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Agroforestry Parklands of the Sudan Savanna in the Context of Climate Change: Firewood Energy in North-western Benin, West Africa.

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DEDICATION

This thesis is dedicated to

The memory of my father: Liman Harou

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ABBREVIATIONS/ ACRONYMS

MDS: Measured per capita firewood consumption in Dry Season.

PDS: Perceived per capita firewood consumption in Dry Season.

MRS: Measured per capita firewood consumption in Rainy Season.

PRS: Perceived per capita firewood consumption in Rainy Season.

FAO: Food and Agricultural Organisation.

ICRAF: International Center for Research in Agroforestry.

VHR: Very High Resolution (satellite imagery).

INSAE: Institut National des Statistiques et des Analyses Economiques (Benin).

NTFPs: Non Timber Forest Products.

WASCAL: West African Science Service Center on Climate Change and Adapted Landuse.

GSP: Graduate Study School.

CRP: Core Research Program.

LOOCV: Leave One Out Cross Validation.

MSE: Mean Squared Error.

ZEF: Center for Development Research, University of Bonn.

BMBF: German Federal Ministry of Education and Research.

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ABSTRACT

Accurate assessment and monitoring of biomass are important for managing terrestrial ecosystems, their sustainability especially for developing world. This case study is interested in the Sudan Savanna agroforestry Parklands of North Western Benin, where agroforestry parklands' systems play key roles in the socio-ecological system among which firewood energy. For many years, research endeavours reported the sustainability of the system, nevertheless with little importance to population growth and the related increasing firewood demand. To address this, various biophysical and socio-economic data were collected on 137 households and their plots belonging to 17 villages spread across Dassari catchment. The first Key findings are that, among the 3 main utilisations of trees in the area, firewood is in the front line. Around 100% and 76% of the households use firewood and NTFPs respectively, while only 8% of them use trees for fodder. Secondly, with an average firewood consumption of 1.026 kg per capita in rainy season again 0.814 kg in dry season, the farmers consume more firewood in the rainy season ($p<0.05$). These values correspond respectively to 1.559 kg and 2.015 kg when considering farmers 'perceptions. Therefore we conclude farmers tend to overestimate the overall quantity consumed ($p<0.01$). Yet, there are many factors impacting the amount of firewood used at the household level although the farmers lack straightforward explanations. Tree branching (30%) is the most encountered firewood collection method. The farmers prefer *Combretum* sp. (69%) among shrubs and *Anogeissus leiocarpus* (23%) among trees. The analysis of the biomass (1, 153, 363, 780.44 ± 636305.2 kg corresponding to 235, 384, 2526 kg in terms of dry wood) revealed that the catchment is a valuable source of carbon sink. Nevertheless, the effect of population growth and climate change humper its sustainability.

Keywords: Agroforestry Parklands, Sudan Savanna, Climate Change, Firewood Consumption, Biomass, Upscaling, Sustainability, Dassari Catchment

RESUME

L'évaluation et le suivi de la biomasse sont importants pour la gestion et la durabilité des écosystèmes terrestres, en particulier pour les pays en développement. Le présent travail s'est intéressé aux parcs agroforestiers du nord-ouest du Bénin, où ils constituent, entre autres, la principale source des bois énergie. Pendant de nombreuses années, les recherches rapportent la durabilité de ce système, sans toutefois prendre en compte la croissance démographique. A travers cette étude, nous avons collecté des données sur 137 ménages et de leurs parcelles. Les premiers résultats ont révélé que les arbres font l'objet d'au moins 3 principales utilisations parmi lesquelles le bois énergie est la plus inquiétante. Deuxièmement, les producteurs consomment beaucoup plus de bois en saison hivernale pendant qu'ils surestiment la quantité du bois qu'ils consomment. Toutefois, la quantité du bois consommée par un ménage dépend des nombreux facteurs. Les producteurs préfèrent *Combretum sp*. parmi les arbustes et *Anogeissus leiocarpus* parmi les arbres. L'analyse de la biomasse a révélé que la zone d'étude représente une source précieuse de séquestration de carbone. Néanmoins, la croissance démographique et les changements climatiques en sont des facteurs limitants.

Mots clés: Parcs Agroforestiers, Savane Soudanienne, Changements Climatiques, Bois Energie, Biomasse, Estimation à grande échelle, Durabilité, Bassin de Dassari

Chapter 1. INTRODUCTION

1.1. Problem Statement

Deforestation is usually interpreted in terms of a rising population of small farmers who habit at the margin of forest resources and cut down these resources for many purposes (Judex et al., 2006). Amongst the intended benefits, there are settlements, income generation, but more importantly agricultural expansion, fuelwood, and fodder (Slingerland, 2000; Houessou et al., 2013).

Agricultural expansion has been reported as the main cause of deforestation in the Sudan savanna region of West Africa (Orekan, 2007; Houessou et al., 2013). In fact, years of (over)exploitation make the soils unfertile, through land degradation, soil erosion and/or nutrients depletion. In such circumstances, the farmlands have to be left uncultivated (fallow) to recover their fertility. However, the fallows periods have been shortened due to increasing population. Hence, fallow cycles were currently reduced from more than 10 years to less than 5 years (Kessler and Boni, 1991; Floret and Pontanier, 2001). Meanwhile, agricultural expansion interacts with other forms of deforestation through firewood demand (Manley et al., 2002a; Manley et al., 2004; Akouehou et al., 2011; Houessou et al., 2013).

These situations still take place in many parts of the Sudan savanna of West Africa. In Benin, studies reported intense conversion of forests into farmlands (Judex et al., 2006; Orekan, 2007; Houessou et al., 2013; Mama, 2013). In Upper Ouémé Catchment of central Benin, Orekan (2007) reported an annual rate of deforestation of around 8% between 1991 and 2000. In northern Benin, beside deforestation due to agricultural expansion, Houessou et al., (2013) reported other driving forces of deforestations among which firewood, fodder, and Non Timber Forest Products (NTFPs). The figure 1 shows the importance of different forms of deforestation in this area.

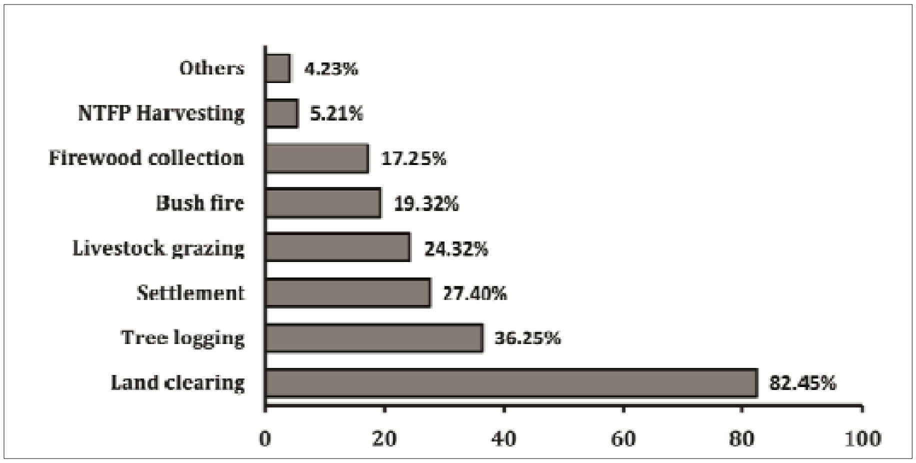

Figure 1. Driving Forces of Deforestation around W Biosphere Reserve in Benin (Houessou et al., 2013).

In the Sudan savanna regions, population growth plays an important role with regards to deforestation/forest use (Aleza et al., 2015a). From the year 1972 to 2006, agricultural areas increased up to 28.4% (Mama, 2013). In central Benin, simulations have shown that by 2015, bush savanna and others are expected to decrease as agricultural area will extend on marginalized lands by nearly 76 % in nine years at a rate of 6.5 % per year (Judex et al., 2006). Future agricultural lands will be located around the main cities due to the combined influence of market access and high population density; even protected areas are seemingly to disappear by 2025 (Judex et al., 2006).

Concerning population growth, two (2) important factors; soil fertility depletion, and the household size and its labor force determine the household stakes regarding deforestation (Caviglia-Harris and Harris, 2011). As soon as the soil becomes unproductive, farmers expand the farm size to meet the food demand of their families. Similarly, when the children (mainly boys) get matured and therefore able to get married, the household head has to share the available land with them as independent farmers. Lacking of available land, scarcity is compensated with land clearing. The combined effect of population growth, low intensification, etc., is then translated into deforestation. As consequence, this transformed the natural forests into what researchers called Parklands (Boffa, 2000; Orekan, 2007).

In West Africa, parkland farming system exists since the Iron Age (Albert et al., 2000). They refer to landscapes derived from human agricultural activities. These agricultural biomes are characterized by discontinuous even-aged trees of low density, scattered multipurpose trees on cultivated or fallow farmlands where Livestock may be a significant or secondary component of the system (Nair, 1993; Kessler, 1992). Parklands are particularly common in the West African Sudan savanna. Their widespread presence evidences the role of local farmers in shaping their agricultural landscape (Boffa, 2000; Aleza et al., 2015a). In this region, for centuries farmers have cut down forests for agricultural purposes while selecting, preserving and protecting useful tree species known for their contribution in rural livelihood (Albert et al., 2000; Maranz and Wiesman, 2003; Petit, 2003).

Such agro-ecosystems are drought-resilient. For this reason, they are considered as valuable means of adaptation as well as mitigation regarding climate change (Hunter et al., 2013). They are also important in reducing the vulnerability of farmers in this regions (Boffa, 1999; Luedeling and Neufeldt, 2012). Various ecosystem products, goods and services are generated by parklands in such an extent that farmers completely rely on them for their subsistence (Boffa, 2000). Nonetheless, the low level of intensification, the looming effect of climate change, etc. make the sustainability of these parklands questionable. Currently, sound management options are needed regarding these useful biomes while talking of their adaptability (Nikiema, 2005; Ouédraogo et al. 2015; Aleza et al., 2015).

To sum-up, these farming systems are consequence of centuries of traditional agricultural practices involving slash and burn agriculture, fallows, tree selection, etc. which overall purpose is to produce enough food for family subsistence (Nikiema, 2005). A major limitation is the inability to implement intensification through fertilizers application, mechanization, and amendments use (Floret and Pontanier, 2001; Judex et al., 2006). Meanwhile, the population continue to increase at a remarkable rate. This is translated into agricultural land expansion. As consequence, land/tree cover is depleted at unprecedented speed.

Agricultural expansion is indeed thought to be the main driver of land use changes in the Sudan savanna of West Africa. This is evidenced by a large perception of farmers in this area (Mama, 2013). Converting forest into parklands testifies the importance of these systems for the local people. Based on data from 1014 rural households across Burkina Faso and Ghana Pouliot et *al*. (2012) demonstrated that agricultural lands and the non-forest environment including parklands are considerably more valuable in supporting rural livelihood of marginalized people.

This is undoubtedly due to the benefits they provide. In this regard, it is worth noted that fuelwood exploitation is more worrying than other types of deforestation, especially in West African rural areas where it represents the main, if not the only, source of cooking energy (Judex et al., 2006; Orekan, 2007; Akouehou et al., 2011; Houessou et al., 2013; Mama, 2013, Konare et al., 2014). Such increasing land-use pressure has been reported to endanger trees in the Sudan savanna of West Africa (Ouédraogo et al., 2015).

Although fuelwood consumption is very important in West Africa, detailed studies looking at its share in terms of deforestation, its sustainability and social implication are lacking. In our knowledge, none of the above mentioned studies was concerned about this aspect. Apropos, only Akouehou et al. (2011) tried a very rough estimation of fuelwood consumption in two urban areas of Benin. At nutshell, estimations in rural area are quasi absent in the current literature. Yet, the fuelwood exploitation in rural area is crucial, if not the most important (Figure 2). This study comes to fill this gap by examining the firewood consumption in a rural area of north-western Benin. It purports at examining the importance of agroforestry parklands as firewood source. While quantifying the current firewood consumption, we will also estimate its production potential and sustainability.

Figure 2. Firewood consumed by a household of less than 6 persons in approximatively 1 month

1.2. Objectives of the Study

The MSc thesis will address the coping potential of the local agroforestry parklands practice in the cycle: firewood demand-deforestation-natural assets depletion-agricultural productivity reduction. Beyond the mere productivity of the practice, its mitigation potential is considered through the following specific objectives:

- ✓ To calculate the balance between the rates of households firewood consumption and the generation of woody biomass in parklands (biophysical and socioeconomic analyses);
- ✓ To estimate the capabilities of “trees in the parklands” (also “trees in the farms”) to capture carbon (biophysical analysis).

