last column have been used to create Figure 9.

Table 26: Theorical Cashew Nut Shell production potential WP_t by country

Country	**Benin**	**Burkina Faso**	**Ghana**	**Ivory Coast**	**Mali**	**Togo**
Annual production [t]	70000-100000	25000-26000	26500-34000	280000-336000	3500-3600	550-700

Table 27: Cashew Nut Shell production potential $WP_{100\%}$ by country

Country	**Cashew nut processing capacity (t/yr)**		**Average process-ing capacity (t/yr)**	**Kernel production capacity (t/yr)**		**Average kernel production capacity (t/yr)**	**Shell production potential $WP_{100\%}$ (t/yr)**		**Average Shell production potential $WP_{100\%}$ (t/yr)**
Benin	1980	2180	2080	396	436	416	1386	1526	1456
Burkina Faso	9000	9000	9000	1800	1800	1800	6300	6300	6300
Ghana	2119	3112	2615	424	622	523	1483	2178	1831
Ivory Coast	15740	20354	18047	3148	4071	3609	11018	14248	12633

Table 28: Actual Cashew Nut Shell production potential (WP_{actual}) by country

Country	**Actual Cashew nut processing (t/yr)**		**Average Cashew nut process-ing (t/yr)**	**Kernel production (t/yr)**		**Average kernel production (t/yr)**	**Shell production WP_{actual} (t/yr)**		**Average shell production WP_{actual} (t/yr)**
Benin	1500	1500	1500	300	300	300	1050	1050	1050
Burkina Faso	2849	3257	3053	570	651	611	1994	2280	2137
Ghana	363	712	537	73	142	107	254	498	376
Ivory Coast	6637	6637	6637	1327	1327	1327	4646	4646	4646

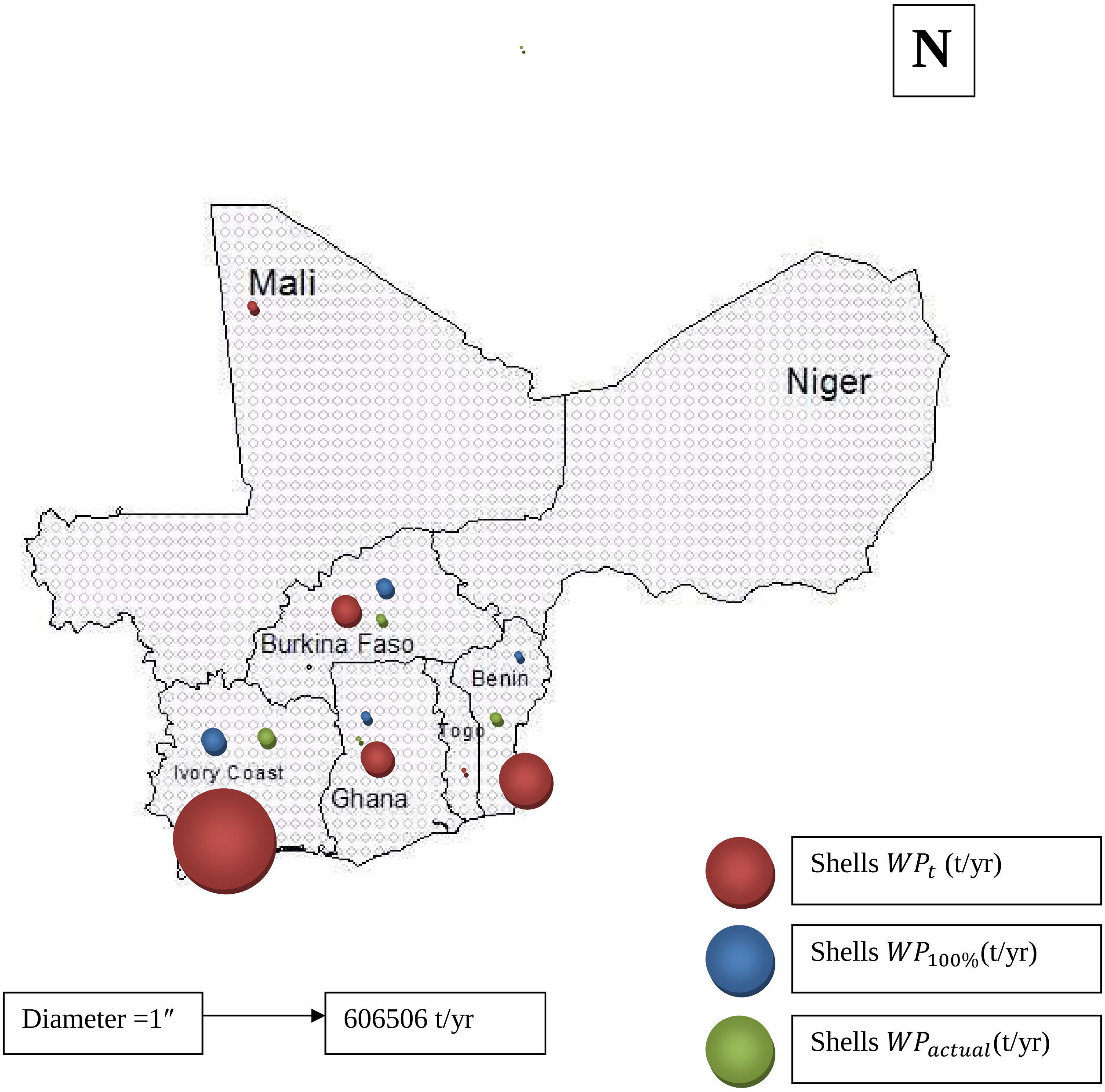

Figure 9: Cashew shell productions potential

7 Annexe 2

The following tables give the results of the calculation of Ground nut shell production potential in the examined countries.

