Sustainable Fuelwood Management in West Africa

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Foreword

The theme of this textbook, ‘Sustainable Fuelwood Management in West Africa’, focuses on one of the most significant aspects of global energy policy. Biomass in general, and especially dendromass, still has a key role as a source of renewable energy. Globally about two billion people are fully dependent on biomass-based energy in their daily life. Half a kilogram of wood per person is needed every day for cooking meals in households everywhere in the world. More than one half of the world’s wood consumption is related to fuelwoods. Typically, in developing countries fuelwoods may account for more than one half of the energy consumption. In many cases, the share of fuelwood may even reach up to 80–90 % of a country’s total energy demand.

This textbook offers relevant information and knowledge for understanding the urgent needs of sustainable forest management in West Africa and similarly in many other regions of the world. Families everywhere have to cook their food. For this they need energy. The available source for billions of inhabitants of the Global Village is dendromass. It is understandable that first people collect firewood of the highest quality for cooking. Due to the pressure of population growth and poor management of forests, the high-quality sources are becoming rare and people have to start using lower-quality firewood for their daily needs. This process will lead to a real energy poverty since families need to collect more and more wood to get the needed calorific energy output for their daily needs. This is a real renewable energy paradox and tragedy.

The biomass-based renewable energy paradox has been somehow realised in various global level discussions of top politicians. Already the United Nations Conference on the Human Environment, held in Stockholm in 1972, proclaimed that man with his power to ‘transform the environment in countless ways and on an unprecedented scale’ is both a ‘creature and moulder of his environment’ and laid down the principle that ‘the capacity of the earth to produce vital renewable resources must be maintained and, wherever practicable, restored or improved’. Two decades later, the United Nations Framework Convention on Climate Change (UNFCCC) made a very similar statement and asked industrialised countries to demonstrate their lead in developing sustainable and renewable energy technologies. The Report of IPCC (2014) says that "bioenergy can play a critical role in mitigation, but there are issues to consider, such as the sustainability of practices and the efficiency of the bioenergy systems". Further, the Paris agreement (2015) of UNFCCC (article5/2) stated that the parties are encouraged to take action to implement "policy approaches and positive incentives for activities relating to reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries".

Implementation of internationally agreed policies must be drastically directed to tackle energy poverty in any possible way. Training is a key action, which has to be available at each level of education from primary schools to universities. Together with information and knowledge related to modern and attractive sophisticated renewable energy technologies, such as solar and wind, also training on sustainable management of energy biomass resources must be available for people and communities who are suffering from energy poverty. Whenever investment opportunities exist, sophisticated technologies, or at least hybrid solutions of solar, wind and biomass, have to be seriously studied. However, one fact is that due to the population increase, especially in the poorest regions, the number of families who are continuously dependent on dendromass-based energy is only slightly decreasing, if at all.

Forest management is a tool for maintaining and developing dynamic relations between forests and man. Fuelwood or forest bioenergy together with several other uses of forest ecosystems and their products can be hundreds and hundreds of different things. Sustainable forest management applies a great number of societal fields such as administration, business and technology, as well as the elementary substance areas of forestry, such as silviculture, growth and yield, inventory, timber harvesting and extraction, work force, demand of refining, recreation, wildlife, aesthetics, urban forestry, etc. One of the greatest global challenges related to of all these activities is to forest hundreds of millions of tonnes of set-aside lands which have been covered by forests in the past. All these above mentioned issues are significant targets of training and education.

Innovations introduce new solutions for the needs of society and aim to improve also the forest-based energy welfare of citizens. The value of innovations is tested in markets and materialised through more consumer-friendly products and services and more efficient processes. Innovations may be related to social and technological development or may be something original and important for systemic progress. The originality and novelty lead to a fully new area through remarkable steps of development or they make it possible to improve existing products or processes through a relatively small but important method. Innovations may support mainstream R&D or may open an avenue of a new developmental paradigm. Many important innovations have been made throughout the history of forestry. One of the most famous and impressive innovations was made by the German forester Hans Carl von Carlowitz in 1713 when he presented the principles of sustainable forest management.

Stakeholders in various societal fields, such as forest or energy sector, continuously present numerous ideas, discoveries, inventions and even innovations. However, only a few of those will ever be implemented. John Maynard Keynes presented in the preface of his magnum opus “The General Theory of Employment, Interest and Money” one very crucial reason for low realisation rates. He stated that “the difficulty lies, not in the new ideas, but in escaping from the old ones, which ramify, for those brought up as most of us have been, into every corner of our minds”. For people living in real energy poverty, this escaping need not be an attempt to switch totally and immediately from biomass to sophisticated high-tech solutions. Instead, it may be a small step towards a more sustainable, healthy and economical way to utilise forest resources for energy in regions such as West Africa.

I wish a greatly innovative mind for every reader of this significant textbook!

Joensuu, August 2016

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Preface

Climate change, sustainably managed renewable raw materials and energy from biomass are some of the major challenges facing mankind in the 21st century. Globally, wood is the most important locally available renewable energy source for the human population. In Africa, fuelwood and charcoal production is the dominant use of woody biomass. When obtained from sustainably managed forests, the use of woody biomass can be seen with positive climatic and socio-economic effects.

This book originated from research undertaken as part of a project, Building Biocarbon and Rural Development in West Africa (BIODEV), implemented in 2012–2016 by a consortium composed of the World Agroforestry Centre (ICRAF), the Centre for International Forest Research (CIFOR), the University of Helsinki (UH), the University of Eastern Finland (UEF), along with national partners of which the most important ones were Sierra Leone Agricultural Institute (SLARi) and Environmental Institute for Agricultural Research (INERA) in Burkina Faso. The project activities have been concentrating on Burkina Faso and Sierra Leone; some activities have been carried out also in Guinea and Mali. The main aim of the project was to achieve sustainable rural development with long-term livelihood and environmental benefits to rural populations and the global community under climate change through science-based, validated and high-value biocarbon approaches. The project aimed also to form replicable high-value biocarbon tools in large landscapes.

The object of this publication is two-fold. Firstly, it provides a state-of-the-art scientific approach to the economic, social and environmental impacts of use of wood energy at a global level for national and regional R&D and educational organisations. Secondly, based on the practice-based research of the project, the book introduces methods and techniques for efficient fuelwood production to be applied to practical problems at a local level for natural resource users as well as local entrepreneurs and organisations. In addition to offering current scientific knowledge about global wood energy industry for researchers and policy makers, we hope that this publication will be useful as course material for training programmes and local development initiatives, especially at university level.

The book is presented in five chapters. For reader-friendly purposes, each chapter is written as an independent section. Chapter 1 provides a comprehensive approach to current conditions and trends in wood energy on a global scale, including discussion of socio-economic factors associated with the use of wood. Chapter 2 focuses on inventory of biomass and forest resources with useful calculation and modelling schemes. The purpose of Chapter 3 is to introduce simple, down-to-earth methods and techniques for efficient charcoal production in rural areas. Chapter 4 examines the bioeconomy aspects of local fuelwood industry, and finally, Chapter 5 discusses the sustainability of fuelwood production based on examples from target regions participating in the BIODEV project.