1.3. Research questions

To address the above mentioned objectives, the following research questions were formulated:

- ✓ How much fuelwood is consumed at household and landscape scales, and how farmers perceive the extent of their consumption and their point of view regarding the sustainability of their consumption patterns?
- ✓ How much fuelwood is stored in the agroforestry parklands, its dynamics and origin, how is it collected and who are involved in the collection?

1.4. Research Hypothesis

Given the above mentioned research questions, we hypothetically considered the following:

- ✓ The firewood consumption is exceeding the carrying capacity of the agroforestry parklands. Otherwise, the system cannot support the consumption in the long run.
- ✓ Although the burden of firewood and other forms of deforestation, the system represent a valuable source of carbon sink.

1.5. Thesis Structure

The thesis is structured in five chapters as it follows:

- Chapter 1; a General Introduction (as it preceded) where we discussed the problem investigated by the thesis whereby we provided its objectives, and research questions.

- Chapter 2; a Review of related Literature in which we will discussed the state of the art of the previous works undertaken in the field of agroforestry with special emphasis on Parklands of the west African Sudan savanna.

- Chapter 3; the presentation of Material and Methods used will provide an overview of the study and a brief description of the study area. Therein, the methodological steps used to collect the data will be also described while discussing the methods used to analysis them.

- Chapter 4; Results and Discussion will present the result obtained and try to discuss them within the context of Chapter 1 (state of the literature).

- Chapter 5; the out coming Conclusion and Policy Recommendations.

Chapter 2. LITERATURE REVIEW

2.1. Agroforestry Systems and their Importance

After years of controversies around its objective definition, Agroforestry is defined as a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence (Lundgren and Raintree, 1982). In this dynamic, and ecologically-based natural resource management practice, trees were deliberately retained on farmlands to support agriculture with an ultimate objective of food production (Nair, 1993; ICRAF, 2000).

Agroforestry systems are classified according to various criterions: the structural, the functional, the socio-economic and the ecological aspect (ICRAF, 2000). In this regards, Nair (1993) stated "*While the structural and functional bases often relate to the biological nature of the woody components in the system, the socioeconomic and ecological stratification refers to the organization of the systems according to prevailing local conditions (socioeconomic or ecological)*". For more information on the classification of these systems the reader is referred to Nair (1993, table 3.1, p. 23). Anyway, a system has to have a woody perennial component in order to be qualified as agroforestry system (Nair 1993).

Alike various criterions are used to classify them, agroforestry systems convey several functions among which there are (Beer et al., 2004; Vaast et *al*., 2005; Charbonnier, 2013):

- The commercial and home use (e.g. fuelwood, timber, fruits);
- The maintenance of soil fertility (e.g. organic matter inputs to the soil, nitrogen fixation and nutrient recycling);
- The buffering from erosion (e.g. reducing the kinetic energy of raindrops);
- The qualitative and quantitative conservation of water (e.g. the activity of roots goes with improved infiltration rate and thus reduced surface runoff);
- The carbon capturing;
- The biodiversity conservation in fragmented landscapes (e.g. improved habitat for many species);

- The regulation of extreme weather events (e.g. tree shading lessen the effect of higher temperature on crops);
- The optimal use of the system's resource (e.g. light, water, nutrients);
- Reduced pressure on natural forests and watershed protection;
- Etc.

As stated above, Parklands systems imply the presence of scattered multipurpose trees on cultivated or fallow farmlands) where livestock may be a significant or secondary component of the system. Therefore, the term 'parklands' calls for landscapes derived from human agricultural activities and characterized by discontinuous even-aged trees of low density and are particularly common in the West African Sudan savanna (Kessler, 1992; Nair, 1993). As stated above, such ecosystems are drought-resilient and may therefore be seen as a means of adaptation as well as mitigation regarding climate change (Boffa, 1999; Luedeling and Neufeldt, 2012). Although trees compete crops for water, nutrients and light, most farmers in semi-arid West Africa consider trees as an integral part of agriculture (Rao et al., 1997; Boffa, 1999; Van Noordwijk, 2011). For them, benefits from the tree products are more valuable than losses in cereal yields (Kessler, 1992).

2.2. Parklands' generation of goods and provision of ecosystem services

2.2.1. Water

The ability of trees to afford water and protect the understorey vegetation from water shortage is particularly relevant in tropical agroforestry systems (Rao et al., 1997). In the Kenyan savanna, Amundson et al. (1995) tested the effects of shade and water on understorey herbaceous productivity. The results suggested that below-crown species reduce their stomatal conductance with the decline of light intensity, and therefore reducing the evapotranspiration and loss of soil water which is conserved for later growth. Contrastingly, open-grassland species, seem to be more active at extracting water from dry soils and transpire it (Amundson et al., 1995).

2.2.2. Soils

According to the FAO harmonized world soil database (Figure 3), the Sudan savanna is dominanted by acrisols (found mostly in Cote d'Ivoire and Ghana), Lixisols (almost everywhere), Leptosoils (mostly found in the Northern part of the sudan savanna), Plinthosols (mostly found in the central part), and Luvisols (found mostly in Benin).

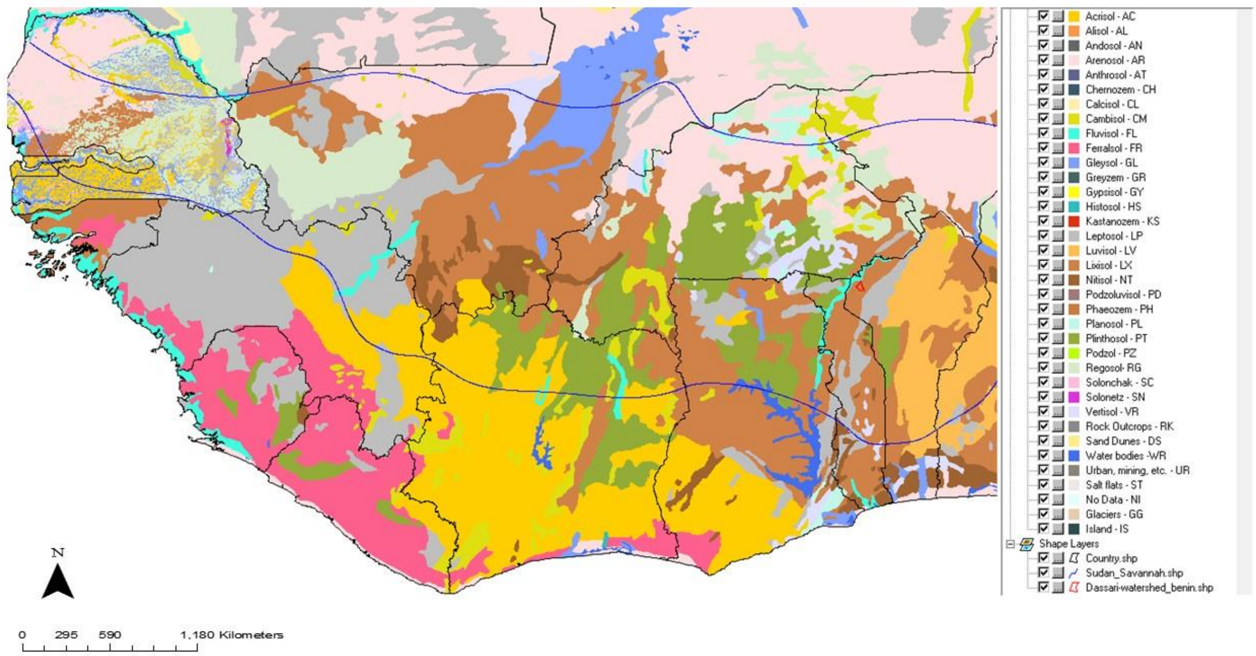

Figure 3. Major Soils type of the Sudan savanna. Source: FAO harmonized world soil database Viewer, Version 1.21.

Acrisols are acidic, highly weathered soils having a higher clay content in an argic subsurface horizon than in the topsoil. With no suitable vegetation cover, acrisols are suited to crusting and therefore to water erosion. As acrisols, lixisols are also highly weathered soils with the majority of clay concentrated in the subsoil leaving the topsoil with low base saturation. They are characteristic of areas with pronounced dry season and are subject to surface crusting. Leptosoils are subject to erosion making their topsoil horizon very shallow. Plinthosols are rich in iron, and poor in humus. They are characterized by kaolinite clay and quartz making their water retention capacity very low. Luvisols have also a lower clay content in the topsoil horizon due to clay migration as a result of washing (Bationo et al., 2006; FAO, 2006; Jalloh et al., 2011). The most common characteristics of these soils types are; low quality clay content, shallow topsoil horizon, low organic matter content and therefore poor water retention capacity.

To sum up, soils in the Sudan savanna, are generally dominated by Kaolinitic clay which are mostly concentered in the subsoil horizon. Therefore the soil fertility relies mainly upon the addition/return of organic matter (Floret and Pontanier, 2001; Manley et al., 2002a). It is recognized that trees can perform these benefits by adding green manure and mulching, adding nitrogen in the case of leguminous species, and by the roots which improve water infiltration and nutrient cycling. However, these effects vary according to several factors such as the tree species, agricultural management, the soil type, plantation tree density or landform (Boffa, 2000). The table 1 summarize some benefits of trees for soils and crops. For instance, species like *Cordyla pinnata* and *Prosopis Africana* have been reported to improve the Cation Exchange Capacity (CEC). Likewise, other species such as *Vitellaria paradoxa* or *Faidherbia albida* can provide suitable PH for crops (Table 1).

Table 1. Effect of trees on soil and crop productivity as reported in the literature

CEC	PH (suitable)	C	Macronutrients (N, P, K)	Micronutrients (Mg, Ca)	Al (low)	Higer crop yield	Higer crop biomass
Cordyla pinnata, Prosopis Africana, Various tree plantation and fallow	*F. albida, V. paradoxa, Hyphaene thebaica, Prosopis africana*	*Cordyla pinnata, V. paradoxa, Various tree plantation and fallow P.biglobosa*	*Cordyla pinnata, F. albida, V. paradoxa, Various tree plantation and fallow, P.biglobosa, Hyphaene thebaica, Prosopis africana*	*F. albida, V. paradoxa, P.biglobosa, Cordyla pinnata, Hyphaene thebaica, Prosopis africana*	*V. paradoxa*	*V. paradoxa, A. digitata, Various tree plantation and fallow, P.biglobosa*	*F. albida, V. paradoxa, Various tree plantation and fallow, A. digitata*

source: *(Kater et al., 1992 ; Floret and Pontanier, 2001; Diakité, 1995 ; Jonsson, 1995 ; Bernard, 1996 ; Moussa, 1997; Samba, 1997 ; Boffa, 1999 ; Sanou et al., 2012 ; Coulibaly et al. 2014).*

2.2.3. Dominant Woody Species

The Sudan savanna agricultural systems are able to host a considerable species diversity. In Burkina Faso, it has been reported between 54 and 86 woody species in farming plots (Nikiema, 2005, Ky-Dembele et *al*., 2007). Among these, 48 species were found in the fallow belt while the other 41 species were recorded in areas under cultivation. Some 17 species are strictly exclusive to the parklands (present in cultivated and fallow areas, but absent in protected areas) shaping the agricultural landscape (Lovett and Haq, 2000). Comparing the species diversity of areas under cultivation against fallow lands, it has been observed that 35% of the woody species recorded in the region are absent in the areas under cultivation (Nikiema, 2005). Species, such as *Acacia seyal*, *Acacia sieberiana*, and *Senna singueana*, are exclusive to the areas under cultivation while other like *Vitellaria paradoxa, Parkia biglobosa, Adansonia digitata* and *Balanites aegyptiaca* are protected and/or domesticated by the farmers themselves, and are therefore considered as key components of their farming systems. For this reason, their conservation is often promoted by extension services (Nikiema, 2005, Aleza et al., 2015).

Parklands in the Sudan savanna are generally dominated by old trees while fallow lands show individuals of smaller diameter, and likely major potential regeneration (Nikiema 2005; Aleza et al., 2015). This regeneration has been reported to originate either from seeds or root buds or both of them (Ky-Dembele et al., 2007). It could therefore substantially contribute to biodiversity since farmer leave vigorous individuals to grow to maturity after the fallow period (Nikiema, 2005).

Based on the species presence and frequencies in cultivated, fallow, and protected area, Niekiema (2005) identified 3 categories of parklands woody species which may help in explaining its current state with regards to biodiversity:

- ✓ The first is represented by <u>selected and protected</u> species by farmers in the farmland as for instance *Bombax costatum, Lannea microcarpa, Parkia biglobosa, Sclerocarya birrea, and Vitellaria paradoxa*;
- ✓ The second category includes <u>persistent species</u> that are able to regenerate by themselves after clearing in the parkland. This category encompasses species like *Combretum glutinosum, Piliostigma thonningii, and Diospyros mespiliformis*;
- ✓ The third one involves <u>planted species</u> where *Eucalyptus camaldulensis* and *Azadirachta indica* can be cited as examples.