Table 29 represents the theorical waste production potential WP_t (Equation 6) of Ground nuts based on the values presented in Table 7. Table 30 gives the Ground nut shell production potential if all semi-industrial and industrial transformation units in each country would work at 100% of their capacity ($WP_{100\%}$) based on the values presented in Table 17.

Table 31 finally gives the actual Ground nut shell production potential (WP_{actual}) of the semi-industrial and industrial units by each country based on the values given in Table 17 as well.

The average values of the last column have been used to create Figure 10.

Table 29: Theorical Groundnut Shell production potential WP_t by country

Country	**Groundnut production (t/yr)**		**Average groundnut production (t/yr)**	**Groundnut oil production potential (t/yr)**		**Average groundnut oil production potential (t/yr)**	**Shells production potential WP_t (t/yr)**		**Average shell production potential WP_t (t/yr)**
Benin	11000	126570	68785	3465	39869	21667	2772	31895	17334
Burkina Faso	264244	287476	275860	83237	90555	86896	66589	72443	69517
Ghana	389649	520000	454824	122739	163800	143269	98191	131040	114616
Ivory Coast	61207	69256	65231	19280	21816	20548	15424	17452	16438.34
Mali	279503	325000	302251	88043	102375	95209	70435	81900	76167
Niger	100000	149600	124800	31500	47124	39312	25200	37699	31449
Togo	33448	41428	37438	10536	13049	11793	8429	10440	9434

Table 30: Groundnut Shell production potential $WP_{100\%}$ by country

Country	**Groundnut processing capacity (t/yr)**		**Average groundnut processing (t/yr)**	**Groundnut oil production (t/yr)**		**Average groundnut oil production (t/yr)**	**Shell $WP_{100\%}$ (t/yr)**		**Average shell $WP_{100\%}$ (t/yr)**
Benin	3810	5910	4860	1200	1861	1531	960	1489	1225
Niger	45000	45000	45000	14175		14175	11340		11340

Table 31: Actual Groundnut Shell production potential (WP_{actual}) by country

Country	**Actual Groundnut transformation (t/yr)**	**Actual Oil production (t/yr)**	**Groundnut shell production WP_{actual} (t/yr)**
Burkina Faso	7910	2491	1993
Niger	15000	4725	3780

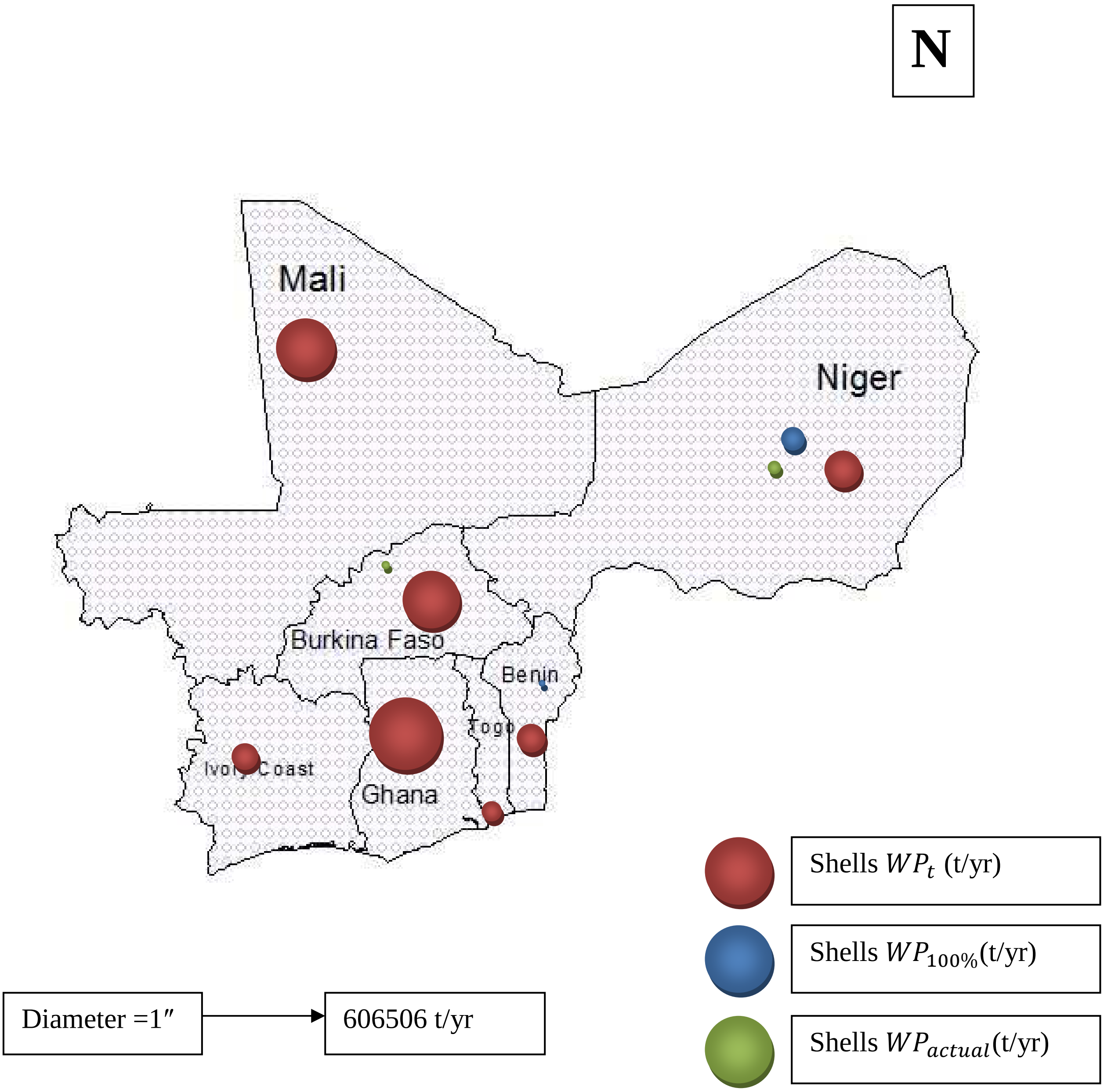

Figure 10: Groundnut shell production potentials

8 Annexe 3

The following tables give the results of the calculation of Jatropha cake production potential in the examined countries.