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List of Abbreviations

AA	*Afzelia Africana*
AGB	Above ground biomass
AM	*Acacia Mangium*
ATR	Attenuated total reflectance
BIODEV	Building Biocarbon and Rural Development in West Africa project
CAF	Chantiers d'Aménagement Forestier
C	Carbon
CC	Canopy cover
CC	Crown cover
CD	Crown diameter
CDR	Climate data record
CO_2	Carbon dioxide
csv	Comma separated values
CWD	Climatic water deficit
D	Diameter
DBH	Diameter at breast height
DG	*Dialium Guineensis*
€	Euro, European currency
E	Environmental stress
E	Exa
EEA	European Environmental Agency
EN	European standard
ETM+	Enhanced Thematic Mapper Plus
EU	European Union
F	Form factor
FAO	Food and Agriculture Organisation
FMG	Forest management group
FTIR	Fourier transform infrared
GA	*Gmelina Arborea*
GIS	Geographic information system
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GoSL	Government of Sierra Leone

GPS	Global positioning system
H	Height
ha	Hectare
ILUC	Indirect land use change
IPCC	The Intergovernmental Panel on Climate Change
IR	Infrared
J	Joule
k	Kilo
LDSF	Land degradation surveillance framework
LL	*Lophira Lanceolata*
LVH	Lower heating value
M	Mega
m-%	Mass-%
MEDD	Ministry of the Environment and Sustainable Development of Burkina Faso
MEF	Ministry of Economy and Finances of Burkina Faso
MEWR	Ministry of Energy and Water Resources of Sierra Leone
MIDGE	Modified inverted downdraft gasifier experiment
SNV	Netherlands Development Organisation
noCAF	outside CAF area
OLI	Operational land imager
Pa	Pascal
PS	Precipitation seasonality
q_{gross}	Gross calorific value
q_{net}	Net calorific value
R&D	Research and development
SFS	Finnish Standards Association
SFM	Sustainable forest management
t	Tonne
TS	Temperature seasonality
UK	United Kingdom
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
VC	Value chain
VCA	Value chain analysis
VDC	Village Development Committee
VOC	Volatile organic compound
W	Watt
w-%	Weight-%

Table of Contents

CHAPTER 1

Wood energy on a global scale 3

Wood energy on a global scale

Blas Mola-Yudego, Olalla Díaz-Yáñez, and Antti Haapala

1.1 Introduction

Wood has probably been the first fuel used by humans, for heating and cooking, and throughout history has been a strategic resource. During the industrial revolution, the use of wood-based resources grew exponentially until they were progressively replaced by coal and oil. Today, however, the use of wood for energy has experienced a huge transformation in terms of technological and economic efficiency, resulting in what we called *bioenergy*.

We can define bioenergy as a renewable energy that uses materials derived from biological sources. These sources are what we define as *biomass*, which entail any organic material that has stored sunlight in the form of chemical energy as carbon chains through the process of photosynthesis. In a way, biomass is similar to fossil fuels, as both are made of biological material. In the case of biomass, we only count living or recently living organisms, whereas for fossil fuels, we are making use of past biomass that was removed from the ecosystem cycles long ago.

In a second sense, biomass also refers to plant or animal matter that can be converted into fibrous products or other industrial chemicals, including *biofuels*. Although biomass encompasses multiple origins, most often the term refers to plants or plant-derived materials, specifically called lignocellulosic biomass. The most common biomass used for energy is wood from trees. At the same time, some of the biomass-based fuels used today also come in the form of dried vegetation, crop residues and aquatic plants.

In its broader sense, bioenergy refers and entails the study of biomass as well as the social, economic, scientific and technical fields associated with using biological sources for energy. The importance of bioenergy lies in its environmental and economic features: it is a renewable source of energy, it has a huge potential for the reduction of CO_2 emissions through the substitution of fossil fuels, it promotes CO_2 storage in vegetation and soil, it is more geographically accessible than fossil resources thus promoting energetic self-sufficiency, reducing the energy supply dependence from third-parties, and it can result in lower costs for the end user when the resources and proper technological conditions are available. For these reasons, among others, wood is becoming a widely utilised source of energy. Today, biomass accounts for almost 15% of the world's total energy supply and as much as 86% in some developing countries, mostly for cooking and heating (FAO 2016). Although biomass cannot replace our current dependence on coal, oil and natural gas on a global scale, it can complement other renewables such as solar and wind energy and locally can play a very important role in the energy mix of regions, where other energy sources are limited.

Nowadays, biomass can either be used directly via combustion to produce heat, or indirectly by transforming it to various other forms of biofuels. For instance, biomass can be converted into charcoal, as has been done throughout history, into bioalcohols (e.g. bioethanol), into oils (e.g. biodiesel) or even into biogas. The conversion of biomass to this wide range of biofuels is performed in different ways, which may include thermal, chemical and biochemical methods. For instance, wood can be subject to partial pyrolysis to produce charcoal. Bioethanol is made by fermenting the sugar components of some plant materials, and include the use of maize, sugarcane and sweet sorghum, among others. And the current technological developments are expanding the pool of raw materials and the level of refinement; today also trees and grasses can be used for ethanol.

1.2 Sources of biomass

Biomass as fuel may include wood, wood waste, straw, manure, sugarcane, and many other by-products from a variety of agricultural, silvicultural and forest industrial processes. In general, wood remains the largest biomass energy source today and examples include forest residues – such as dead trees, small size stems, branches and tree stumps – yard clippings, wood chips and even municipal solid waste. Industrial biomass (agriculture and energy crops) can be grown from numerous types of plants, including miscanthus, switchgrass, hemp, corn, poplar, willow, sorghum, sugarcane, bamboo, and a variety of tree species, ranging from eucalyptus to oil palm (Table 1).

Energy crops are cultivations aiming at maximising the production of biomass for energy. It can entail several alternatives: from annual crops, that can be used to produce liquid fuels for transportation, through the use of grain or oils, and heating fuels by using their by-products (e.g. straw), to short rotation bushes or trees grown to produce woody biomass that can be used for direct combustion to produce heat or electricity, or be the raw material of further chemical uses.

The industry also produces by-products that are the main source for fuels with higher energetic density, such as black liquor and pellets. Black liquor results from the pulp and paper industry during the process of delignification. There can be large quantities of these by-products; for instance, it is estimated that a single pulp mill can produce 1.7–1.8 t of dry solids of black liquor per tonne of pulp, and represents a combined potential energy supply of 250–500 MW (Larson et al., 2000). Pellets result from the sawmill industries, and consist of condensing by-products like sawdust into compact cylindrical shape pieces with low moisture content and a high calorific value. Since pellets present a regular geometric size, they can behave like a fluid, allowing automatisation and maintenance as easy as oil heating. They are often used in small boilers (<25 kW), particularly in Northern Europe (Selkimäki et al., 2010) and allow heating production at residential level. In Europe, pellet production has been estimated at around 11.5 Mt, often linked to sawmill industry cores in Northern and Central Europe (Mola-Yudego et al., 2014).

Table 1. Classification of biofuel sources by different characteristics. The focus of this chapter is on the highlighted sources.

Source				Use	Biomass type
Energy crop	**Biomass plantations (*Populus sp*, *Salix sp*...)**			Direct	Woody
	Energy grass			Direct	Herbaceous
Agriculture	Energy cereal crops			Direct	Herbaceous
	Energy grain			Direct	Herbaceous
	Straw			By-products	Herbaceous
	Horticulture			By-products	Other
Forest	Roundwood industry by-products	Saw-mills	Chips	By-products	Woody
			Bark	By-products	Woody
			Sawdust	By-products	Woody
			Cutter shavings	By-products	Woody
		Pulp-mills	Black liquor	By-products	Other
	Logging residues (branches, tops and stumps)			Direct	Woody
	Thinning (small trees)			Direct	Woody
Industrial by-products	Food processing residues			By-products	Other
	Animal by products			By-products	Other
End-use materials	Used wood			Recovered	Woody
	Used fibre products			Recovered	Herbaceous
	Used food product (seeds)			Recovered	Other

When considering the energy products or carriers, there is a close correlation between the price and energy content of woody fuel: crude logs being at one end of the price range, whereas much higher unit prices can be obtained from refined wood products that can deliver higher energy output. Definitions of different wood-derived energy products are versatile and they are often used in common language as synonyms. *Wood fuels* or *fuelwood* include all fuels consisting of wood matter. *Standardised fuelwoods* are considered to include products such as wood pellets, wood briquettes, wood chips, firewood, all wood collected for non-industrial use, e.g. in households and small commercial and public sector buildings. *Non-standardised fuelwoods*, in turn, include the segregated and often manually collected fuelwoods from gardens, parks, roadside, maintenance, vineyards, fruit orchards, hedges, used wood and demolition wood, etc. A special case of this group is *demolition wood*, which has in energy statistics normally been counted as recovered wood. This group includes the used wood (scrap wood) arising from demolition of buildings (roofs and floors, etc.) or civil engineering installations. *Used wood* is in energy statistics normally counted as recovered wood and it includes the mechanically treated wood from wooden packaging like pallets, etc.