Selection, direct sowing, protection and tree plantation by farmers are good news and may be considered as a potential for adaptation strategies. Therefore, this may compensate for the agricultural-based biodiversity loss reported in the literature (Lovett and Haq, 2000; Nikiema, 2005). Sowing of desired parkland species may compensate for the lack of regeneration (Nikiema, 2005) insofar that it considers the seedling sprouts (Ky-Dembele et al., 2007). It has been reported that seedling sprouts were predominant (83%) compared to root suckers (4%), true seedlings (5%), coppices (5%), water sprouts (2%), layering (less than 1%) in the plantlet population of a selectively cut savanna-woodland of Burkina Faso.

2.2.4. Human-beneficial Byproducts

The valued parkland trees species fulfil a wide range of multipurpose uses in the Sudan savanna including food, medicine, cooking oil, firewood, shelter, tools, forage, many other products known as Non-Timber Forest Products (NTFFs), etc. Some species provide up to 3 different products from various parts (Nikiema, 2005; Mertz et al., 2001).

Non-Timber Forest Products (NTFFs) are broadly found in local or urban markets. Results of a survey conducted by Nikiema (2005) in Zoundweogo (Burkina Faso) revealed 24 different products formulas produced seasonally and regularly supplied to local and urban markets thought major trade ratios occur in the rainy season. The predominant species found are *Vitellaria paradoxa*, *Parkia biglobosa*, *Adansonia digitata*, *Tamarindus indica*, *Lannea microcarpa* and *Saba senegalensis*.

Species like *Acacia senegal*, *Parkia biglobosa* and *Vitellaria paradoxa* and their by-products have been reported as valuable source of income and diet in the rural west Africa (Ouédraogo, 1995; Nikiema, 2005; Mertz et al., 2001). In Burkina Faso, the average daily per-capita consumption of Soumbala (a condiment byproduct of *Parkia biglobosa* seeds) is 3 g (Ouédraogo, 1995). The trade of Soumbala is estimated in FCFA to approximate 5 billions per year (about US$ 8.3 millions) which is equivalent to an annual income of between US$ 80 to 100 for a farmer that owns 10 mature *Parkia biglobosa* trees (Nikiema, 2005).

Apart from their economic value, the parkland tree species embed other socio-cultural values. In fact, some species have a central place in traditional ceremonies. For instance, during wedding, bride and bridegroom are supplied with some specific tree-based products that include Soumbala, in the case of the family of the bride for the Mossi people in Burkina Faso (Nikiema, 2005).

Also, fodder-provider tree species exist in the parklands. Some investigations have shown that some of these species are preferred by livestock, triggering a win-win situation towards in livestock-trees system. Such a symbiotic integration is known to improve livestock productivity while improving soil fertility (Nikiema, 2005).

Apart from food and NTFPs, the West African parkland species are also sources of other products such as fuelwood which constitutes the main source of domestic energy in the region (Slingerland, 2000).

A study by Akouehou et al. (2011), including 154,346 households in Cotonou and 45,623 in Porto-Novo, revealed that the fuelwood supplied to these urban centres comes from almost all over the country and employ around 100,000 persons among which women represent 80%. In Cotonou only, the annual consumption of fuelwood reaches 727 655.872 tons or 1094.05 kg per capita. With 3.8 to 4.13 % of population growth in these urban centers, the effect will affect the parkland productivity (INSAE, 2013). Simulation from 1992 to 2027 showed an increasing trend in the fuelwood demand contrary to its production potential (Akouehou et al., 2011). Needless to say that local Markets and exploitation sites for wood have to be created and controlled. Organisation of primary production, local level conservatoire, and sustainable production, through a resource planning, need to be set up.

According to the same authors, the annual fuelwood production amounts for around 11.2 millions of cubic meters of wood mostly coming from the green vegetation. Parklands contribute for 20% of this quantity. This huge consumption of fuelwood may be explained by the current tax policies on wood in the region. Increasing this tax (or taxe produit forestier) from 200 FCFA to for instance 1000 FCFA can discourage the consumer and shift them towards a sustainable energy consumption.

2.3. Parklands' Misuse and their Effects

Apart from fuelwood exploitation, parkland tree species are also subject to other threats including branching and lodging. The latter tend to increase as population does as there is a correlation between dwelling agglomeration and deforestation. In the rural area of West Africa, where people are lodged in dispersed settlements, housing-based deforestation has been also reported (Wills, 1962; LARES, 2000).

In northern Ghana, parkland degradation like branching for firewood, branching for housing, and overexploitation of land have been noted to be more important near houses agglomeration although was noticed also a compensating return of organic matter due to livestock dropping (Duadze, 2004). In more than 27,000 localities of Benin, LARES (2000) reported that 63% of them have less than 50 inhabitants, 26% have between 50 and 300, and only less than 10% are true villages. Such lodging pattern implies issues with regards to land tenure and land productivity since fuelwood collection is expected to degrade the woodland around the settlements. As farmlands are encroached by unorganized housing since farmers use to settle near their own farms, the parkland deforestation therefore occurs along.

Livestock, are important factor of branching in West Africa. In Kaibo (Burkina Faso), Slingerland (2000) revealed that althought resources are not scarce, herdsmen cut branches of *Acacia* spp., *Anogeissus leiocarpus, Sterculia setigera* and *Balanites aegyptiaca* to facilitate browsing by goats. In this region, up to 70 % of the parkland trees show signs of cutting evidencing the influence of herders' action. Apart from this, goats are often blamed for destroying woody vegetation through their feeding habits. In such a context, there is need to examine the management and performance of the system.

2.4. Parklands under Agricultural Management

Trees that compose parklands vary with regards to socio-ecological conditions, but in all cases keeping a low density (Boffa, 1999; Manley et al., 2002; Aleza et al., 2015). The diversity, regrowth or regeneration and tree density depend upon the local anthropogenic and biophysical endowments and peculiarities (Boffa et al., 2000; Kessler, 1992; Ouédraogo et al. 2015). In the Sudan savanna of Burkina, Boffa (1995) reported an average density of *Vittelaria paradoxa* to approximate 15 trees per hectare over a total tree density of 27 in Thiougou while Kessler (1991) reported it to be between 15 and 30 trees per hectare.

The tree density has declined after the droughts of the 1970's as consequence of the reduction of the fallow period and population growth. According to Boffa (2000) large trees density declined (from 0.15 trees ha^{-1} year^{-1} between 1957 and 1984 to 0.57 trees ha-1 year-1 between 1984 and 1988, and from 10.7 to 8.3 trees ha-1 year-1 between 1965 and 1989 respectively) in Samba village (Burkina Faso), and Sod village (Senegal). Nevertheless, some regeneration spots have been reported in the literature. In Kano (Nigeria), increases from 12.9 to 15.2 trees ha-1 year-1 have been reported between 1972 and 1981 (Cline-Cole *et al*., 1990).

It has been reported that certain trees species can provoke higher crop yield (Boffa, 2000; Manley et al., 2002a; Manley et al., 2002b). Combination of specific tree and crop may result in increased crop productivity (Boffa, 2000). Key factors are tree shading and the amount of photosynthetically active radiation, tree based-soil fertility, tree root activities such as hydrological conductivity, etc. (Boffa, 2000; Sanou et al., 2012; Coulibaly et *al*., 2014). In Nobéré (Burkina Faso), Millet and Sorghum perform better under *Adansonia digitata* and *Vitellaria paradoxa* compared to *Parkia biglobosa* (Sanou et al., 2012; Coulibaly et *al*., 2013). Other crops (like Taro) require shading and performs better under *Parkia biglobosa* (Sanou et al., 2012).

Many authors reported the cycling and management of organic matter in traditional farming system of West Africa is sustainable (Kessler and Boni, 1991; Floret and Pontanier, 2001; Boffa et al., 2000; Slingerland, 2000; Duadze, 2004; Manley et al., 2002a; Manley et al., 2002b; 2004). This occurs within concentric ring pattern stated by Duadze (2004), this farming system composed with three main concentric land uses starting from the upper plateau to the lowland (Manley et al., 2002a). It includes a bush ring (Duadze, 2004) under semi-permanent cropping where groundnut and cotton are grown (Manley et al., 2002a; 2002b; 2003), a compound ring (Duadze, 2004) under continuous cereal cropping devoted to millet, maize, groundnut and sorghum (Manley et al., 2002a; 2002b), a palm grove with palm oil, and rangeland and a lowest paddy fields for rice (Manley et al., 2002a; 2002b).

With a relatively low population density, this system is self-sufficient through many transfers and on-site recycling of herbaceous and wood biomass which produce huge volume of mulchi. Moreover, livestock and human droppings bring high Carbon inputs to staple crops in the compound ring where Nitrogen and Phosphorus depletion are very low although the continuous cropping. Manley et *al*. (2004) quantify this depletion to approximate 4 kg ha^{-1} $year^{-1}$ for Nitrogen and 1 kg ha^{-1} $year^{-1}$ for Phosphorus only when other abiotic flows were included. This soil fertility regeneration process has been endangered with the rapid population increase because massive nutrient losses occur at burning fallows, crop harvest (27%), and livestock overgrazing (59%). Nonetheless, livestock dropping accounts for nearly 80% of C, N and P returns to the soil (Bationo, 1998; Manley et al., 2004).

In the Sudan savanna, as stated above, domestic energy derives from wood and charcoal mainly coming from the parklands. Often misused, for instance in the case of charcoal production, it is important to consider the amount produced per unit of wood. This amount depends on the species and their lignin content, the wood diameter and its humidity, etc. Akossou et al. (2013) reported a decrease in charcoal production among *Prosopis Africana, Anogeissus leiocarpa* and *Tectona grandis* due to their wood densities. Also, wood humidity influences the carbonization time as well as the quantity and crude yield of charcoal. In Benin, traditional charcoal production does not take into account these parameters of optimal production (Akossou et al., 2013). Hence, parklands deforestation could be reduced if these conditions would be taken into account.

2.5. Partial Conclusion

Parkland farming system in West Africa is an ancient practice revealing the role of local farmers in shaping the agricultural landscape. Its purpose is to produce, with limited means, enough food for family subsistence. However, population growth results in agricultural expansion and degradation of natural assets.

Trees perform many functions in the farm, such as soil and water conservation, NTFPs, etc. These parklands perform a wide range of other ecosystem services. However many of them are underestimated (e.g. fodder and fuelwood) and are specially misused in local parklands. Scientific literatures focusing on that are relatively scarce; studies quantifying the consumption of fuelwood, fodder, and other branching at household as well as watershed scales are needed to fill this gap. Therefore, understanding the overall interaction of biomass production and consumption at local and watershed level would help to understand its dynamics and better design the systems. This would help for making informed decision, by then optimize the overall productivity and sustainability of the systems.

Chapter 3. MATERIALS AND METHODS

3.1. Presentation of the Study Area

Dassari catchment is located in north western Atakora department in Benin (Figure 4).

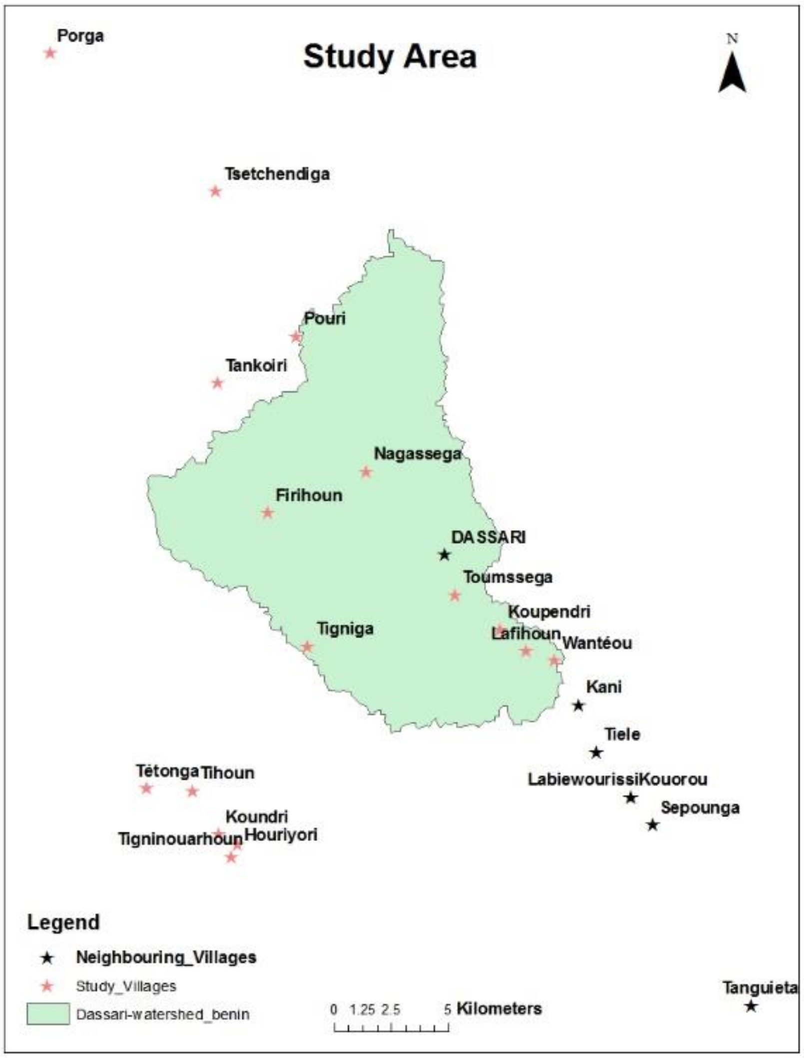

Figure 4. Map of the study area

The catchment is endowed in terms of rivers and streams. Some are permanent while other are ephemeral occurring only during the rainy season. The catchment is crossed north-south by a main road that links Benin with Burkina Faso and Togo in the north, passes by Tanguieta and Natitingou and continues southwards to Cotonou in the Gulf of Guinea. Several secondary roads connect minor cities in and near the catchment which during the rainy season often become non practicable. As consequence, most of the villages are located along the main roads (Figure 4).