Table 32 represents the theorical waste production potential WP_t (Equation 7) of Jatropha cake based on the values presented in Table 8.

Table 33 gives the Jatropha cake production potential if all semi-industrial and industrial transformation units in each country would work at 100% of their capacity ($WP_{100\%}$) based on the values presented in Table 18.

An actual Jatropha oil production cannot be given here, because no data on real production of the oil presses has been available.

The average values of the last column have been used to create Figure 11.

Table 32: Theorical Jatropha cake production potential WP_t by country

Country	**Plantations harvested (ha)**	**Jatropha oil production potential (t/yr)**	**Jatropha seed cake potential WP_t (t/yr)**
Benin	5160	5676	18163
Burkina Faso	70000	19320	61824
Ghana	1534	1687	5400
Ivory Coast	18148	19962	63881
Mali	3830	1057	3383
Niger	100	28	88
Togo		0	0

Table 33: Jatropha cake production potential $WP_{100\%}$ by country

Country	**Jatropha processing capacity potential (t/yr)**	**Jatropha oil production potential (t/yr)**	**Jatropha seed cake potential $WP_{100\%}$ (t/yr)**
Burkina Faso	10164	2338	7481
Mali	2132	490	1569

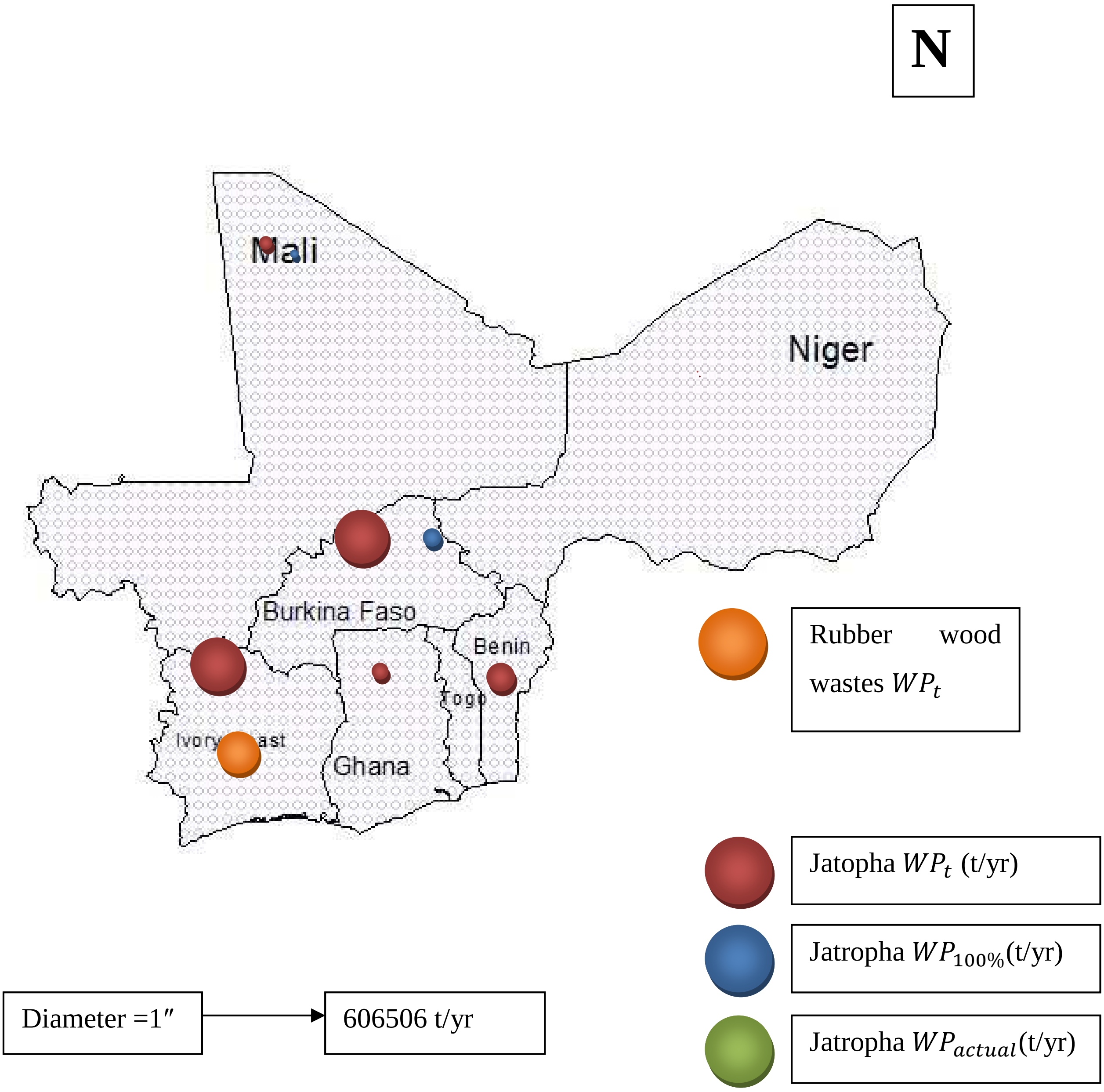

Figure 11: Jatropha seed cake and rubber wood waste production potential

9 Annexe 4

The following tables give the results of the calculation of oil palm waste production potential in the examined countries.

Table 34 represents the theorical waste production potential WP_t (Equation 8) of palm oil based on the values presented in Table 9.

Table 35 gives the oil palm waste production potential if all semi-industrial and industrial transformation units in each country would work at 100% of their capacity ($WP_{100\%}$) based on the values presented in Table 21. **Table 36** finally gives the actual oil palm waste production potential (WP_{actual}) of the semi-industrial and industrial units by each country based on the values given in Table 21 as well.