The energy content of biomass, including wood, is characterised by a few basic concepts. The *calorific value* or *heating value* of wood and other fuels is defined as the amount of energy per unit mass or volume released on complete combustion. For this measure, there are two options: *gross calorific value* (q_{gross}) is a measured value of the specific energy of combustion for unit mass of a fuel burned in oxygen in a calorimetric bomb under the specified conditions. This measure is often labelled as *higher heating value*. Estimation of the water content in fuel can be problematic and therefore the term *calorific value* is to be intended as *net calorific value* (q_{net}) or *lower heating value* unless specified otherwise. This takes into account the water vaporisation during the calorimetric analysis as the amount of energy in wood needed to turn the water of the sample into vapour is not available for heat release. To calculate the difference, we need to know that water evaporation involves the consumption of 2.44 MJ per one kilo of water and the moisture content of the wood sample analysed. In addition to calorimetric values, the biomass mass is a significant factor when total energy availability is being assessed.

The energy content of wood has little variation in calorific value between species when tested at the same moisture content. The calorific heating value of dry matter varies slightly from one tree species to another (ca. 18–22 MJ kg^{-1}), being slightly higher in coniferous than in deciduous tree species. This is caused by the higher lignin and resin contents in coniferous species. Compared to cellulose (ca. 17.2–17.5 MJ kg^{-1}) and hemicellulose (ca. 16 MJ kg^{-1}), wood lignin has a much higher energy content (ca. 26–27 MJ kg^{-1}). There is significant variation between species in their moisture content when the timber is green, at the time of felling, and the rate at which this moisture is lost during seasoning. Some typical calorimetric values for biomass resources are summarised in Table 2.

Table 2. Heat content for various biomass fuels (dry weight basis)*

Fuel type and source	Higher heating value (MJ kg^{-1})	Lower heating value (MJ kg^{-1})
Woody crops		
Black locust	19.5–19.9	18.5
Eucalyptus	19.0–19.6	18.0
Hybrid poplar	19.0–19.7	17.7
Willow	18.6–19.7	16.7–18.4
Forest residues		
Hardwood	18.6–20.7	
Softwood	18.6–20.1	17.5–20.8

*Data from: Tillman, 1978; Jenkins, 1993; Jenkins et al., 1998.

Burning of oversized wood pieces also results in lower energy content per unit mass (tonne) of wood and the moisture enclosed in the wood restricts the burning reaction, resulting in a higher amount of ash, and reduces the practical heating value obtained from the wood. The importance of raw material moisture is significant also in the context of fuelwood use. Dry biomass has a greater heating value (or net energy potential), as it uses little of its energy to evaporate any moisture.

Compacted forms of biomass such as wood pellets and briquettes can also be used for combustion. Charred or other torrefacted wood products contain higher energy density (energy per unit mass) than dried wood, as the bound water and light volatile organic compounds (VOCs) included in the trees are released. The products are also lighter, which makes their transportation more efficient. The conventional charcoal is a perfect example of a charred energy product and the residue of making charcoal can be further utilised in making charred pellets and briquettes. The production of charcoal briquettes consists of a few simple stages: grinding of charcoal, the preparation of briquette mass, briquetting using high pressure (ca. 5 MPa) and drying. The outcome is a high-quality fuel with high mechanical strength (6.9–9.8 MPa), high density (0.9–1 g cm^{-3}), high calorific value (30–32 MJ kg^{-1}) and low water absorbency (Koverninskiy, 2002). In addition to ground charcoal, only some binders are used to make the briquette stabile and compact. These can be some leftover products of thermal processing of solid fuels and oil refining or food processing plant materials – typically starch or lignin rich fractions including dextrin, starch, molasses, lignosulphonate or willow pitch. Other compacted forms, like black liquor, may actually have lower heating values (LHV, 12.3 MJ/kg^{-1}) due to the presence of inorganic chemicals (45%) resulting from the process of delignification (Naqvi et al., 2010)

1.2.1 Forest biomass

Forest biomass is today the largest source of woody biomass in most of the world. The use of forest biomass for energy is still increasing and it is expected to continue in the near future. Technological developments have significantly improved efficiency when using fuelwood, making wood biomass the most used source of renewable energy in the EU. Forest-based biomass for energy represents a great opportunity to promote forestry in countries with a less developed or non-existent forest sector.

However, wood for energy is a local source, and its utilisation greatly depends on what is locally available. In addition, management practices (silvicultural treatments) greatly affect the amount of forest biomass that may be available for bioenergy. For example, thinning regimes designed to obtain valuable timber wood result in varying amounts of small diameter trees as a by-product that could be used for bioenergy. At the same time, the valorisation of biomass fractions that can be used for energy (and that otherwise would have no market) can make silvicultural treatments more cost-efficient. In certain areas, that means that the demand of low-quality biomass, based on very small diameters for energy, result in pre-commercial thinnings decreasing e.g. the risk of forest fire, or the use of logging residues and stumps as fuelwood could be a way of developing post-harvesting management practices.

There are several assortments that can be used for energy and involve a variety of forest operations and machinery. Currently, the main source for producing forest chips for energy in Europe is logging residues, representing 41% of the sources of forest chips, and whole trees or stemwood from pre-commercial thinning, representing 21% of the sources (Díaz-Yáñez et al., 2013). This wood biomass follows a chain of operations from the forest to the bioenergy plant (*procurement chain*) which varies from country to country depending on the local conditions, location of the forest areas, market structure and machinery availability, among others.

Each biomass assortment typically follows a different procurement chain. In Europe, the most extended procurement chain for logging residues from final fellings involves felling/cutting by harvester, forwarding and skidding by forwarder, chipping or crushing at the roadside and transportation by truck to the plant. In the case of pre-commercial thinning are felling/cutting by harvester, forwarding and skidding by forwarder, chipping or crushing at the roadside and transportation by truck. The most typical procurement chain for the five countries that use this source (Germany, Poland, Lithuania, Norway and the UK) concerning industrial roundwood from final fellings is felling/cutting by harvester, forwarding and skidding by forwarder, transportation by truck and chipping or crushing at the terminal. Concerning industrial roundwood from thinning, it is different in the four countries that use this source (Germany, Poland, Sweden and the UK). Germany and Poland chipped at the plant, Sweden at the terminal and the UK at the roadside. Finally, concerning other sources of biomass as roots and stumps from final fellings, only a few countries consider effectively their use to produce forest chips for energy, mostly due to environmental concerns.

1.2.2 Wood energy plantations

Plantations can also deliver large amounts of wood for energy or other industrial purposes (Figure 1). The recent goals in energy policy, linked to ambitious plans for fossil fuel substitution, may require large amounts of wood. In this context, plantations will play an increasingly important role. The European Environmental Agency (EEA) stressed the potential that short rotation plantations can play in the biomass supply for energy in the EU (Wiesenthal & Mourelatou, 2006), which can account for a substantial part of the environmentally-compatible agricultural bioenergy supply, and with a potential that can out-match the forest-based estimates by 2030. Arguably, in countries with better climatic conditions for agriculture and limited forest resources, its future role can become more relevant than the forest based potential.