Dassari is one of the three WASCAL catchments part of the common sampling frame of the Core Research Program. All catchments are located in the Sudan Savanna (around 11°N) and are supposed to be ecologically representative of the region although differ in socioeconomic and administrative aspects. Although the unit is essentially geographic (hydrological catchment), overlapping and administrative boundaries were considered along when socioeconomic data were required.

As shown in Figure 5, the climate of the study area has a strong seasonality. The rainy season is unimodal extending from March to October. Rainfall is unequally distributed; the month of August have the highest amount although March-April record the highest amount of

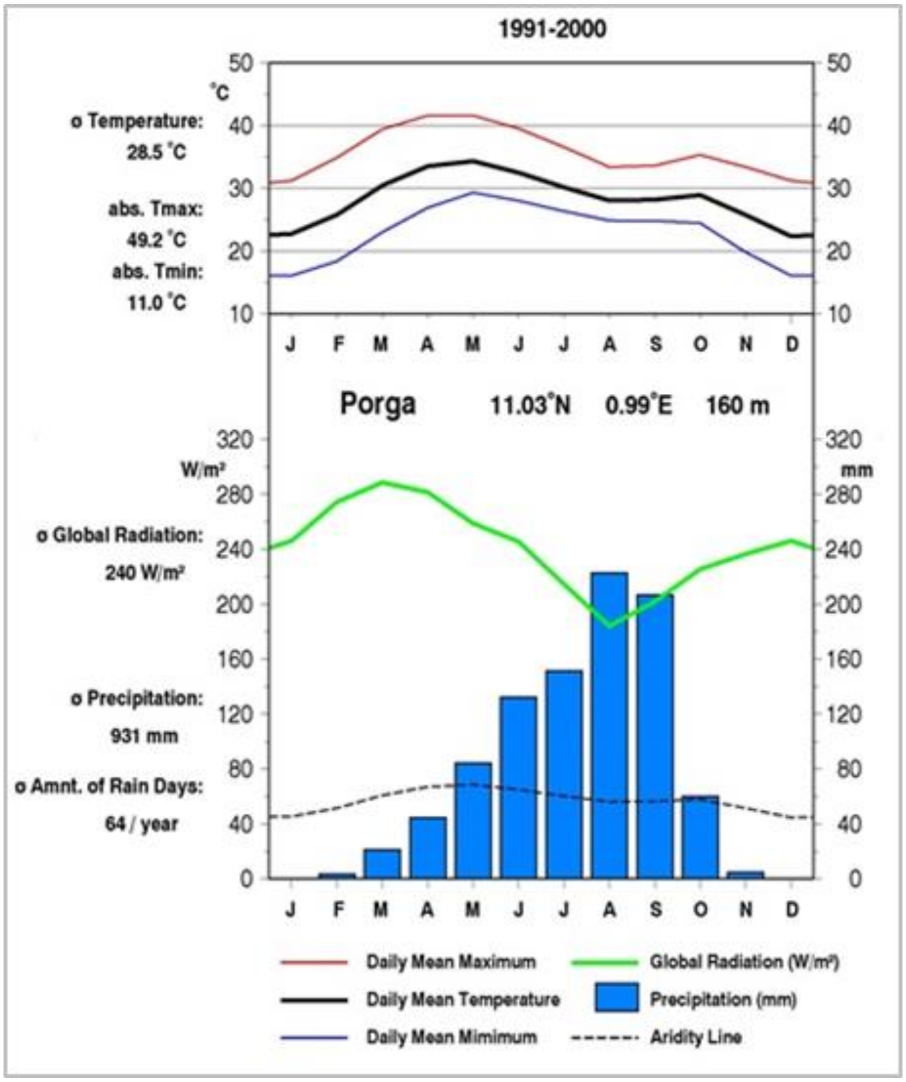

Figure 5. Climate of the study area

rainy days. The highest temperature is recorded around April-May and can reach more than 40˚C with an average of nearly 34˚C. The lowest temperature is recorded in December-January and fluctuates between 12 and 32˚C for an average of 22˚C.

In the study area, houses are made of clay materials. Two main types of roofs can be found. Some are made of sheet metal while other are made of a mixture of clay and straws in a traditional architecture (Figure 6). Mostly stored at home (Figure 6) (near the main room), firewood is also kept on the farm (sometimes far from the homestead).

Figure 6. Picture of a typical homestead in the study area

Just near the main entrance of the homestead, a small room (Figure 7) is sometimes

Figure 7. Firewood (left) and grain (right) storage rooms during the rainy season

found. This small hut made of wood, clay, and straw, having an opened door, serves to stock a certain amount of firewood during the rainy season. The purpose is to avoid using humid wood which is difficult to use for cooking. Additionally, another (sometimes 2 to 3) storage structure is also found around the homestead. This serves to store grains (Figure 7). The most commonly stored grains are maize and sorghum.

3.2. Overview of the Study

As stated above, this study used data ranging from socio-economic to biophysical. The Figure 8 summarizes the overall research idea. Firstly, we estimated the firewood consumption from farmers' perceptions. Secondly, we measured the exact quantity these households consume at daily scale. This was repeated during the dry and the rainy season and served to disclose the farmers 'perception and the validity of their sayings. Other sets of biophysical data related to

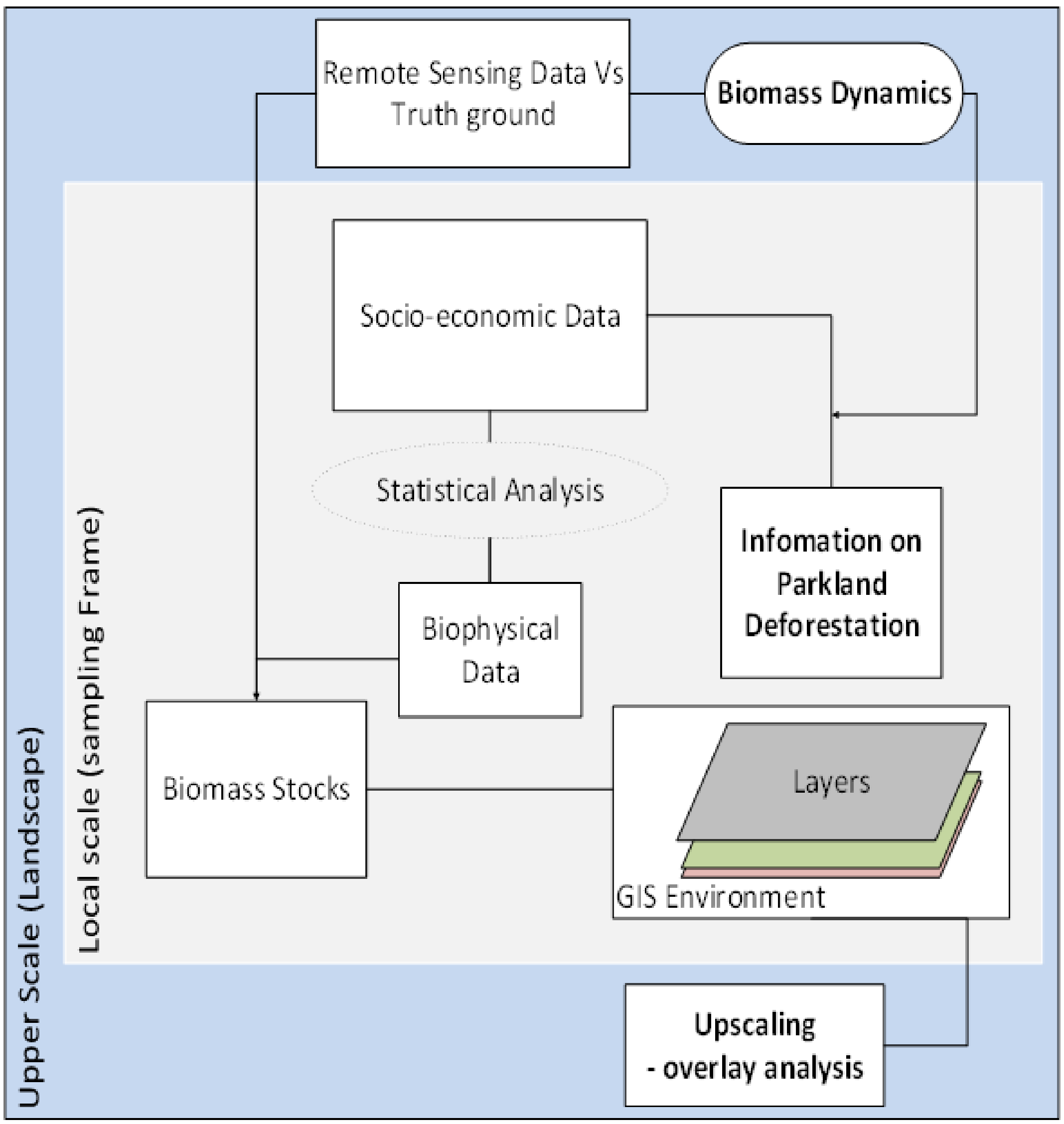

Figure 8. Overview of the study

trees were also collected. This allowed to estimate the available biomass and the potential firewood stored in “trees in the farms”. Lateral to that, other data from remote sensing were used to capture large scales information. These were supplemented with the biophysical and/or socio-economic data whenever necessary. The data were submitted to both statistical and GIS analysis. So doing, local scale information were up-scaled to landscape level and long run projections were performed.

Data were collected building up on an existing household database, that comprises 137 geo-localized households and their farming systems belonging to 17 villages spread across the catchment.

3.3. Data collection and Analysis

3.3.1. Data Collection

The data were collected between October 2014 and February 2015. Firewood consumption was estimated through both farmers’ perceptions (Figure 9) and field measurements

Figure 9. Households’ interviews

(Figure 10). Farmers were asked to estimate (in kg) their own household’s daily consumption of fuelwood (charcoal, and/or firewood). In some cases, the interviewer has to provide explanations, through practical examples, to allow the farmer to get an idea of what is a kilogramme. Other questions related to the tree species used for fuelwood, the fuelwood collection methods (such as tree branching, tree logging, etc.), the origin of the fuelwood (parklands, bush, etc.), the social groups involved in the collection (children, women, or men) were asked.

Based on Winrock International Institute’s guide for studying carbon in forestry and agroforestry plantations (MacDicken, 1997), the farmer interviews were implemented to describe the farming/cropping systems, including trees and crops, in the sampled plots. The interviews were carried out on the plots (Figure 9). While the farmers provided the majority of the information, visual inspection of the plots was also used to fine tune and complement them. The collected data concerned the approximate period the agroforestry parkland was being cultivated, the land use of the plot before, the different crops present on the plot, the tree components of the agroforestry system, etc. Nevertheless, only those data that are related to firewood consumption will be presented for the purpose of this thesis.

Lateral to the socio-economic estimations, comparable and complementary field measurements (Figure 10) were also performed. Firstly, field measurements concerning the firewood consumption were carried out. Secondly, we implemented other field measurements with regards to trees biomass estimations. This served as a proxy for estimating the available fuelwood stock in the farms and the trees regeneration rate.

Figure 10. Field measurement: biomass estimation (left), estimation of firewood consumption (right)

The field measurements concerning the fuelwood consumption consisted in measuring the quantity of wood consumed by the households. The idea consists in estimating this amount with the collaboration of the household members. The methodology (Figure 10) consisted in marking a quantity of fuelwood (enough for the daily use), and weighting it using a scale (balance). The farmers were asked to use only and only the marked/weighed fuelwood. After the day, the interviewer comes back and weights the rest of the marked quantity of fuelwood. This operation was repeated during the dry and the rainy season. These more precise data served to cross-check the farmers estimations.