The average values of the last column have been used to create Figure 12.

Table 34: Theorical oil palm waste production potential WP_t by country

Country	**Oil palm fruit production (t/yr)**		**Average oil palm fruit production (t/yr)**	**Palm oil production potential (t/yr)**		**Average palm oil production potential (t/yr)**	**Waste potential WP_t (t/yr)**		**Average Waste potential WP_t (t/yr)**
Benin	244000	250000	247000	56120	57500	56810	72956	74750	73853
Ghana	1953300	2103600	2028450	449259	483828	466543	584037	628976	606507
Ivory Coast	1200000	1300000	1250000	276000	299000	287500	358800	388700	373750
Togo	115000	130000	122500	26450	29900	28175	34385	38870	36627

Table 35: Oil palm waste production potential $WP_{100\%}$ by country

Country	**Palm oil processing capacity(t/yr)**	**Waste potential $WP_{100\%}$(t/yr)**
Ghana	316800	136224
Ivory Coast	1850000	795500
Togo	600	258

Table 36: Actual oil palm wastes production by country

Country	**Palm oil processing capacity used(t/yr)**		**Average palm oil processing Capacity used (t/yr)**	**Wastes potential WP_{actual} (t/yr)**		**Average waste potential WP_{actual} (t/yr)**
Benin	9020		9020	11726		11726
Ghana	126000		126000	163800		163800
Ivory Coast	290000	325000	307500	377000	422500	399750
Togo	48		48	62		62

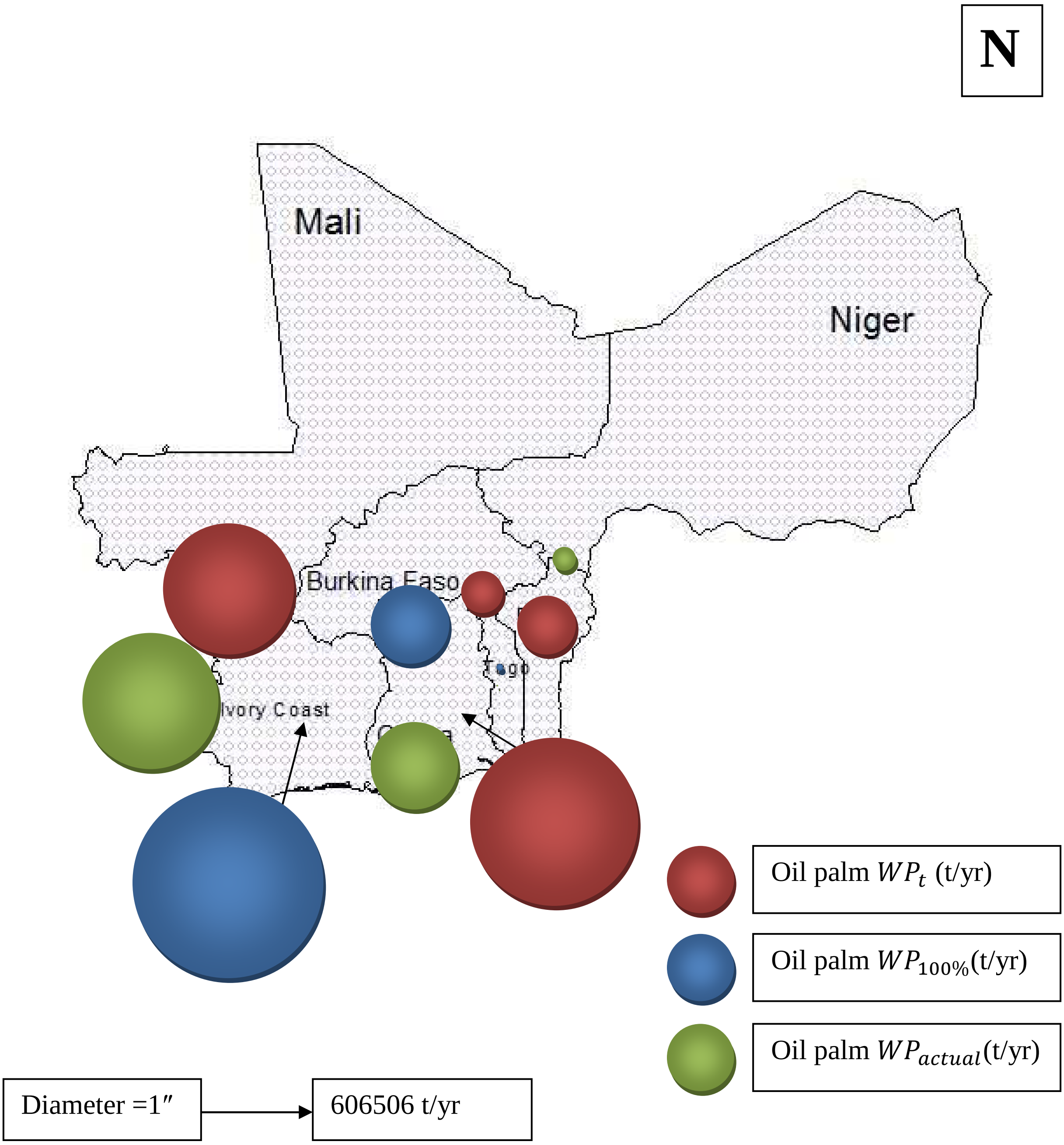

Figure 12: Oil palm wastesproduction potential

10 Annexe 5

The average values of the last column have been used to create **Figure 11**.

Table 37 represents the theorical waste production potential WP_t (Equation 10) of rubber wood based on the values presented in section 4.2.5.

The average values of the last column have been used to create Figure 11.

Table 37: Theorical rubber waste production WP_t in Ivory Coast

Old plantation cut (ha)	**Quantity of timber wood (t/yr)**	**Sawmills processing yield**	**Rubber wood wastes WP_t (t/yr)**	**Rubber wood dry waste WP_t (t/yr)**
1500	120000	0.44	43680	38438.4

11 Annexe 6

The following tables give the results of the calculation of Shea cake production potential in the examined countries.