Figure 1. Short rotation forestry for energy: a willow plantation on agricultural land in Central Sweden. Photograph by Blas Mola-Yudego.

There are different types of wood energy plantations, and short rotation forestry has been among the already most established commercially (see figures at FAO, 2008). We can define short rotation forestry as plantations with fast-growing tree species and rotations shorter than 20–25 years. Although traditionally used for pulp production, in the last decades a growing number of plantations have been established to produce wood biomass for energy, commonly in the form of direct combustion to produce heat and/or electricity. Short rotation plantations are mainly practiced on agricultural land and its management (e.g. density planted, fertilisation, harvesting cycles, etc.) is less intensive than conventional agricultural crops but more intensive than conventional forestry.

In Europe, one of the first countries considering the option of using short rotation forestry schemes for energy on a commercial scale was Sweden. In the 1970s, along with concerns over energy dependency from oil, the country started several research initiatives on the plant biology and stand ecology of fast-growing tree species for the production of energy. Initially, there were tests for alder, birch, poplar and willow, among others. These early initiatives concluded that willow presented some advantages that eventually made it the preferred candidate for use in Nordic conditions. The management regime was established on its potential to be grown in coppice with re-growth after harvest. In the 1980s, the establishment of the first commercial plantations took place, growing exponentially until the 2000s when they reached c. 16,000 ha (some details of this development can be found in Mola-Yudego & Gonzalez Olabarria, 2010). This made Sweden the leader of short rotation forestry both in area and in experience with this type of cultivations.

In recent years, other countries have implemented similar plans to establish short rotation plantations for energy, e.g. by the middle 2000s willow was established in the UK, Poland and Germany, reaching sizable areas. Moreover, other species were practiced, such as poplar (e.g. Italy, Germany, France, Spain, Sweden), hybrid aspen (e.g. Estonia), eucalyptus (e.g. Spain, Portugal, the UK), robinia, (e.g. Hungary), paulownia (e.g. Spain), depending on the local climatic conditions.

All these species share characteristics that favour its use for energy production. All of them are, by definition, high yielding, as sustained and reliable yield is a key factor for the success of energy schemes based on plantations (Mola-Yudego et al., 2014). Some country averages range from 4.5 m^3 ha^{-1} $year^{-1}$ in Portugal to 24.5 in Germany, 25.7 m^3 ha^{-1} $year^{-1}$ in Belgium and 27 m^3 ha^{-1} $year^{-1}$ in the Netherlands (Figure 2) (combining reports in Ericsson and Nilsson, 2006, Mola-Yudego, 2010). In addition, these plantation schemes provide large amounts of lignocelluloses shortly after establishment, and have a broad genetic base. Some are easy to breed through vegetative propagation, some can have the ability of re-growth even after multiple harvests, and in general low economic investments are required after their establishment. Harvesting is usually conducted every three to five years for willow (Mola-Yudego & Aronsson, 2008), but other species like poplar have longer rotations (Dimitriou & Mola-Yudego, 2016).

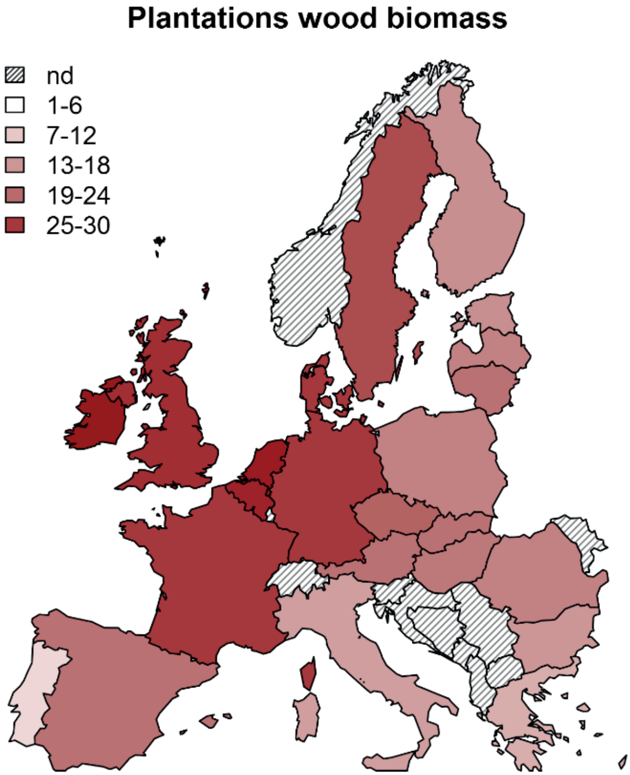

Figure 2. Estimates of country average yields of wood biomass for energy from short rotation plantations (m^3 ha^{-1} $year^{-1}$) in Europe. The boundaries used in this map do not imply endorsement or acceptance by the authors.

It must be noticed that, besides their role in substituting fossil fuels, wood energy plantations can provide multiple benefits, as they mean more efficient land use management, present positive effects on rural economies, contribute to a more diversified crop alternative, and present several environmental applications concerning wastewater treatment and environmental control and biodiversity, e.g. improved water quality in terms of nutrient leaching (e.g. Dimitriou et al., 2012a), improved soil quality in terms of increased carbon storage and decreased heavy metals (e.g. Dimitriou et al., 2012b), and higher phyto- and zoodiversity when compared to traditional agricultural crops (see summary in Langeveld et al., 2012). Furthermore, fast-growing plantation schemes have been used to treat and utilise municipal and industrial wastewaters and municipal sludge, or for soil phytoremediation from heavy metals, producing not only biomass but also environmental services, providing additional business opportunities. These positive externalities must be taken into consideration to expand planted areas, especially when they come into agreement with environmental and socio-economical goals. On the other hand, plantations compete with existing land uses, like food production, which must be carefully examined before implementing large-scale programmes.

The percentage of agricultural land that can be dedicated to fast-growing plantations is therefore a fundamental question that must be studied, since it frames the potential disruptions that plantations can have on agricultural markets and sets their effective dimension as a source of wood biomass for energy. Some regulations may, therefore, restrict its expansion beyond a point that can harm the environment or the economy. However, the current incipient state of plantations in many countries rather calls for policies to encourage their development (e.g. an example of the effect of policies in the areas planted can be found in Mola-Yudego & Pelkonen, 2008).

The expansion of plantations is mostly driven by the adoption of the cropping system by farmers or local agents, and those are influenced by the economic and policy framework (Mola-Yudego et al., 2014). One clear incentive to attract farmers to adopt energy crops is the profitability of the cultivation, which is linked to the revenues of the wood chips, the management costs and, also, the local perception about the crop. However, in most areas energy crops are a new cultivation that involve among others, new machines, practices and varieties, and this translates into additional risks to be taken by farmers or local agents. There are higher chances that the varieties are not well adapted to specific conditions, that tending practices are not well performed or that machines present problems, all due to lack of experience with the cultivation. In addition, due to their novelty, the market conditions may be more volatile than in well-established crops (e.g. cereal). Proper policies are, therefore, necessary to create the proper conditions for the development of stable markets and to convince farmers that the production of the crop will be reliable, will not result in failure, and prices will be high enough during the next years to compensate the investments.