Key assumption in this study was that farmers get great part of the firewood from the parklands, and therefore contribute to their degradation. To confirm/infirm this assumption, we accompanied farmers where they collect the firewood. So doing, the origin of the firewood, who (men, women or children) are involved in the collection, and how they get it (branching, collection, etc.), were disclosed. These also served as checklists for equivalent responses from farmers' perceptions.

To estimate the biomass/fuelwood stands in the farms, dendrometric measurements were performed. Agroforestry systems exhibit four (4) carbon pools that can be indirectly quantified using the biomass inventory method outlined in MacDicken, (1997). These are:

- ✓ Above-ground biomass/necromass;
- ✓ Below-ground biomass (tree roots);
- ✓ Soil carbon;
- ✓ Standing litter crop.

In the present study, only the first one was examined. For the biophysical measurements, a farm was randomly sampled from each farmer and the measurements were conducted therein. The procedure consisted in preparing a sketch map, and delimiting the farm contour by GPS tracking while recording the tree coordinates. On each of the measurement plots, we inventoried woody stems >5.0 cm Diameter at Breast Height (DBH). The following biophysical measurements were considered (MacDicken, 1997; Coulibaly et al., 2014):

- ✓ The different species within measurement plots;
- ✓ Their total height (estimated); from the soil surface up to the limit of the crown using a clinometer;
- ✓ Stem diameter at breast height (DBH).

3.3.2. Secondary data

The secondary data used in this study consist of two remotely sensed data sets as introduced in section 3.2. The first represents the buildings (homesteads) of the catchment (Feuerstein, 2015). The second represents the trees of the catchment (Forkuor et *al*., 2014). The data were obtained from the Work Package 2.1: Remote sensing based analysis of Land Cover and Land Use Change pathways and drivers. The data were received in shapefiles in which homesteads and trees are represented by polygons. Therefore, key features considered in this study are the area and perimeter of these polygons; testifying the amount of reflected energy by the targeted objects.

The size and shape of the polygons give an idea of the reflectance values. The use of band ratio indices (NDVI, GVI, etc.) has been found to be very useful as a framework for providing upscaling mechanisms of detailed site measurements of biomass on the ground, whereby the strength and the form of such relationships vary considerably with canopy type and structure, the state of the health of the vegetation and many other environmental parameters in the study area (Ponce-Hernandez, 2004; Forkuor et *al*., 2014; Feuerstein, 2015).

In the following, we will refer to “area” when talking about the area occupied by the tree canopy (as a function of the amount of the reflectance in the satellite images). Likewise, the term “perimeter” will be refer to when talking about the tree canopy circumference. We consider both area and perimeter of the shapes because 2 trees having the same area (in square meters) may have different perimeters (in meters).

The Analysis of the households were based on a very high resolution Remote Sensing data set from 8th of November 2013. In Dassari, most homesteads hold at least one building with corrugated iron sheet roofing. Therefore, the classification method used was based on the assumption that every household has one building with metal sheet roof. A Producer's accuracy of 100% and a User's accuracy of 60% were achieved.

3.3.3. Data Analysis

As described above, the firewood consumption was estimated twice for the dry and rainy season, firstly by asking farmers to estimate their own firewood consumption for both dry and rainy season, and later on by measuring it in situ for both seasons. Prior, we standardized it to per capita consumption by dividing the total consumption of each household by the corresponding number of household members (household size). A paired sample t-test was then conducted to capture the differences between the mean values of the different independent variables, and assess the accuracy of farmers’ perception and the effect of seasonality as it follows:

- ✓ Pair 1: Measured per capita firewood consumption in Dry Season (MDS) against the Perceived per capita firewood consumption in Dry Season (PDS);

- ✓ Pair 2: Measured per capita firewood consumption in Rainy Season (MRS) against the Perceived per capita firewood consumption in Rainy Season (PRS);
- ✓ Pair 3: Measured per capita firewood consumption in Dry Season (MDS) against the Measured per capita firewood consumption in Rainy Season (MRS).

Further descriptive statistics and relationships between variables (Type of Firewood used versus Firewood Collection Method) are disclosed through graphs, contingency table analysis and related statistical tests like Khi square test with Fisher's Exact confrontation and Cramer's V. In addition, considering the trees species used for firewood by each household, and the same trees in the farms, we calculated the mean distance the farmers travel to collect the firewood. This was achieved using the *earth.dist* function of the fossil package in R (Vavrek, 2011).

The above ground biomass for each plot was determined using the following equation (Brown et al., 1989):

$$y = 34.4703 - 8.0671\,D + 0.6589 \times D^2$$

(Where y is the above ground biomass in kg and D = diameter at breast height (1.3 m)). At plot level, the biomass was determined by adding values from individual trees. Knowing the plot size, we reported the quantity of biomass per hectare. Therefrom, the carbon stock and sequestration were deducted (C = 0.5 ×biomass (Ponce-Hernandez, 2004)). As the atomic weight of carbon is 12 atomic mass units, and that of Oxygen is 16, then the weight of Carbon dioxide (CO_2) is 44 mass units, and so it is easier to calculate the sequestration potential as:

Sequestered CO2 = (44/12) × C (Pambudhi, 2010);

Sequestered CO2 = 3.67 × C

It is worth to note that "biomass is not wood or firewood". Therefore, we estimated the wood specific gravity for every single tree after estimating its biomass according to the following equations (Chave et al., 2014).

$$AGB = \exp[-1.803 - 0.976 \times E + 0.976 \times \ln(\rho) + 2.673 \times \ln(D) - 0.0299 \times [l\,n(\rho)]2\,]$$

The model was derived based on the analysis of a global database from 4004 tropical trees (DBH ≥ 5 cm). The data collection used destructive sampling at 58 sites across the tropics, thus included a wide range of climatic conditions and vegetation types.

The measure of environmental stress (E) was retrieved from http://chave.ups-tlse.fr/pan-tropical_allometry.htm, using *ncdf* (David, 2014.) and *raster* (Robert, 2015) packages in R, as described by Chaves et al. (2014).

Thereafter, the corresponding dry wood was estimated, referring to the well-known Archimedes' principle, with regards to the density of water (1m^3 of water corresponding to 1000kg and a density of 1 (Simpson, 1993)).

After calculating the biomass and the corresponding wood, generalized linear models (between the biomass of individual trees and their area/perimeter of their corresponding polygons from the remotely sensed data) were derived using *glm* function of the stats package in R (R Core Team, 2015). We adopted a generalized linear modelling approach because the data, or simply the residuals, were strongly skewed after fitting linear models (Austin, 2007). In real world survey, such as agricultural, ecological survey, etc., data are often skewed and linear models may lead to erroneous model fit (Chandra and Chambers, 2008). Prior to fitting the models, the trees points' data were joined to their nearest polygons using the same *earth.dist* function of the fossil package in R (Vavrek, 2011).

The derived models were used to predict the total biomass and corresponding wood for the whole catchment using *predict* function of the same stats package. The same procedure was used for the estimation of firewood consumption. Table 2 and Table 3 present the performance of the various models. For the biomass prediction, the model 1 (based on polygon perimeter) was used for the prediction; as it gave the lowest AIC (Akaike information Criterion). For the firewood consumption, only one model per season (rainy and dry) was found and the predictions were performed based on them. The models performances were examined using the *cv.glm* function of the boot package in R (Davison and Hinkley, 1997). Both models seem to be satisfactory looking at the LOOCV error.

Table 2. Performance of models used for the prediction of biomass and firewood stands

		Estimate	Std. Error	t value	Pr(>|t|)	LOOCV error (MSE)	
						raw	bias-corrected
Model1* (AIC: 984)	Intercept	1.61	0.05	32.42	0.01	4.07	4.07
	AREA	0.09	0.01	6.54	0.01		
Model2* (AIC: 982.79)	Intercept	1.40	0.08	17.64	0.01	4.09	4.09
	PERIMETER	0.15	0.02	6.69	0.01		

* *Family = gaussian (link = "log")*

Table 3. Performance of models used for the prediction of households' firewood consumption

		Estimate	Std. Error	t value	Pr(>|t|)	LOOCV error (MSE)	
						raw	bias-corrected
Model1* (AIC = 515.65) (Rainy Season)	(Intercept)	0.09	0.01	6.83	0.01	70.99	70.99
	Perimeter Area Product	0.00	0.00	1.99	0.01		
	Area	-0.00	0.00	-2.20	0.01		
	Perimeter Area Product: Area	-0.00	0.00	-1.61	0.11		
Model2 (AIC = 554.44) (Dry Season)**	(Intercept)	14.75	3.13	4.70	0.01	75.48	75.48
	Area	0.09	0.13	0.72	0.47		
	Perimeter	-0.35	0.21	-1.67	0.05		
	Area: Perimeter	0.00	0.00	1.01	0.31		

*** Family = gaussian (link = "identity")*

**Family = Gamma (link = "inverse")*

For the biomass prediction models, the intercept as well as the predictors were significant (p = 0.01) owing to a very strong relationship between the response (biomass) and the predictor variables (reflectance or polygons area and perimeter). For the rainy season firewood consumption model, only the interaction of the predictor (area) is not significant as does the predictor (area) and the interaction (area Vs perimeter). This implies that both model could be successfully used for predicting the response variable but have rather different sensitivity (Zheng and Agresti, 2000).

Trees growth rate was determined following Zeide (1978), Paine et al. (2012), and Sedmák and Scheer (2014). First, a quantiles regression (QR) between the age of the sampled trees, and growth variables (such as trees heights, DBH, Db) was used to determine suitable inflexion points (Figure 11). Quantile regression has potential and a strong theoretical justification in Liebig's law of the minimum while reported to be robust to outliers (Austin, 2007).This was achieved using *gcrq* of the quantregGrowth package in R (Muggeo, Sciandra, Tomasello and Calvo, 2013). The suitable lambda value was selected after the largest cross validation score (Austin, 2007) (Figure 11).

In reference to trees ages, a total of 3 points corresponding to 1999 (trees present 15 before 2014), 2009 (trees present 5 before 2014), and 2014 (trees present during the study year) were found. Secondly, the data were divided into 3 parts based on these points using subset function in R. The 3 subsets correspond therefore to all sampled trees in 2014, all sampled trees in 2009, and all sampled trees in 1999. Based on these, we determined the absolute (AGR) and relative (RGR) growth rate of the biomass and the corresponding dry wood. In this study, we

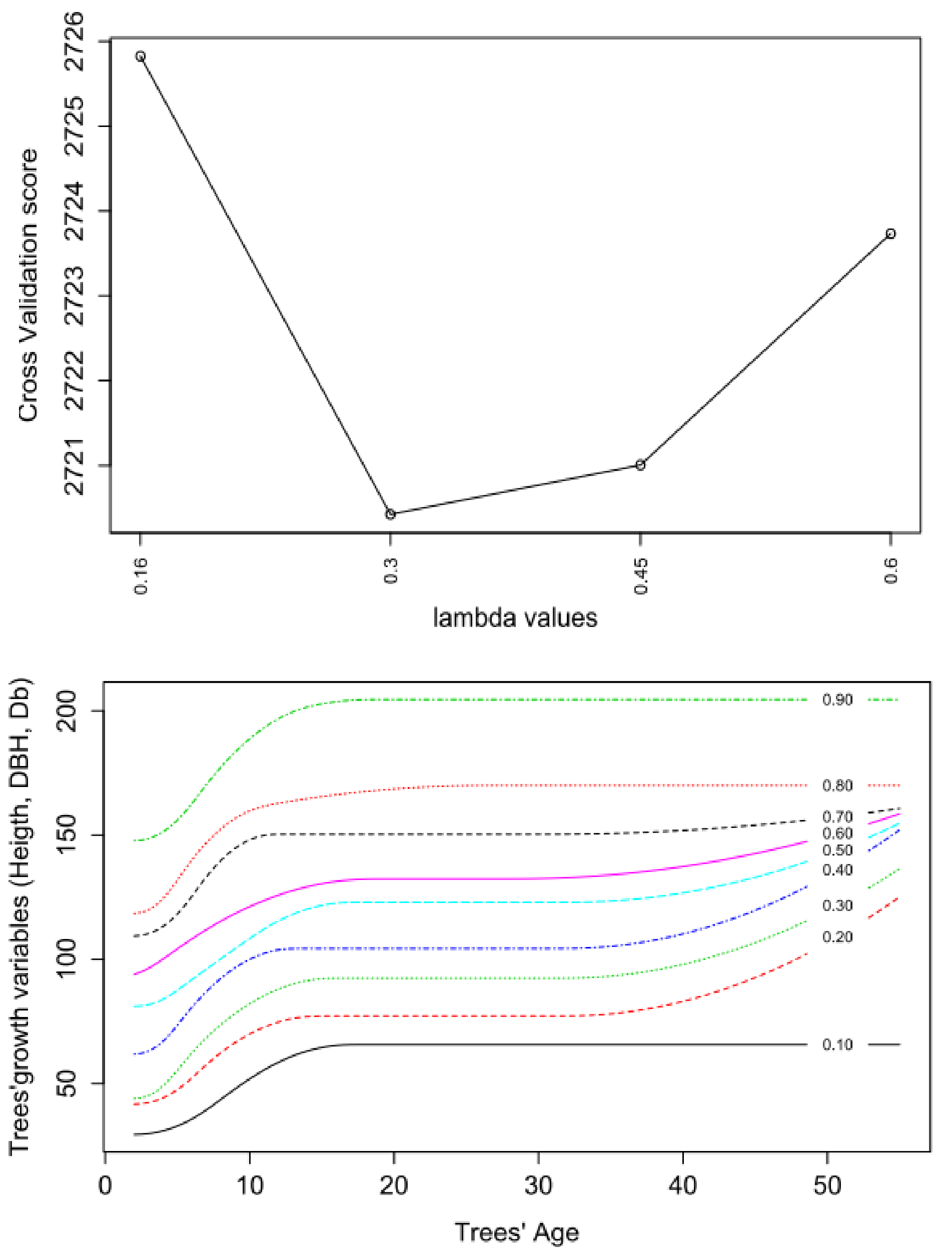

Figure 11. Quantiles regressions (left) based the best smoothing parameter; lambda (right) after k-fold' cross validation

consider the AGR as the derivative with respect to time of the function used to calculate the biomass, and the RGR is the AGR divided by the current biomass (Paine et al., 2012).