Table 38 represents the theorical waste production potential WP_t (Equation 9) of Shea cake based on the values presented in Table 11.

Table **39** gives the Shea cake production potential if all semi-industrial and industrial transformation units in each country would work at 100% of their capacity ($WP_{100\%}$) based on the values presented in Table 24.

Table 40 finally gives the actual Shea cake production potential (WP_{actual}) of the semi-industrial and industrial units by each country based on the values given in Table 26 as well.

The average values of the last column have been used to create Figure 13.

Table 38: Theorical Shea cake production potential WP_t by country

Country	**Shea nut production (t/yr)**		**Average Shea nut product-ion (t/yr)**	**Shea nut butter production potential (t/yr)**		**Average Shea nut butter product-ion potential (t/yr)**	**Shea nut cake potential WP_t (t/yr)**		**Average Shea nut cake potential WP_t (t/yr)**
Benin	14056	20000	17028	4779	6800	5789	7646	10880	9263
Burkina Faso	70000	90000	80000	23800	30600	27200	38080	48960	43520
Ghana	50000	65000	57500	17000	22100	19550	27200	35360	31280
Ivory Coast	28000	40000	34000	9520	13600	11560	15232	21760	18496
Mali	80000	85000	82500	27200	28900	28050	43520	46240	44880
Niger	15000		15000	5100	0	5100	8160	0	8160
Togo	14000	15000	14500	4760	5100	4930	7616	8160	7888

Table 39: Shea cake production potential $WP_{100\%}$ by country

Country	**Shea nut processing Capacity (t/yr)**	**Butter production potential (t/yr)**	**Shea nut cake potential $WP_{100\%}$**
Benin	15000	5100	8160
Burkina Faso	30348	10318	16509
Ghana	31200	10608	16973
Ivory Coast	25000	8500	13600
Mali	50000	17000	27200
Togo	33000	11220	17952

Table 40: Actual Shea cake production by country

Country	**Shea nut processing Capacity used (t/yr)**	**Butter production (t/yr)**	**Shea nut cake production WP_{actual} (t/yr)**
Benin	3500	1190	1904
Ghana	4100	1394	2230
Ivory Coast	2500	850	1360
Mali	12000	4080	6528

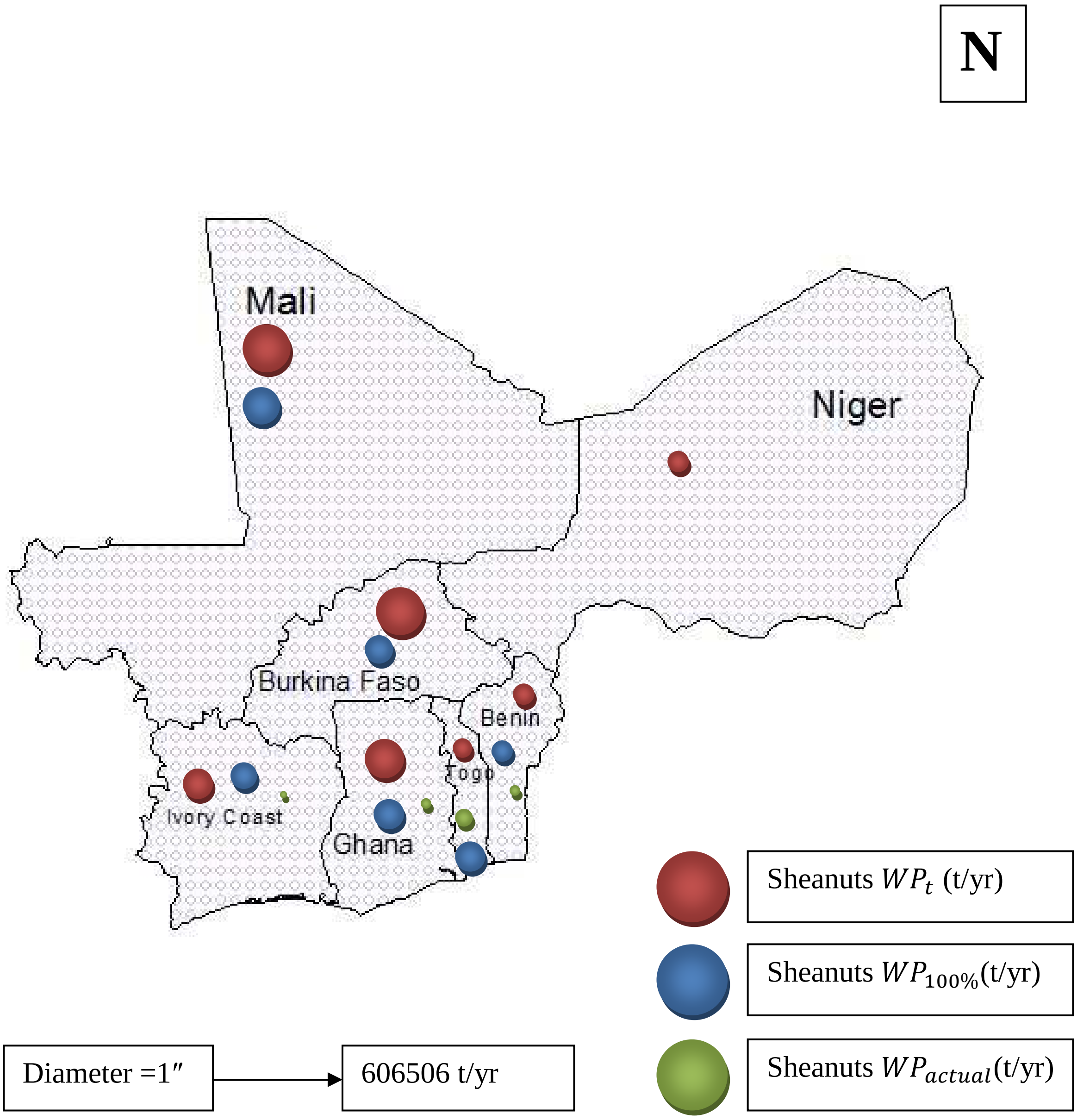

Figure 13: Shea nut cake production potential

12 Table of References

[1] *UNITED NATIONS* ECONOMIC COMMISSION FOR AFRICA, "Biofuels: What strategies for developing the sector in West Africa?," Report, Distr.: LIMITED CEA-AO/CIE.11/2008/4b Original: FRENCH, pp. 1, 2008, http://www.uneca.org/wa/meetings/ICE11/RapportEco-Biocarburants-en%20AfriqueENG.pdf