1.3 Wood biomass potentials: forest and plantations

An accurate estimation of biomass potentials is fundamental to successful energy planning. For that, the nature and characteristics of both forest and plantation-based biomass must be considered. Forest wood biomass for energy includes all those biomass fractions that traditionally are not used for industrial purposes or that, due to some management limitations (e.g. lack of machinery for small diameters), are left in the forest. At stand level, this includes small diameter trees and dead trees, which are cut in pre-commercial thinning. At tree level, it entails those parts that are harvested but are not used for industrial purposes. In order to estimate biomass potentials in forests, we need to estimate how much biomass we would obtain from the stand in the form of small diameters through pre-commercial thinning and dead trees, and we therefore need to estimate the amount of biomass that is allocated outside the *merchantable-stem* in e.g. branches, tops, stumps, roots, etc.

This can be done at stand level estimating how the diameter distribution will proceed and designing forest management plans that consider small diameters for energy use, at tree level, using *allometric* equations, which aim at predicting how biomass is distributed in the tree. These equations, however, depend of the age of the tree and the species. For instance, a 30-year-old Scots pine in Finland allocates 71.3% of the biomass on the stem, 15% on live branches, 6% on dead branches and 7.7% in foliage. A similar Norway spruce tree allocates 68.2% of the biomass on the stem, 15.5% on live branches, 2.3% on dead branches and 12.3% on foliage (Hakkila, 1991). These figures change along the years, as trees allocate more biomass on the stem at the expense of foliage, and the amount of dead branches decreases significantly when the tree is mature (i.e. 80 years). In addition, these fractions have different energetic content. For the same trees used as example, the stem heating value (dry mass) of the stem is 19.3 and 19 MJ kg^{-1} for pine and spruce, respectively, whereas for branches it increases to 20 and 19.7 MJ kg^{-1} and for foliage, to 21 and 19.2 MJ kg^{-1}, respectively (Nurmi, 1993).

Many studies estimate forest-based biomass for energy at country or regional level, deriving these fractions from existing national statistics on wood removals and forest inventories. However, the various parameters to be estimated often lead to assumptions in order to simplify the calculations, especially when done on a large scale, e.g. by using general expansion factors that consider these fractions as fixed percentages of the total removals, according to species. However, it must be taken into account that, in some cases, wood harvests are below the growing rate of the forests (annual net increment); thus there is additional biomass that can be harvested in the future and is not being currently used (for economic or other reasons). More accurate estimates should not only consider current removal rates but also the maximum amount of forest harvests that could be performed sustainably. Once put all together, these fractions will render us with a reasonable estimate of biomass that could be retrieved for energy; the theoretical potential of the forest.

At the same time, assumptions need to be made to differentiate this theoretical potential (all biomass that can be used for energy) from the available potential, which include limitations concerning machines, protected areas, accessibility criteria (i.e. slopes), etc. Each limitation considered translated in a reduction factor that is applied to the theoretical potential. There is a large variety of allometric equations to be used, assumptions applied to the different steps and the portfolios of limitations considered can be different. This means that there can be differences between the estimates of biomass potentials among different studies, and special attention should be paid to the methods used in each of them.

At the global level, the theoretical potential associated to forest and excluding plantations is estimated to be 6100 Mm^3 (71 EJ) of wood biomass surplus available for energy in 2050 (Smeets & Faaij, 2007). Out of this figure, however, the technical potential is reduced to 5500 Mm^3 (64 EJ); the economic considerations would further reduce it to 1300 Mm^3 $year^{-1}$ (15 EJ $year^{-1}$). Finally, ecological restrictions would leave it at 700 Mm^3 $year^{-1}$ (8 EJ $year^{-1}$). In addition, logging and processing residues and wastes can produce 2400 Mm^3 (28 EJ) of wood. This is a large figure, especially taking into account that it does not include forest plantations, and shows that forests can serve as a major raw material supply for energy in the near future.

In addition to the wood potential from forest lands, plantations must be also considered in calculations for overall potentials. In this case, however, the main parameters to be estimated refer to the total yield of the plantations, irrespective of the fractions and allocation of biomass in the trees, since all the biomass produced will be used as fuels. There are also several species that can be used in fast-growing systems, and each of them may have different growth patterns and regional optima. In addition, it must be taken into account that there are constant improvements concerning plant material and management methods that result in yield increases (e.g. in Sweden, Mola-Yudego, 2011). Plantation productivity, however, is not the only parameter to estimate in order to retrieve the potential; it is necessary to establish an assumption concerning the percentage of current agricultural land that can be dedicated to fast-growing plantations for energy.

1.3.1 Potentials in Europe

There is a large potential of forest biomass. In practically all EU countries the current energy use from biomass is less than the resources, although some studies point out that this can change in the near future (Mantau, 2010). At European level, Karjalainen et al. (2004), Asikainen et al. (2008) and Anttila et al. (2009) have produced theoretical and available potentials for all the countries, under different conditions and scenarios. The leading producers for potential of energy from forest biomass are located in Northern Europe (Figure 3) and are the countries with bigger forested areas. These countries (France, Sweden, Germany, Finland and Poland) produce 58% of the total primary energy production coming from solid biomass. But the big divergence among the potential estimations of the different countries and studies is also a fact as they use divergent methodologies, assumptions, constraints and biomass categories.

Concerning plantations, currently the largest extent of commercial plantations in Europe is Sweden, (entailing about 0.45% of the arable land of the country), followed by Denmark (0.22%), the Netherlands (0.18%), Italy (0.15%), Estonia (0.11%). Germany and the UK also present significant areas planted, but only account for 0.04% and 0.07% of the arable land. Some studies have estimated the percentage taking into account current land use utilisation, production trends and ecological restrictions, among others. For example, in Germany, Aust et al. (2014) suggested 5.7% of agricultural land for fast-growing plantations, and in Sweden, Naturvårdsverket (1998) suggested 14% of the Swedish arable land could be used for energy plantations by 2021.

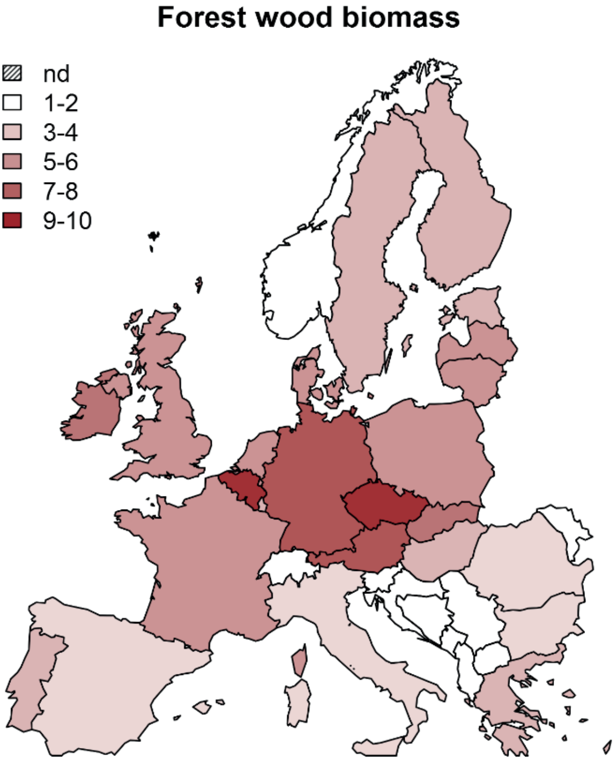

Figure 3. Estimates of country average yields for forest wood biomass for energy, including forest residues, small stems, stumps and roots, restricted to available resources (m^3 ha^{-1} year^{-1}). The boundaries used on this map do not imply endorsement or acceptance by the authors.