Chapter 4. RESULTS AND DISCUSSION

4.1. Tree Products Use

We have found that apart from using wood for construction, trees perform multiples roles and functions, but are predominant: firewood, NTFPs, and fodder. Firewood is used by all the households as source of cooking fuel (Figure 12) and represents 54 % of the overall use of trees. Our results are consistent with those of Konare et al. (2014) who found fuelwood used for cooking representing 90% of the total energy used in Mali. The second main tree products are

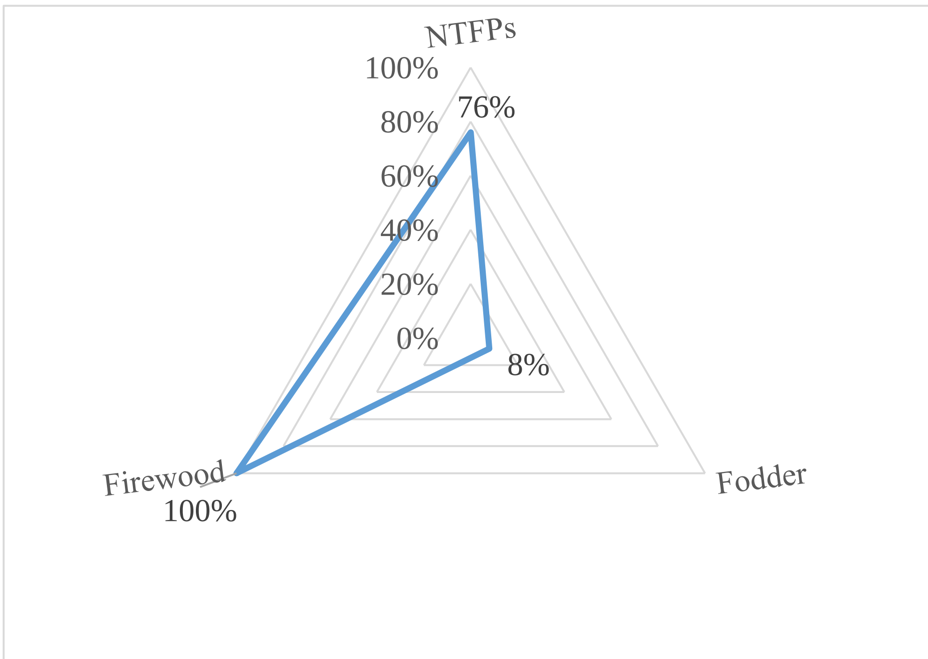

Figure 12. Tree products use frequencies (cases)

represented by a variety of NTFPs. Around 76 % of the households did mention of using various tree parts as NTFPs (Figure 12). This correspond to nearly half (41.3 %) of the overall tree products use in the area. The third use and of minor importance, is represented by fodder. Probably due to small livestock holding, mainly small ruminants like goats and ships, trees are not subject to exaggerate exploitation due to fodder. As shown by this study, only 8 % of the household use tree parts for livestock feeding (Figure 12). Otherwise, trees' branches / leaves use towards that end accounts only for 4.3 % in the overall trees use.

4.2. Variation in Firewood Consumption

About 86.4 % of the farmers affirm experiencing changes in the volume of firewood consumed (Figure 13). We examined the reasons that farmers argue to explain the variability in

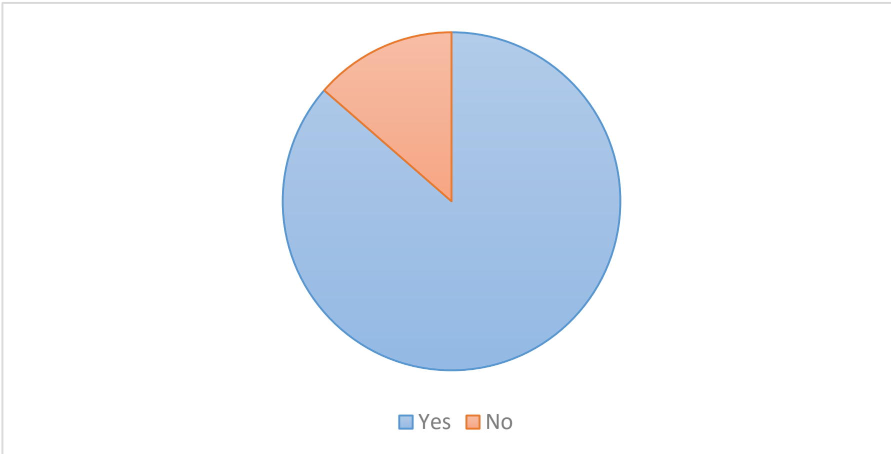

Figure 13. Perception of variability in firewood consumption

firewood consumption. For that, we estimated the relative frequencies of farmers' "yes/no" responses. Disintegrating the "yes/no" responses, we came across that certain farmers recognizing there is a variation in terms of firewood consumption have actually no idea when it comes to explain the reason behind this variation. Wood humidity, is noted as major factor influencing firewood consumption, about one third of responses; seasonality, wind, and household size also appear relevant but in minor extent (Table 4). Wood humidity has been also reported to negatively impact charcoal production (Akossou et al., 2013). Nevertheless, almost one third of the surveyed farmers do not acknowledge changes in firewood consumption.

Table 4. Farmer's responses to variation in firewood consumption

Reason of Variation in Firewood Consumption	Variation in Firewood Consumption
No idea / not vary	31.2%
Effect of Wind	11.7%
Seasonality	14.1%
Household size	9.3%
Wood Humidity	33.7%
Total	100%

Looking closely at these responses, the reasons that individual farmers argue, except for wood humidity, are rather fuzzy and permit double interpretations. For instance, seasonality encompasses things like ceremonies that are mostly happening in dry season, the fact that during the drought and dry Season the wood is drier, the availability of wood stock and other alternative fuels in dry season, the low wood density in dry season, the air humidity or farm occupations during the rainy Season. The effect of wind acts in two main different ways: the negative and the positive effect.

Some of these responses are explained as following, the more the ceremonies like traditional baptism (mostly happing during the dry season), the more firewood consumed. Likewise, the drier the wood, the better it burns, and so the less firewood is required to cook a given amount of food. The larger the availability of wood stock (or other fuel type like crop residues), the less rational utilisation of fuel. In other words, the abundance of the fuelwood causes the farmers to use it in an extravagant manner. While some of them perceive the wind in lowering the consumption; since it increases the burning potential of the fuelwood, other are quite sure it contributes to increase that consumption; because it dissipates the fire, especially in the case of three stones stoves.

4.3. Type of Fuelwood used and Collection Methods

Four main types of fuelwood were identified charcoal, non-fragmented wood, fragmented woods, and wood fragments. We defined *Non-fragmented woods* as tree trunks or large branches that are burnt as it is without being cut into small fragments. These are suited for cooking the local beer known as "tchoukoutchou" in Benin or "dolo" in Burkina Faso. *Fragmented woods* are non-fragmented woods that have been longitudinally cut in smaller pieces to make the wood easier for use. *Wood Fragments* are small to medium size branches that can be directly burn in the cook stove. Based on these definitions, our results showed that farmers do not have a distinguished preference for any type of firewood, they equally use them. However, charcoal, happens to be of minor importance, (0.4%) since its use is very limited in the study area. However, it is worth to say that some farmers produce charcoal for selling, to supply neighbouring towns like Tanguieta, Dassari, or Tantega, so charcoal bags are exposed along the road to be sold (Figure 14). In this area therefore, even the cook stoves are designed to "run in firewood instead of charcoal" (Figure 14). Apropos, Akossou et al. (2013) reported that Charcoal production, mainly traditional, is an increasing practice and therefore requires considerable attention.

Figure 14. Charcoal bags (left) for sales along the road, cook stoves types in the dassari catchment

About firewood collection (Figure 15), farmers assert that branching is the main type of collection method (30%), followed by collection of dead trees/branches (29%), collection of farmland residues (24%) and trees logging (17%). Most of the interviewed farmers stated that logging has drastically reduced, primarily coerced by the custodians and forest services. This has been confirmed through field observations.

To estimate the relationship between the type of firewood used and the collection method reported by farmers, we applied a Chi square test for two ways contingency tables analysis. It

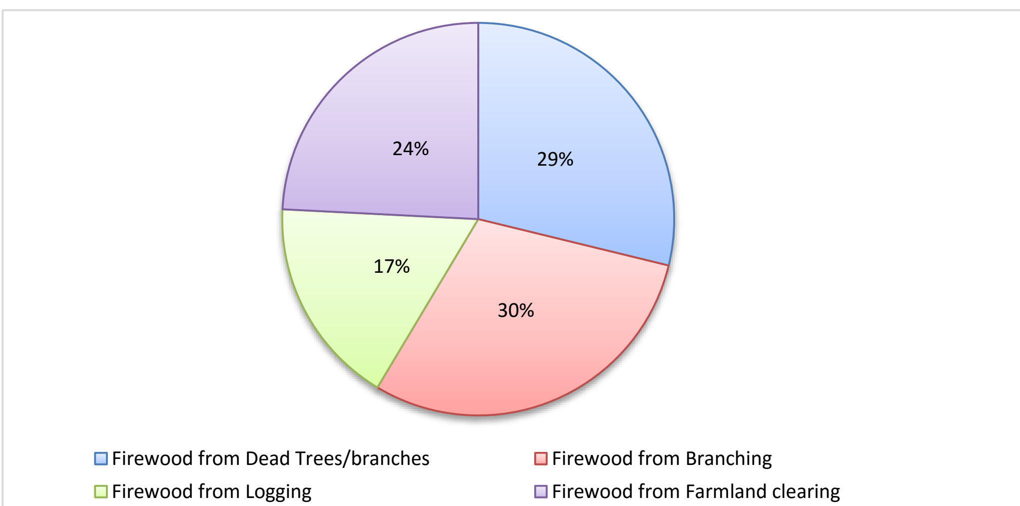

Figure 15. Firewood collection methods

tested if the type of firewood collected by farmers was anyhow correlated to the collection method implemented. Hypothetically, it was not reasonably expected that someone that primarily use wood fragments (small branches) would cut trees down and likewise, that a person using mainly branching as firewood collection method would not use non-fragmented wood.

The contingency table analysis shows statistical significance ($p < 0.01$) in favour that the type of fuelwood used is related to the collection preferences of the farmers (Table 5). But the important question is which variables are related to each other and what is the direction of the relationship, e.g. is the use of fragmented wood related to logging and/or branching? To answer this question, a pair-wise comparison was performed (Table 5).

Table 5. Pearson Chi-Square tests for contingency table between type of firewood used and firewood collection method

		Firewood type use
Firewood Collection Method	Chi-square	70.556
	df	12
	Sig.	.000*

Table 6. Pair-wise comparison Chi square test

	(2-TAILED)	NON-FRAGMENTED WOOD	WOOD FRAGMENTS	FRAGMENTED WOOD
DEAD WOOD	Pearson Chi-Square	37.48 (p< 0.01)	N.S.	N.S.
	Fisher's Exact Test	p< 0.01	N.S.	N.S.
	Phi/ Cramer's V	0.653 (p < 0.01)	N.S.	N.S.
LOGGING	Pearson Chi-Square	4.55 (p = 0.03)	8.1 (p<0.01)	9.5 (p<0.01)
	Fisher's Exact Test	p = 0.03	p<0.01	p<0.01
	Phi/ Cramer's V	0.23 (p = 0.03)	0.30 (p<0.01)	0.33 (p<0.01)

N.S. = Non-Significant.