[2] Philippe Girad and Abigaïl. Fallot, "Review of existing and emerging technologies for the production of biofuels in developing countries," Journal Energy for Sustainable Devolopment,vol. x N°2, pp. 92, 2006.

[3] Dr. Joël Blin, "Les filières Biomasse Energie ," Master II Energy course 2iE, 2010.

[4] International.Energy.Agency(IEA), "Sustainable Production of Second -Generation Biofuels: Potential and perspectives in major economies and developing countries," Information paper, pp. (25, 58, 199-2002), 2010, http://www.iea.org/papers/2010/second_generation_biofuels.pdf

[5] Graham von Maltitz et al. , "Analysis of opportunities for biofuel production in sub-Saharan Africa," *Brief environmental, Report*, pp. 1-3, 2009, http://www.cifor.cgiar.org/publications/pdf_files/EnviBrief/04-EnviBrief.pdf

[6] Economic Community of West African States, "Livre blanc pour une politique régionale," Report, pp. 29-34, 2006.

[7] Moses Hensley Duku et al. , "A comprehensive review of biomass resources and biofuels potential in Ghana," Renewable and Sustainable Energy Reviews 15 (2011), pp. 404-415, 2010.

[8] M Fatih Demirbas and mustapha Balat, "Biomass pyrolysis for liquid fuels and chemicals:A review," Journal of Scientific & Industrial Research, Vol. 66, pp. 797-804, October 2007.

[9] F.Broust (CIRAD, France), "Overview of fast pyrolysis principles,processing and applications," francois.broust@cirad.fr

[10] Steev Lynn et al. , "ETUDE DE LA FILIERE ANACARDE AU MALI," EnterpriseWorks/VITA Report, 2006, http://www.euacpcommodities.eu/files/0WSTD01PCDAMaliCashewVCStudyFRENCH.pdf

[11] Philippe Constant et al. , "Analyse de la chaîne de valeur du secteur anacarde au Burkina Faso," Report, pp. 4-12, 2010, http://www.agoatoolkit.com/agoa/French/Produits%20Cibles/Cajou/Guide%20a%20l'exportation%20de%20la%20Noix%20de%20Cajou/03.pdf

[12] A.G. Mohod et al. , "Processed cashew shell waste as fuel supplement for heat generation," Journal Energy for Sustainable Development, Volume XII No. 4, pp. 73-76, 2008.

[13] ACi and GTZ, " *Apprécier la qualité des Noix de cajou Brutes*," Technical Handbook, http://www.rongead.org/IMG/pdf/Dossier_anacarde_10web-2.pdf

[14] Dr. S. H. Azam-Ali, "Small-scale cashew nut processing," Report, 2001, http://anacardium.info/IMG/pdf/Small-scale_Cashew_Nut_Processing_-_FAO_2001.pdf

[15] Alain Soglo and Edouard ASSOGBA, "Etude sur la compétitivité de la filière anacarde du Bénin," Report, 2009, http://anacardium.info/IMG/pdf/Competitivite_de_la_filiere_anacarde_au_Benin_-_avr_2009.pdf

[16] Seth Osei-Akoto, "A Value Chain Analysis of the Cashew Sector in Ghana," ACi report, 2010, http://www.agoatoolkit.com/agoa/English/Select%20Products/Cashews/Cashew%20sector%20Development%20Country%20Study/02.pdf

[17] Shrikant Chopra, "ETUDE POUR L'IDENTIFICATION DES FILIERES AGROINDUSTRIELLES PRIORITAIRES DANS LES PAYS MENBRES DE L'UEMOA" Report, 2008, http://www.brmnbenin.org/pdf/Synthese_etude_filiere_agroindustrielles_version_09%20_Mai%2009.pdf

[18] Sutter Pierre Luc, "Analyse de la filière anacarde au Burkina-Faso: identification des leviers d'actions pour une meilleure valorisation des ressources paysannes," Final year of Master Report, 2010, http://www.rongead.org/IMG/pdf/Memoire_Sutter_PL-2.pdf

[19] Célia Novello and Cynthia Santamaria, "L'Allergie alimentaire à l'arachide," Report, 2005, http://julientap.free.fr/travail_fichiers/allergie_arachide.pdf

[20] FAOSTAT, Web Page, Access date: 5/20/2011, Available: http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor

[21] MINISTERE DU DEVELOPPEMENT RURAL, "PROGRAMME DE RELANCE FILIERE ARACHIDE," Report, 2000, http://www.hubrural.org/pdf/benin_relance_arachide.pdf

[22] MINISTERE DE L'AGRICULTURE DE L'HYDRAULIQUE ET DES RESSOURCES HALIEUTIQUES, "RESULTATS DEFINITIFS DE LA CAMPAGNE AGRICOLE ET DE LA SITUATION ALIMENTAIRE ET NUTRITIONNELLE 2009/2010," Report, 2010, https://docs.google.com/viewer?a=v&q=cache:XJacBe7I_MUJ:www.countrystat.org/country/bfa/documents/docs/resultats_definitifs_campagne_2009_2010.pdf+http://www.countrystat.org/country/bfa/documents/docs/resultats_definitifs_campagne_2009_2010.pdf&hl=fr&gl=fr&pid=bl&srcid=ADGEESgBajzs7y6Yo_DnG_Jqh1EsJhdoyNTziCMM4WXeSSNB1v9muenR55u_FczFoZ0WqhcmVIs0DfQ2RfX20eLJ8xF7NdmXvLODxlN7FHWnjmpuP34fvF-SuuI8EvEeNXa38MphM2de&sig=AHIEtbTyCIQBHq9lxWzIKjPEnA_6H6SVHg