All in all, the average estimates in the EU for current conditions above ground biomass are estimated to be as high as 600 Mm^3, and a total theoretical potential to be over 900 Mm^3, but different limitations can reduce the realisation of this potential into usable biomass for energy (Díaz-Yánez et al., 2011). Including these limitations, and combining estimates for forest and plantation biomass for energy for all the EU countries (Figure 4), we estimate 75 Mm^3 in Germany, 70 Mm^3 in Sweden, 65 Mm^3 in France and 56 Mm^3 in Finland for a total 485 Mm^3. This is calculated using only currently available forest biomass according to Karjalainen et al. (2004) and Asikainen et al. (2008), as well as our own databases of plantation yields for all the EU countries (which include our own yield estimates) assuming a fixed 5% of agricultural land is used for plantation schemes.

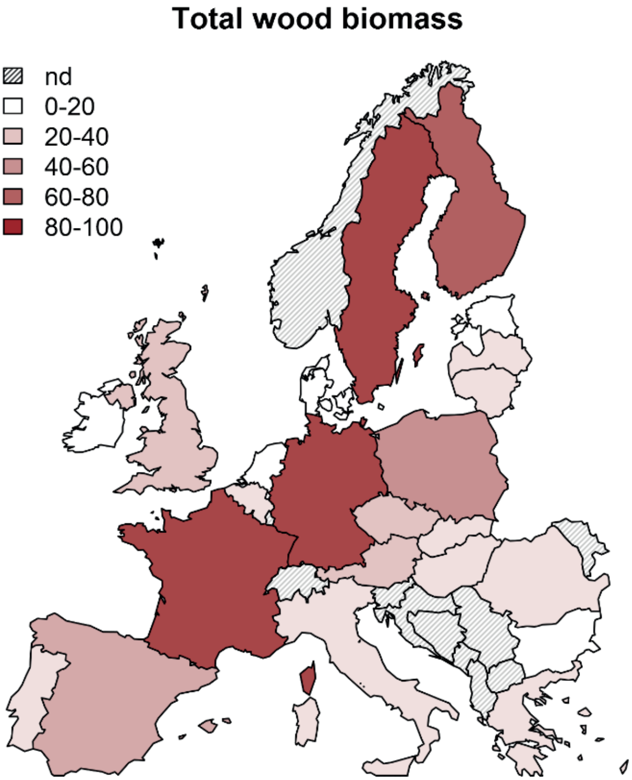

Figure 4. Total wood biomass potentials in Europe entailing plantations and forest sources, in Mm³. The boundaries used on this map do not imply endorsement or acceptance by the authors.

1.3.2 Potentials in Africa

African fuelwood and charcoal production is the predominant use of woody biomass in many countries. The production of wood products is in this context not much refined, and the value chain tends to be short. However, the cost of the end product remains reasonably low and its end use requires no specific furnaces. In order to understand wood energy production in Africa we need to look to the trends in forest resources, location and uses. Africa still has a negative trend in forest area and growing stock. Although the negative tendency has decreased in the period 2010–2014 (FAO 2015), removals are still higher than the annual net increment. On the other hand, planted forests are increasing. Today, several plantations in Africa have as primary objective the production of energy.

In Africa, forests and woodlands are unevenly distributed making sources for energy also scattered across the continent. Forest resources are mainly located in western, southern and central Africa. The countries with the highest average growing stock per hectare are Côte d'Ivoire, Cameroon, Gabon, Republic of the Congo, Democratic Republic of the Congo, Kenya and Madagascar (FAO 2015).

In this context, it should be noted that Africa's wood production is increasing, which includes industrial roundwood production and wood fuel. For obvious reasons, North Africa is the sub-region with less wood removals, while east, central, west and south have most of the forest removals. Wood for energy production is also mainly coming from these areas. Compared to the world average, where about half of the forest removals are used as wood fuel, in Africa this percentage is around 90% (Figure 5). The demand of wood products is likely to remain constant in Africa, contrary to what is expected at the global level, whereas wood as a renewable source of energy will most likely continue

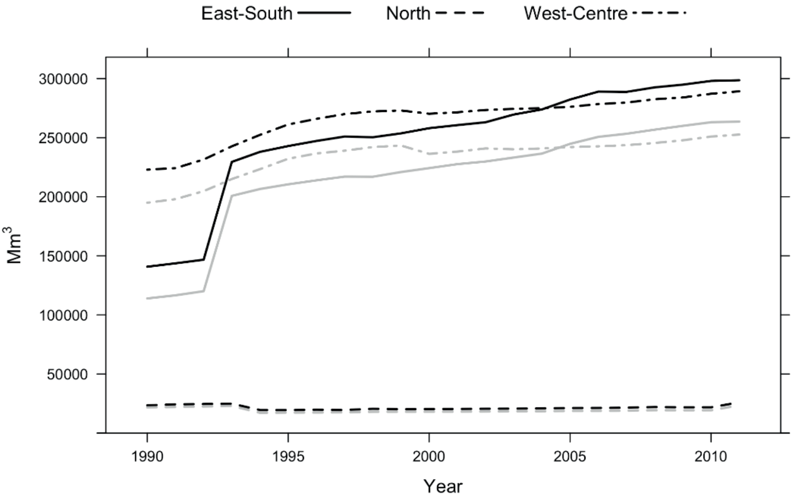

Figure 5. Total removals Mm³ (black) and wood fuel use as a part of the total removals (grey) for Africa. The geographical distribution and data has been obtained from FAOSTAT data (FAO 2015).

By country, the wood potential for energy ranges between nearly none to 9 Mm^3 (Figure 6). The highest potentials are in South Africa, Nigeria and Côte d'Ivoire, corresponding to countries with large, accessible forest areas. The lowest are in Libya, Mauritania, Liberia, Togo and Namibia, with more limited forest lands. If we compare the African sub-regions, West and Central Africa have the highest wood potentials for energy. These countries have experienced a steady increment in the utilisation of wood fuels compared to southern areas of the continent.

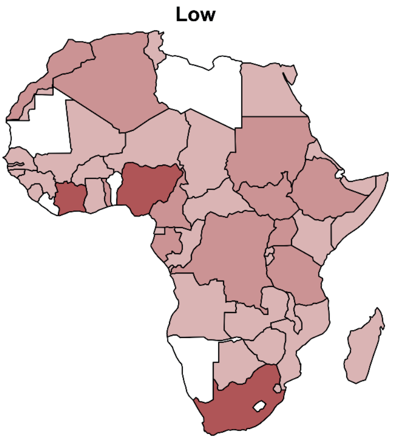

Figure 6. Technical potentials for modern fuelwood in Africa (Mm^3) for 2005, considering highest and lowest estimates (Anttila et al., 2009). The boundaries used on this map do not imply endorsement or acceptance by the authors.

We must take into account that countries with the highest growing stock per hectare are not necessarily those presenting the highest wood potentials for energy. This is due to the inclusion of technical restrictions for wood recovering and mechanised harvesting. In this respect, South Africa is one of the countries with highest biomass for energy potential. The technical potential for modern fuelwood in South Africa for 2005 was estimated in 9 Mm^3 (at the highest end of the estimation), and the potential of forest chips for energy was estimated in 2 Mm^3. In this area, the typical procurement chain of forest chips for energy will be followed by manual felling/cutting, forwarding and skidding by skidder, chipping or crushing at the plant and transportation by truck (Figure 7), which reflects a lower level of mechanisation than the most common procurement chains in Europe (Díaz-Yáñez et al., 2013).