The results indicated a strong correlation between dead wood as firewood collection and the use of non-fragmented wood ($p<0.01$). The result hold also for Fisher's Exact Test ($p< 0.01$). Further Cramer's V results showed an association of rounded 0.65 ($p < 0.01$) between the two variables. In addition, logging as method of obtaining firewood is strongly correlated with both non-fragmented woods, wood fragments, fragmented woods ($Khi^2 (1) = 4.55$, $p = 0.03$; $Khi^2 (1) = 8.1$, $p<0.01$; $Khi^2 (1) = 9.5$, $p<0.01$ respectively). These results are confirmed by Fisher's Exact Test ($p = 0.03$, $p<0.01$, $p<0.01$ respectively for non-fragmented wood, wood fragments, and fragmented wood). The Cramer's V provided correlation coefficients of 0.23 ($p=0.03$), 0.30

(p<0.01), 0.33 (p<0.01) respectively for non-fragmented wood, wood fragments, and fragmented wood.

Summing up: Most of the farmers who use non-fragmented firewood are likely to use dead wood instead of logging, and presumably cut down living trees when there is no other choice. These farmers who prefer non-fragmented wood represent 33% of the recorded responses or 24.60 % of the entire population, while only 4.4 % are logging (or 17% of recoded responses). In other words, the most important part of logging for firewood in Dassari catchment concerns dead trees; living trees exploitation towards this end is limited to branching.

The ones who prefer fragmented wood are more likely to cut down living trees compared to those using non-fragmented wood and wood fragments. These represent also one third of the farmers. The farmers who log use preferably wood fragments than non-fragmented wood, which also reach one third of them. In the nutshell, these famers also log only when woods fragments are not available.

4.4. Firewood Consumption

Concerning firewood, it seems that there is an oscillation in the consumption according to seasons. The average firewood consumption per day per person is 0.814 kg and 1.026 kg in dry and rainy season respectively (Table 7). These quantities are lower compared to that found by Akouehou et al. (2011) who estimated the daily per capita consumption in Cotonou to approximate 3 kg (or 1094.05 kg annum). However, the contexts are slightly different since these authors estimated the consumption in urban areas and indirectly from interviews. In addition they used census data to estimate the per capita consumption.

Table 7. Per capita firewood consumption statistics (kg/day)

	MEAN	**STD. DEVIATION**	**STD. ERROR MEAN**
MDS	0.814	0.517	0.075
PDS	2.015	2.422	0.353
MRS	1.026	0.550	0.080
PRS	1.559	1.338	0.195

MDS: Measured Per capita Firewood Consumption (kg/day) in Dry Season;
PDS: Perceived Per capita Firewood Consumption (kg/day) in Dry Season;
MRS: Measured Per capita Firewood Consumption (kg/day) in Rainy Season;
PRS: Perceived Per capita Firewood Consumption (kg/day) in Rainy Season.

To test the assumption that the measured and perceived (as well as the dry and rainy season) firewood consumption are different, a dependant sample *t*-test was performed (Table 8). The results assert that the average firewood consumption is greater in rainy season and also that farmers overestimate their own consumption. In the study area, households consume more firewood in rainy season compared to dry season, (p=0.05). Asked about, farmers tend to overestimate the quantity consumed in dry (p=0.01) as well as rainy season (p=0.01). However, the two-tailed test revealed to be non-significant regarding seasonality in the measured consumption of firewood.

Table 8. Paired samples test

	Paired Differences				
Per capita Firewood Consumption	Mean	SD	95% Confidence Interval of the Difference	t	Sig. (1-tailed)
MDS - PDS (Paired 1)	-1.20	2.50	[-1.935, -0.467]	-3.3	0.00
MRS – PRS (Paired 2)	-0.53	1.46	[-0.964, -0.102]	-2.5	0.00
MRS – MDS (Paired 3)	0.21	0.73	[-0.002, 0.427]	2	0.02

4.5. Tree Species Used for Firewood

Looking at the different types of vegetation (shrubs and trees), and tree species that are used for firewood (Figure 16), provides the understanding of which type of collection (logging or branching) and at which extent.

Shrubs (41.60 %) recorded the highest rate of use as firewood tree species compared to trees (45%). Among shrubs, the farmers seem to be more interested by *Combretum sp.* recording up to more than 1/3 (35%) of the overall species used for firewood. These are followed by *Maytenus senegalensis* scoring approximatively 1/10 (9.90%). Among the tree species, the most commonly used is *Anogeissus leiocarpus* with more than 1/10 (10.60%) of the overall species use. Three (3) other tree species (*Pericopsis laxiflora, Azadirachta indica, and Parkia biglobosa*) followed scoring each less than 1/10 of the overall tree use. These results are in line with previous findings asserting that *Anogeissus leiocarpa, Pterocarpus erinaceus,* and *Vitellaria* *paradoxa* are among the most used trees species for charcoal in the Sudan savanna of West Africa (Idjigbérou, 2007; Kokou et al., 2009; Akosso et al., 2013).

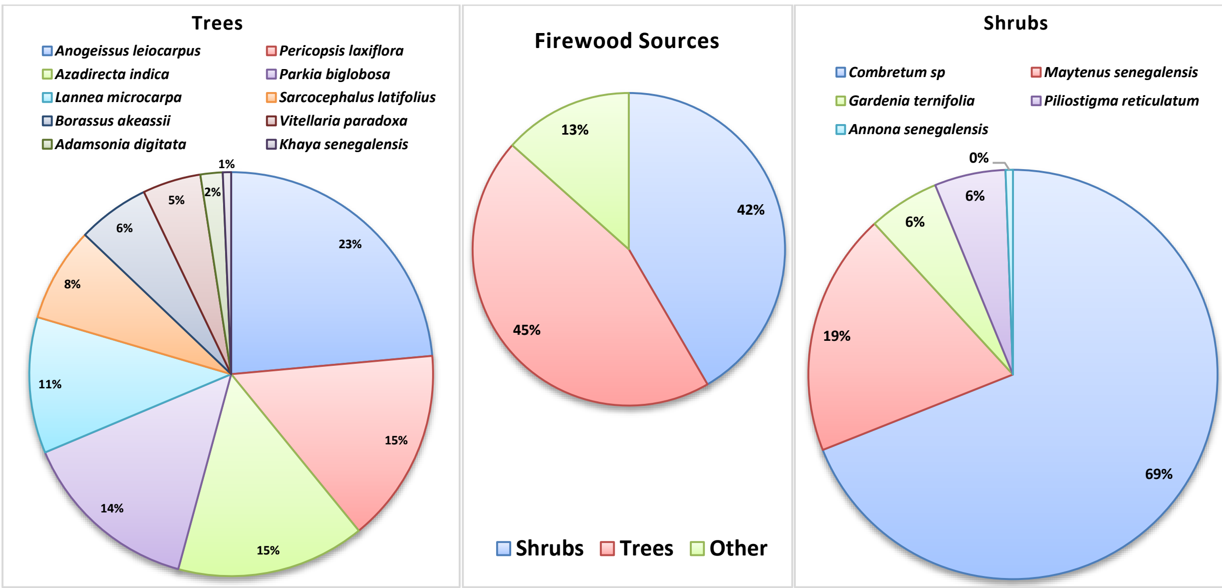

Figure 16. Percentages of different trees and shrubs species used for firewood

Summing-up, farmers (in Dassari catchment) prefer shrubs to trees when it comes to firewood. Among shrubs, they prefer *Combretum sp.* and *Maytenus senegalensis* to a certain extent. The most used tree species are *Anogeissus leiocarpus, Pericopsis laxiflora, Azadirecta indica, and Parkia biglobosa* are also often used for firewood.

Sarcocephalus latifolius was ranked first, second, third, and fourth by respectively around 1/3 (29.9%), 1/3 (26.2%), 1/6 (19.7 %), and 1/6 (15.1%) of the farmers (Table 9). Therefore, this tree species seems to provide the best firewood in the area. It is followed by *Anogeissus leiocarpus*, *Maytenus senegalensis*. Although widely used by the farmer as firewood species, *Combretum sp.* and *Maytenus senegalensis* species (Figure 16) are not ranked as the best first shrubs species for firewood (Table 9). Likewise, the most widely used tree species for firewood (*Anogeissus leiocarpus. Pericopsis laxiflora, Azadirecta indica, and Parkia biglobosa*) are not ranked as first in terms of providing the best firewood. Therefore, in the study area firewood use depends on other considerations rather than the quality of the wood. This is not the case for Togolese charcoal producers who select the trees based on their suitability (Kokou et al., 2009).

Table 9. Percentages of tree species ranking as they provide the best firewood

	species	Ranked First	Ranked Second	Ranked Third	Ranked Fourth
1	*Anogeissus leiocarpus*	23.00	11.90	9.20	1.90
2	*Azadirecta indica*	6.90	7.10	5.30	1.90
3	*Combretum sp.*	1.10	3.60	23.70	34.00
4	*Lannea microcarpa*	2.30	2.40	9.20	5.70
5	*Maytenus senegalensis*	25.30	10.70	6.60	3.80
6	*Parkia biglobosa*	3.40	8.30	3.90	5.70
7	*Pericopsis laxiflora*	6.90	15.50	5.30	3.80
8	*Sarcocephalus latifolius*	29.90	26.20	19.70	15.10
9	*Vitellaria paradoxa*	1.10	1.20	2.60	1.90
10	*Adamsonia digitata*		1.20		1.90
11	*Borassus akeassii*		6.00	1.30	3.80
12	*Gardenia ternifolia*		1.20	5.30	1.90
13	*Other (like Maerua crassifolia)*		3.60	2.60	11.30
14	*Piliostigma reticulatum*		1.20	5.30	5.70
15	*Khaya senegalensis*				1.90

In our case, an explanation could be the abundance of the species and their socio-economic values. Some authors reported that trees species from Leguminosae and Combretaceae families are among the most abundant in the Sudan savanna (Kokou et al., 2009; Aleza et al., 2015b). Therefore, the wide spreading use of Combretum sp. as firewood species may be the cause of its use. Another explanation could be the high regeneration power of these species as some Combretaceae are able to regenerate by themselves after land clearing as stated by Nikiema (2005). What is sure is that the farmers select the tree species as reported by the majority (93 %) of them. This has been reported by many authors (Boffa, 2000; Boffa, 2000; Albert et al., 2000; Maranz and Wiesman, 2003; Petit, 2003). Indeed, in the sake to optimize agricultural production, farmers preserve some trees known for their positive impact on soil fertility and other rural livelihood, etc. (Nikiema, 2005). The distance travelled by the farmers in search of firewood seems to vary according to tree species (Table 10). Remind that this distance has been calculated according to the locations of the households, their responses regarding the trees species they use for firewood, and the locations of these same trees in the farms. The result stipulates that *Vitellaria paradoxa* seem to be the furthest trees from the homesteads while *Sarcocephalus latifolius* is the nearest (Table 10). In average, the firewood is found as far as 10 km from the homestead. Nonetheless trees are everywhere in the catchment.

Table 10. Households' distance to trees species used for firewood in km

Tree species	Distance			
	Min.	**mean**	**SD**	**Max.**
Adansonia digitata	5.40	9.69	4.31	23.27
Anogeissus leiocarpus	4.11	10.69	4.72	25.00
Azadirachta indica	4.93	9.55	4.33	22.81
Borassus akeassii	5.04	9.67	4.43	23.77
Combretum spp.	6.18	11.36	4.67	26.11
Ficus sp.	5.81	10.79	4.13	22.68
Khaya senegalensis	6.47	11.36	3.94	22.25
Lannea microcarpa	7.37	11.53	4.63	26.77
Maytenus senegalensis	4.07	10.94	4.65	23.97
Other	4.80	9.64	4.35	22.18
Parkia biglobosa	7.16	10.99	4.39	25.78
Pericopsis laxiflora	4.66	11.12	4.49	22.19
Piliostigma reticulatum	2.95	11.66	4.86	23.19
Sarcocephalus latifolius	0.15	8.85	6.38	28.61
Vitellaria paradoxa	14.08	15.74	2.07	22.63
Average	**5.55**	**10.91**	**4.42**	**24.08**

In the study area, a traditional behaviour we noted during the data collection is that trees near the homesteads are very rarely used for firewood. Usually, the Farmers (mostly women or children) form a small group of not more than 10 persons and go together far from the homesteads where they collect each one a quantity of around 10 to 30 kg of firewood. This is done during almost the entire dry season. This also relates to the aspect of trees selection reported in the literature. Trees around the homesteads are seldom use for firewood because they provide shade and protection apart from other values like soil fertility or income, etc. (Ouédraogo, 1995; Mertz, et al., 2001; Nikiema, 2005).