[23] INSTITUT D'ECONOMIE RURALE, "***Caratéristiques Techniques culturales des variétés d'arachide au Mali***," Web Page, Available: http://www.maliagriculture.org/fiches/arachide.html

[24] Michael Melzer, "Bibliographic Research :Identification of potential biomasses in Burkina Faso and western Africa for energetical valorization via flash pyrolysis," Report, 2010, michael.melzer@2ie-edu.org

[25] Wouter Achten, "Sustainability evaluation of biodiesel from Jatropha curcas L. A life cycle oriented study," Thesis in Bioscience engineering, pp. 3-44, 2010, https://perswww.kuleuven.be/~u0053809/PhD/WA_PhD%20manuscript_Final.pdf

[26] DOVE BIOTECH LTD, "JATROPHA CURCAS L.AN INTERNATIONAL BOTANICAL ANSWER TO BIODIESEL PRODUCTION & RENEWABLE ENERGY," Report, 2002, http://www.dovebiotech.com/pdf/JATROPHA%20CURCAS%20L.pdf

[27] Sabina Anokye Mensah,"Jatropha Oil Production as Biofuel for Shea Butter Processing Machine in Ghana:Quality Characteristics and Storability of the Derived Shea Butter," Thesis, 2010, http://opus.kobv.de/btu/volltexte/2010/1759/pdf/Doctoral_Thesis_SAM.pdf

[28] belga/7sur7, "A l'heure des biocarburants, la Côte d'Ivoire se lance dans le jatropha," Web Page, Access date: 5/2/2011, Available: http://www.7sur7.be/7s7/fr/1505/Monde/article/detail/328899/2008/06/27/A-l-heure-des-biocarburants-la-Cote-d-Ivoire-se-lance-dans-le-jatropha.dhtml

[29] BPR Afrique, "*blog jatropha BPR Afrique*," Web Page, Access date: 4/10/2011, Available: http://bpr-afrique.com/blog-jatropha/blog1.php

[30] Géraldine Pallière (GERES) et al. , "Les enjeux des agrocarburants pour le monde paysan au Mali," Report, 2009, http://www.riaed.net/IMG/pdf/Enjeux-jatropha-paysans-maliens.pdf

[31] Anne Hébert et al. , "COCOTIER ET PALMIER A HUILE " CIRAD Report, 2007.

[32] Ricardo Carrère, "Le palmier à huile en Afrique: le passé, le présent et le futur," Report 2010, http://www.wrm.org.uy/countries/Africa/Palmier_a_huile_en_Afrique.pdf

[33] Ministére de l'Agriculture de la Côte d'Ivoire, Web Page, Access date 3/29/2011 http://www.agriculture.gouv.ci/index.php?option=com_content&view=article&id=72&Itemid=72

[34] Jean-Marc Noël, "Résidus d'huilerie de palme." CIRAD Report, 2003-2007

[35] W. Killmann and L.T. Hong, "Le bois d'hévéa – succès d'un sous-produit agricole," journal *Unasylva 201, Vol. 51, pp.66-72, 2000.*

[36] *GREL*, Web Page, Access date 4/15/2011, Available: http://www.afriren.com/fr/nos-projets/grel?tmpl=component

[37] GREL, *Compagny profile document,* ,http://www.diplomatie.gouv.fr/fr/IMG/pdf/GREL_Profile.pdf

[38] Auke Koopmans and Jaap Koppejan, "AGRICULTURAL AND FOREST RESIDUES -GENERATION, UTILIZATION AND AVAILABILITY," Paper presented at the Regional Consultation on Modern Applications of Biomass Energy, 6-10 January 1997, Kuala Lumpur, Malaysia, 1997.

[39] Marie-Hélène Dabat et al. , "Appui à la définition de stratégies de développement des filières agro-sylvo-pastorales et halieutiques sélectionnées dans les régions d'intervention du PADAB II« Goulots d'étranglement et actions pilotes »," CIRAD, Report, pp.8-15, 2009.

[40] Anselme Rungundu, "*GESTION DE L'ENERGIE DANS L'ENTREPRISE BURKARINA*," Final year of Master Report(2iE), 2009, Anselme.Rungundu@2ie-edu.org

[41] Tandjiekpon André Mahoutin, "Analysis of the Benin cashew sector value chain," ACi report, pp. (2,4), 2010. http://www.agoatoolkit.com/agoa/English/Select%20Products/Cashews/Cashew%20sector%20Development%20Country%20Study/01.pdf

[42] William Fotseu Noumoye "POSSIBILITES D'UTILISATION DE L'HUILE DE JATROPHA DANS LES MOTEURS DIESELS DU CERCLE DE KITA," Final year of Master Report(2iE),2010, William.Fotseu@2ie.edu.org.

[43] FAO, "*palm oil processing units*," Web Page,Access date 3/10/2010, Available: http://www.fao.org/DOCREP/005/Y4355E/y4355e00.htm#Contents

[44] Zhou Yongdong et al. , , "Rubberwood Processing Manual," Report of Research Institute of Wood Industry Chinese Academy of Forestry, 2007, http://www.paneltech.cn/rubberwood/Rubberwood%20Processing%20Manual.pdf

[45] Eric Serges Noumi, "ETUDE SUR L'OPTIMISATION ENERGETIQUE DE LA FILIERE KARITE AU BURKINA FASO," Final year of Master Report(2iE),2010, eric.noumi@2ie.edu.org.