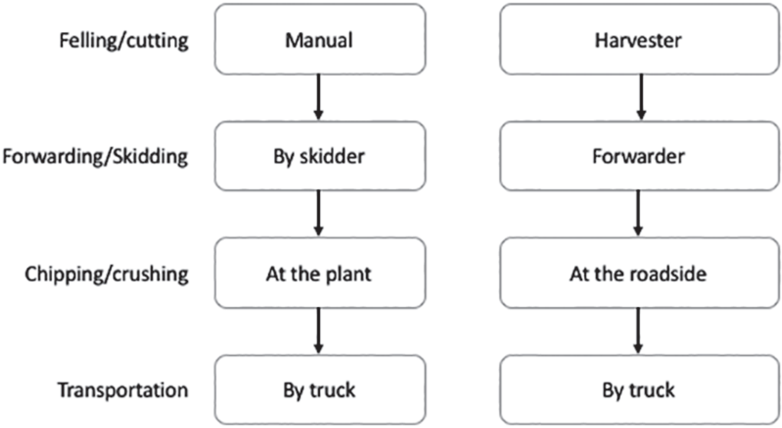

Figure 7. Typical procurement chain of forest chips for energy from industrial roundwood from final fellings in South Africa (left) compared to the most common chain in Europe (right).

There are unused large wood potentials for energy in Africa and there are trends of a progressive realisation into effective energy production. However, bioenergy development implies an intensification of the utilisation of natural resources and it is, therefore, not exempt from criticism. Many forest and land use conflicts have been studied directly related to bioenergy utilisation (Gritten & Mola-Yudego, 2011), particularly in Africa (Gritten et al., 2013). There are five main issues that have been identified as the main drivers of conflict associated to bioenergy utilisation (Arevalo et al., 2014a; 2014b). Firstly, bioenergy plantation conflicts centred on the establishment and/or management of plantations for the production of energy (Smalley & Corbera, 2012). Secondly, biomass extraction conflicts centred around the extraction of biomass, typically from forests, for energy use, as is the case for the use of logging residues and stumps (Global Forest Coalition, 2010). Thirdly, illegal biomass extraction conflicts, for example the illegal charcoal burning taking place in many Sub-Saharan countries (Zulu, 2010). Fourthly, bioenergy transformation conflicts centred on issues associated with the transformation process of the feedstock into energy (including the processing at power plants and the transportation in and out of those plants), as is the case in the conflict around a UK biomass gasification plant described by Upreti and Horst (2004). Finally, the bioenergy governance conflicts centred on the impact of policies, trade interests, market and other governance processes (e.g. sustainability criteria, certification, boycotts) over bioenergy developments that affect issues such as indirect land use change (ILUC) or food prices (e.g. Pye, 2010).

In this sense, there has recently been concern in African countries over large-scale plantations for first generation biofuels from food crops (e.g. maize, sugar cane), as well as from inedible oily seeds like *jatropha*. The sustainability of these developments, often promoted by international investors and for international markets, has been criticised. Some of the criticism includes issues with the consultation or participation of local communities, the establishment of plantations ahead of proper technical and market feasibility studies, and the negative impacts with respect to climate change and biodiversity. In fact, biofuel developments have been shown to be drivers of deforestation in areas of Kenya (Arevalo et al., 2014) Latin America, South-East Asia and Sub-Saharan Africa. As an example, an estimated deforestation in Mato Grosso (Brazil) attributed to soybean production for biodiesel has reached as high as 6% annually (Gao et al., 2011).

There is a large potential for the development of a competitive bioenergy sector in Africa that provides environmentally-friendly and cost-efficient energy, as well as other positive externalities. However, this development is attached to challenges for its success that entail technological solutions, social and economical measures, and an effective governance and policy framework, among others. Despite the risks and problems to be overcome, the experience in pioneer countries, in Europe and elsewhere, prove that this development is both feasible and beneficial.

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CHAPTER 2

Inventory of biomass and forest resources..............29

Inventory of biomass and forest resources

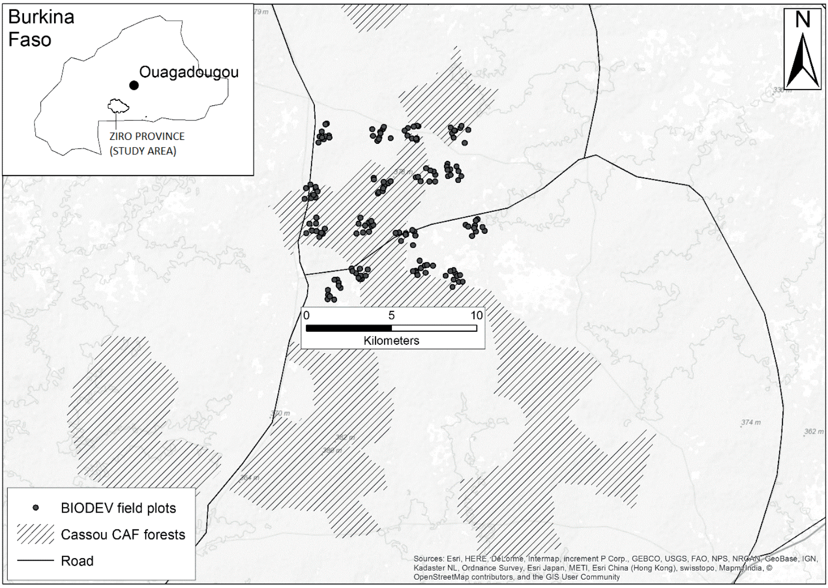
Markus Melin, Janne Heiskanen, Petteri Packalen and Ruben Valbuena

Forest inventories provide the base knowledge needed for forest planning and management. The measurements can be made for a single forest stand or they can cover an entire nation, as with National Forest Inventories. The core idea is that when done properly, the measurements provide objective and statistically valid information about the status of the target area's forests, which then is of decisive importance when planning the future use of these forests. This importance was also realised in the BIODEV project and so field inventories of forest resources were conducted in the target countries of Burkina Faso and Sierra Leone to gain more insights into the status of the forests. This chapter summarises the methods of inventory, calculations, as well as the results and a case study where the measured information was integrated with remote sensing data.

2.1 Study areas

Forest inventories provide the key information needed to make sound and sustainable forest policies at the local as well as global level. A noted problem in both of the target countries was the lack of objective, measured information about the status and abundance of forest resources. In the BIODEV project, this information was needed to assess the amount of fuelwood as well as carbon stocks. Therefore, forest inventories were carried out in both countries at two distinct target sites, one in each country.

In Burkina Faso, the study area is located in the southern part of the country, Ziro province. The study area and its location are shown in Figure 1.



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, Mapmyindia, © OpenStreetMap contributors, and the GIS User Community

Figure 1. Map of Burkina Faso showing the study area and BIODEV field plots.

The land cover in the area consists of savanna woodlands with variable densities of tree crown cover, surrounded by settlements and agroforestry parklands, which are typically dominated by single species, like *Vitellaria paradoxa* (Boffa 1999). The majority of the forest area in the Ziro province is under community forest management and protection (Chantiers d'Aménagement Forestier, CAF), a 1986 participatory programme aiming at providing sustainable fuelwood production for the capital Ouagadougou, which involves the local communities in the practical management of forests (Coulibaly-Lingani et al., 2011).

In Sierra Leone, the study area was located in the northern province, in the Bombali district. The study area and the field plots are shown in Figure 2.

The forests in Northern Sierra Leone are, according to the Government of Sierra Leone (GoSL, 2014), classified as moist semi-deciduous forest. Outside of the forested areas, the north is represented by savanna woodlands.