4.6. Upscaling Biomass Stands in the Farms and Households' Firewood Consumption

4.6.1. Biomass per Individual Trees and Farmer Plot

Like the biomass, the dry wood provision of the trees vary strongly among individual trees as well as farmers plots (Table 11; Table 12). This is also true for within the same plot.

Considering the investigated plots, our results estimate an average biomass of 22.28 kg m^{-2} (Table 11). Converted into dry wood, this gives an amount of 2.88 kg m^{-2}. The average biomass per tree is 3091 kg m^{-2} with correspond to 366.25 kg m^{-2} of dry wood (Table 12).

The variation within the same plot could be the results of differences in agricultural managements among the farmers. The differences between individual's trees can be explained by the natural variability among species. For instance, the catchment is endowed with baobab (*Adamsonia digitata*) which are the largest trees species. In this area, in most cases, parameters (like Height, Db, DBH, biomass, etc.) taken from this trees species may be considered as a statistical outlier relative to other species. Other trees species like Karite (*Vitellaria paradoxa*) are of relatively small size (Aleza et al., 2015).

Table 11. Biomass and corresponding firewood; summary statistic per farmers' plot

		Min.	Mean	SD	Max.
Biomass per Plot (kg/m2)	Transect1	0.15	25.45	58.37	383.70
	Transect2.	0.13	19.11	34.22	234.60
	Average	**0.14**	**22.28**	**46.295**	**309.15**
	Transect1	0.06	3.09	3.86	27.63
Wood per Plot (kg/m^2)	Transect2.	0.05	2.66	2.73	15.80
	Average	**0.05**	**2.88**	**3.295**	**21.71**

Table 12. Biomass and corresponding wood; summary statistic per individuals trees.

		Min.	Mean	SD	Max.
Biomass per Tree (Kg)	Transect1	9.79	3431.00	19872.16	317200.00
	Transect2	9.79	2751.00	7529.66	82520.00
	Average	**9.79**	**3091.00**	**13700.91**	**199860.00**
	Transect1	5.57	356.10	610.82	7240.00
Wood per Tree (Kg)	Transect2	5.57	376.40	516.32	3773.00
	Average	**5.57**	**366.25**	**563.57**	**5506.50**

The consequence of this variability is translated into differences in terms of the impacts the trees may have on the other farm components like crops (Ponce-Hernandez, 2004). As reported by some authors (Kessler, 1992; Sanou et al., 2012; Charbonnier, 2013), the shading effect vary from species to species because of the differences in their canopy. Kessler and Boni (1991). According the farmers themselves, trees like Nere (*Parkia biglobosa*) are only kept in the farms because of their fruits; but have negative impact on the understorey crops. This assertion is consistence with the literature (Coulibaly et al., 2014). According to these authors, tree pruning could be an option to optimize agricultural production while expecting the other services (firewood, NTFPs, return of soil organic matter, etc.) from the trees.

4.6.2. Total Biomass Stands and Firewood consumption at the Catchment level

Examining the overall biomass and firewood availability in the catchment, the results of the model predictions give a total of 1,153,363,780.44 kg and 2,353,842,526 kg respectively for the biomass and the dry firewood (Table 13). Compared to the field data (mean biomass per tree = 3091.00 kg), the model performed well with 3834.17 kg per tree as predicted biomass.

Table 13. Model predictions for biomass and firewood stands "in the farms" as function of trees polygons from VHR (catchment level)

	Mean	SD	Total Biomass (kg)	Total wood (kg)
Model1 (perimeter-based)	3834.17	636305.2	1,153,363,780.44	235,384,2526
Model2 (area-based)	1016	4685.19	305,623,650.33	623,732,041

The model for firewood consumption predicts a yearly firewood consumption of 177, 456, 08 kg for the whole catchment. On a daily basis, the overall firewood consumption of the catchment is predicted to approximate 57,755.18 and 44,142.80 kg respectively the rainy and the dry season (Table 14). This corresponds to a daily consumption of 13.68 and 10.46 kg

Table 14. Model predictions for household firewood consumption as function of household polygons from VHR satellite imagery

	Households Daily Consumption at Catchment level			Total yearly Consumption at Catchment level
	Mean	SD	Sum	
Model1 (Rainy Season)	13.68	23.95	57755.18	6930622
Model2 (Dry Season)	10.46	7.54	44142.80	10814986
Total	**24.14**	**31.49**	**101898**	**17745608**

respectively for the rainy and the dry season. These model predictions also keep fit with the result of the paired sample t test asserting that the farmers consume more firewood in rainy season.

It is clear that such a wide spreading fuelwood consumption will have a direct consequence on the tree layer. This justifies the need for developing cleaner sources of energy. Such attempt should engage the local population on a participatory basis. Unfortunately, as stated by Konare et al. (2014), "*several projects to address fuelwood issues have failed because of misunderstandings between project managers and local people*." Nonetheless, it is worth to mention that during the study period, we noted an example of such alternative namely "projet Wanrou" which aim at reducing the current firewood consumption through sensitization, and implementation of a very low cost traditionally improved cookstoves. Such institutional supports are needed and the good news is that most of the women in the area are willing to adopt the technology. As they said, the cookstoves save a lot of firewood compared to the 3 stones one.

Another interesting aspect that we looked at in this study is the Carbon (C) stored and the corresponding Carbon dioxide (CO_2) sequestered by the trees in the study (Table 15). Likewise, the C loss and CO_2 emission due to firewood were investigated at yearly time scale. The result estimates the current potential for C sequestration of the parklands to approximate 125,237,265 C kg. This is equivalent to 459,620,764 CO_2 kg. Meanwhile, the households emit approximatively 8,475,580 C kg and 31,105,380 CO_2 kg per year.

Table 15. Carbon sequestration potential of trees and carbon emission threat from the households

	Mean	**SD**	**Total**
Total C storage potential of the trees (C kg)	410.0668	408.0792	125,237,265
Total CO2 sequestration potential of the trees (CO_2 kg)	1,504.945	1,497.65	459,620,764
Yearly C Loss due firewood (C kg)	2,007.956	1,731.283	8,475,580
Yearly CO2 Emission due firewood (CO_2 kg)	7,369.197	6,353.808	31,105,380

At glance, the average sequestration potential of individual trees and the mean household CO2 emission exhibit strong variability, as does the biomass and the dry wood, when compare to their respective standard deviations. This evidences the heterogeneity of the landscape. Very recently, Ouédraogo et al. (2015) evaluated the effects of human disturbance on tree populations in the Sudanian savanna, and found out that saplings are trapped and escape to mature vegetation only with difficulty. On the one hand, dendrometric parameters are naturally heterogeneous (Ponce-Hernandez, 2004; Aleza et al., 2015), on the other hand a size-class is relatively higher because of anthropogenic disturbance leading to size-class distributions (Ouédraogo et al., 2015; Aleza et al., 2015). Such heterogeneity is frequently encountered in ecological modelling (Chandra and Chambers, 2008). At plot level, the form of the distribution may be due to the influences of the farmers (like the recurrent bush fire trees are subject in the region) and the inherent heterogeneity of the species (Fletcher et al., 2005; Austin, 2007). Cross-checking the two sides (sequestration and emission), there is a reason to worry. For this reason, the next section will examine the sustainability of the consumption.

4.6.3. Sustainable consumption: Biomass Regrowth in a Context of Increasing Demography

Worrying about the burden of firewood consumption led us to examine the biomass regrowth (Table 16). The analysis of the data subsets, derived through quantile regression, results in increasing biomass amount between 1999 through 2009 to 2014.

Table 16. Trees' growth rates

Biomass (Kg)		**Growth Rate**	
		AGR (Kg/Year)	RGR
1999 (15 years before)	192,641.45	14499.86	0.0429
2009 (5 years before)	337,640.05		
2009 (5 years before)	337,640.05	80884.04	0.109
2014 (0 year before)	742,060.27		

- *Average RGR = 0.0759*

Considering the value of 0.0304 as the population growth rate in the study area (INSAE, 2013), the current tree growth rate (0.0759; taken as the mean on the two periods), assuming that both trees and peoples are growing following a geometric series, assuming that the rainy season lasts a period of 120 days in the study area (Houndénou and Hernandez, 1998), and everything being equal, we tried to perform some scenario upon a period of 200 years (Table 17).

Table 17. Climate and demographic changes Scenario

	Scenario0	Scenario1	Scenario2	Scenario3
Firewood Production	4.502671×10^{15}	4.502664×10^{15}	9.396095×10^{11}	9.396095×10^{11}
Firewood Consumption	7.083711×10^{9}	3.394562×10^{13}	7.083711×10^{9}	3.394562×10^{13}
Difference	4.502664×10^{15}	4.468726×10^{15}	9.325258×10^{11}	-3.30060×10^{13}

Scenario 1: Population Growth Rate reach Tree growth Rate (i.e. with population growth)

Scenario 2: Tree growth Rate decreases to Population Growth Rate (i.e. with Climate Change)

Scenario 3: Population Growth Rate reach Tree growth Rate and Tree growth Rate decreases to Population Growth Rate

The results showed that the current situation (senario0) seems to be sustainable. Nevertheless, playing with the growth rates, we realized the fragility of the equilibrium. Both population growth and Climate Change seem to impact the equilibrium. With these scenario, the impact of Climate seems to be more worrying than the impact of population growth in the study area. When considered at the time, the system is no longer sustainable as the difference between the firewood production (of the trees) and its consumption (by the households) yields a negative value. Like many authors (INSAE, 2013; Akouehou et al., 2011; Nikiema, 2005; Ouédraogo et al. 2015; Aleza et al., 2015), we therefore concluded that the adaptability of the system relies strictly on adapted management options.

4.7. Outlook

As noted, the use of Charcoal is uncommon in the study area. It is produced by some of the farmers for sales, but not really to be used in the villages. Mostly consumed in the countries towns, charcoal is exposed around the main road, and so it is accessible by passengers. In Dassari catchment, most of the cook stoves are designed to "run in firewood"; instead of charcoal. Although beyond the scope of this study, the charcoal production/consumption in the study area, seems to embed interesting aspects for further research. Further study need to be undertaken in order to enlighten the different aspects of its production, consumption, marketing, and more importantly its implication for sustainability. For methodological raison and time limitation, this study did not take into account the share of consumption attributed to “tchoukoutchou”, although very important. We therefore believe that further studies are needed to fill this gap.

Other parklands products like NTFPs and fodder are very importance and translate in to clear words the multi-functionality of agroforestry systems. These are also beyond this study but need to be investigated in details. Another important aspect to be investigated is the impact of trees on agricultural production as described in WaNuLCAS model which has already been calibrated by Coulibaly et al. (2015) for *Parkia biglobosa*, *Adamsonia digitata*, *Vitellaria paradoxa*. This is a good start but other parklands trees species of the Sudan savanna also need to be investigated.

Chapter 5. CONCLUSION AND POLICY RECOMMENDATION

In the study area, tree are used for at least 3 main purposes. The most important is firewood for domestic cooking (used by 100% of the households), the second is represented by a variety of NTFPs (used by 76% of the households). They are also used as fodder, although it is used only by 8% of the households. It is therefore worth noted that only firewood is worrying with regards to sustainability. To meet the goals of international policies such as REED (Reducing Emissions from Degradation and Deforestation), policies addressing lower firewood consumption are to be promoted especially when considering the galloping demography in the region.

The farmers consume more firewood in rainy season compared to dry season, and overestimate the overall quantity consumed. Also, most of them believe in the variability of firewood consumption although there is no clear trend in their sayings. Among the various reasons reported by the farmers, only household size is not climate-driven. Therefore, clean energy policies or any attempt towards a lower firewood consumption have to mainstream the current changing climate. Firewood is also obtained and used through different forms while the use of charcoal is very limited to relatively urban areas. Most of the firewood used by the farmers is obtained through tree branching (30%) while logging is very limited (17%).

In the study area, farmers prefer using *Combretum* shrubs species although not providing the best firewood for cooking; as does *Sarcocephalus latifolius* tree species. Given that the farmers have certain preferences with regards to plant species when it comes to firewood, more specific studies are needed in order to estimate the regeneration power of the most used species. Also, it will be important to disclose the reason why the best species in terms of firewood are not the most frequently used, although it is well known that the farmers select specific species towards this end. Collected mainly by women and children, important part of the firewood comes from the agricultural plots (parklands).

Trees in the study area constitute an important sources of carbon sink. Nevertheless, climate change associated with increasing demography seems to limit this performance. Therefore, policies towards reforestation, controlled population growth, cleaner sources of energy, etc. are urgently needed.

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