[46] African Cashew Alliance, "ACA Annual Conference Maputo, Mozambique 14 September 2010," Report, 2010

[47] Philippe Constant((PDA/GTZ)Cashew nut adviser), "List of cashew processing plant in Burkina Faso – 2009/2010," Report, 2010, Contact: tel: 226 50 33 19 10, 226 76 92 29 93 , 226 70 20 49 01

[48] Jean Bosco Dibouloni (UTAB), Personal conversation, 5/25/2011, tel: 78 03 39 05.

[49] Shakti Pal Regional, Cashew Processing Expert.ACi, Personal conversation, 5/28/2011, shakti.tns@gmail.com, tel: (233) 24-5527270

[50] Jean-Luc Knodene et al. , "FABRICATION DE BEURRE DE CACAHUETE," Report, 2003.

[51] Dr Rocio A Diaz-Chavez, "Mapping Food and Bioenergy In Africa," Report, 2010.

[52] Jan de Jongh et al, "Jatropha oil quality related to use in diesel engines and refining methods.," Report, 2007.

[53] Jean-Paul LAUDE, "Situation de la filière Jatropha au Burkina Faso Perspectives pour le court terme," Report, 2009.

[54] Agro Radio Hebdo , "*huile et graine de jatropha du centre songhaï*," Web Page, Acces date: 4/1/2011, Available: http://hebdo.farmradio.org/2009/05/04/1-afrique-jatropha-une-culture-importante-mais-pas-une-culture-miracle-radios-rurales-internationales-reuters/

[55] CIRAD, "Le Palmier à huile ou Elaeis guineensis," Report, 2007.

[56] Ahoba Assande, "L'HEVEA SOURCE DE REVENU ADDITIONNEL EN FIN D'EXPLOITATION DE LATEX," Report, 2001.

[57] Mr BORO from Projet National Karite, Personal comunication, 5/20/2011, tel: 78815511.

[58] ACA, "Cashew Industry Agrees on Guidelines for Growing Business in Africa," Report, 2010.

[59] Thiombiano Sylvain Tiabri "ADAPTATION DE L'OUTIL EX-ACT ET EVALUATION DE L'EMPREINTE CARBONE DE LA FILIERE ANACARDE AU BURKINA FASO.," Final year of Master Report(2iE),2010, sylvain.thiombiano@2ie.edu.org..

[60] Dr Miaman Kone, "Analysis of the Cashew Sector Value Chain in Côte d'Ivoire," ACi report, 2010. http://www.africancashewinitiative.org/files/files/downloads/aci_cote_d_ivoire_gb_150.pdf

[61] Amado, Seyni Nouhou, "CAPITALISATION DE L'EXPERIENCE SAHELIENNE EN MATIERE DE BIOCARBURANT CAS DU NIGER," Report, 2007.

[62] Moussa Touré, "*commercial pressures on land*," Web Page, Access date: 4/24/2011, Available: http://www.commercialpressuresonland.org/press/c%C3%B4te-divoire-biocarburants-10-000-ha-de-jatropha-sortent-de-terre-au-centre

[63] West Africa Trade Hub, "Investing in Shea in West Africa: A U.S. Investor's Perspective," Technical Report, 2010.

[64] GTZ, " major Cashew nuts units energy audit," Report, 2009.

[65] Centre du Commerce International et AAFEX "SITUATION ACTUELLE ET PERSPECTIVE DU SECTEUR DE L'EMBALLAGE AGRO ALIMENTAIRE," Report, 2006.

[66] lefaso.net. "*unite de production d'huile de jatropha*," Web Page, Access date: 5/8/2011 , Available: http://www.lefaso.net/spip.php?article39177

[67] Le premier ministére.du Mali "*Mali Biocarburant" SA contruit une usine D'une capacité de 2000tonnes/an à Koulikoro*," Web Page, Access date: 3/5/2011, Available: http://www.primature.gov.ml/index.php?option=com_content&view=article&id=178:inauguration--usine-de-biocarburant-a-koulikoro&catid=33&Itemid=100120

[68] Ghana4all, "PROFILE OF 2002 & 2003 GC 100 MEMBERS AND BRIEF STATEMENTS FROM THEIR CEO's," 2003.

[69] GOPDC, . Web Page, Access date: 3/24/2011 Available: http://www.gopdc-ltd.com/

[70] GhanaBusinessIndex. Web Page, Access date: 5/4/2011). Available: http://business.everythinghana.com/index.php?option=com_mtree&task=viewlink&link_id=43&Itemid=26

[71] La Fédération Nationale des Coopératives des Planteurs de Palmier à Huile de Côte D'ivoir, Web Page, Access date: 3/4/2011 Available: http://fenacopahci.com/filiere_actuelle.html

[72] Jean-Louis GBANGBO, "Palmier à huile: Palmci veut la palme," Web Page, Access date: 3/10/2011, Available: http://okibat.afrikblog.com/archives/2009/06/14/14075558.html

[73] Emmanuel Adjovi, "*Togo : l'huilerie qui recherche des régimes de palme*," Web Page, Access date: 5/2/2011, Available: http://www.syfia.info/index.php5?view=articles&action=voir&idArticle=1072

[74] Steve Morin, "ANALYSE DE COMPÉTITIVITÉ DE LA COLLECTE ET DE LA TRANSFORMATION DU KARITÉ EN GUINÉE," Report, 2005.

[75] Martine François "Le marché du karité, entre économie de subsistance et capitalisme mondialisé," Report, 2007/2009.

[76] Trade Facilitation Office (TFO) Canada, Web Page, Access date: 5/4/2011, Available: http://www.tfocanada.ca/global/File/May%2025%20to%20June%203%20Burkina%20II%20Shea%20butter_Eng_LH.pdf

[77] West Africa Trade Hub, Web Page, Access date: 6/1/2011 Available: http://www.watradehub.com/fr/node/779