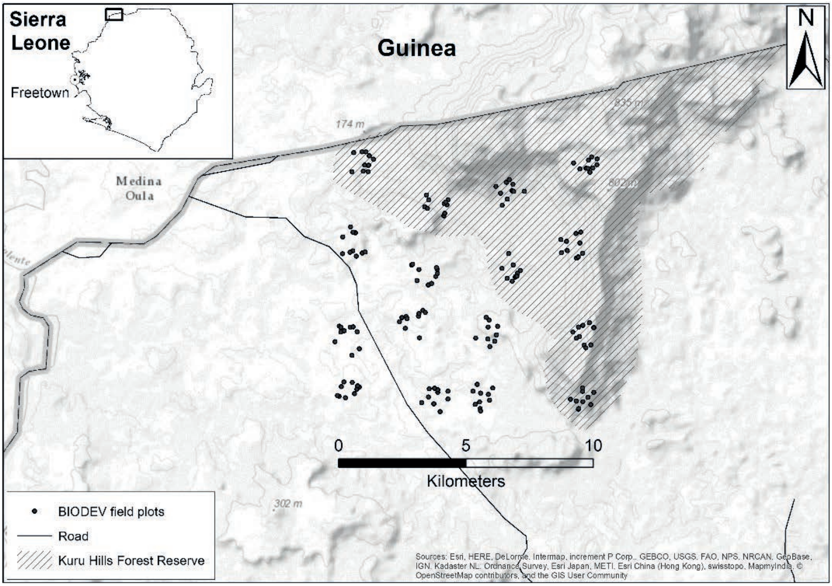


Figure 2. Map of Sierra Leone showing the study area and BIODEV field plots.

What was common for both study areas was that the layout of the field plots allowed us to make comparisons between forest reserve and surroundings. The forest structures between these classes were compared in relation to the types of trees growing in the areas (species distribution), their structure (diameter at breast height, DBH, and height) and quantity (stems ha^{-1}) as well as total volume of both, living and deadwood (m^3 ha^{-1}). In Burkina Faso (Figure 1), the plots were located both inside and outside of the managed CAF forests, which allowed us to estimate whether the CAF forests were different from private ones and whether the abundance of forest resources in general differed between the two cases. In Sierra Leone, the plots were similarly located inside and outside of Kuru Hills Forest Reserve, which made it possible to assess the human-induced differences in forest structure and species distribution, because the Kuru Hills are rather inaccessible due to their steep slopes and rugged terrain (not as much agriculture and wood harvesting, except for the plain areas). This was a natural focus of the upcoming analysis: to assess how good the situation could be. Figures 3 and 4 show examples of both countries' forests in a semi-natural state, when not over harvested.

The images show that the capabilities for increased wood production already exist; the forests would do well if they were maintained well. Similar observations were made also during the field campaign.

Figure 3. Planted forest in Ouagadougou where the understory has been cleared, but where the dominant layer has been preserved from cutting. Photograph by Markus Melin.

Figure 4. Natural forests in northern Sierra Leone still have some of the giant trees growing (left). A planted forest on the Njala University campus at the age of just five years (right). Photographs by Janne Heiskanen (left) and Markus Melin (right).

2.2 The inventory scheme and field measurements

The field data for Burkina Faso was collected between December 2013 and May 2014. Sierra Leone data was collected between March and July 2014. The sampling design in both areas followed that of the Land Degradation Surveillance Framework (LDSF) (Vågen et al., 2010). In this design, 160 plots are placed in a 10 km x 10 km square, which is further divided into 16 tiles (2.5 km x 2.5 km) forming a regular grid inside the 10 km x 10 km area. Next, the centre point of a 1-km^2 circle is randomly placed inside each tile and then 10 plots are randomly placed within this circle. Now, each tile has 10 circular plots, with a radius of 17.84 m (0.1 ha area). In addition, four sub-plots with a radius of 5.64 m (0.01 ha) are placed inside the 0.1 ha plots so that one plot is placed in the centre and the three others 12.2 m away from the centre, evenly distributed. The outcome is a spatially stratified and randomised sampling design. Figure 5 shows an example of the sampling design. Figure 6 shows the sample plot design.

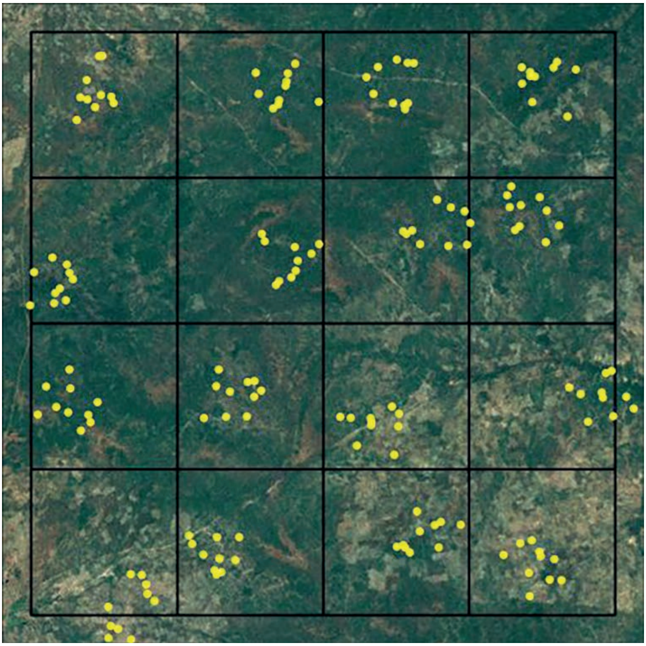


Figure 5. The BIODEV site in Burkina Faso showing the sampling design. 16 tiles, each tile is 2.5 km x 2.5 km. (Heiskanen et al., 2013)

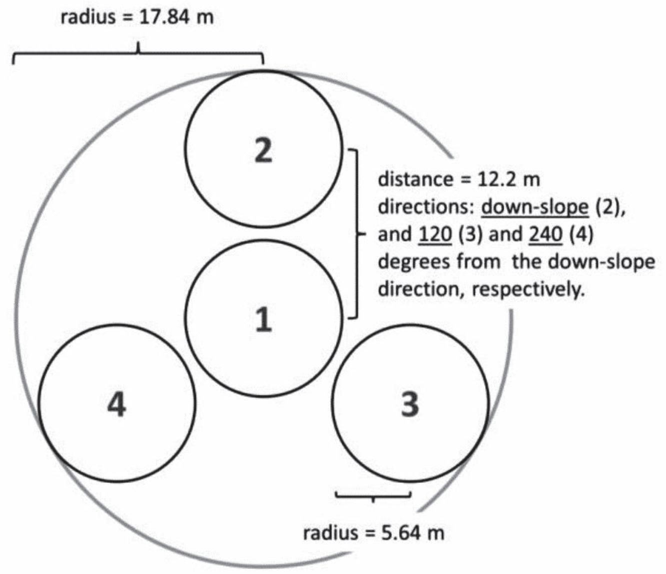


Figure 6. The 0.01 ha sub-plots organised inside the 0.1 ha main plot (outermost circle). (Heiskanen et al., 2013)

In each of the 0.1 ha plots (big plot), tree species and diameters at breast height (1.3 m, DBH) were measured for all the trees with a DBH > 10 cm. Height and crown diameter were then measured for the smallest, largest and median trees (in relation to DBH). The 0.01 ha sub-plots were used to measure smaller trees and shrubs. In the sub-plots, all the trees with a DBH between 4 and 10 cm were counted, and height, diameter and species were recorded for the median tree (in relation to DBH). Diameters were measured with diameter tapes and calipers; heights with a hypsometer (Suunto PM-5/1520). Crown diameters were measured with a measurement tape by taking two crosswise measurements (one from the direction with the largest diameter and another perpendicular to it). The widths of the crown were determined by visual vertical sights. Additional measured variables were amounts of deadwood (standing or downed). Standing dead trees with a DBH > 10 cm were measured from the big plots. Those standing dead trees with a DBH between 4 and 10 cm were counted from the sub-plots and the DBH was estimated for the median tree. Downed deadwood was measured in the sub-plots. Every piece with a diameter > 4 cm was measured for diameter and length. The diameter was always measured from the middle point of the piece that was located inside the sub-plot. Similarly, the length was only recorded for the part of the piece inside the plot. Decay class was also recorded for the downed dead trees (recently fallen, partly rotten, rotten). Furthermore, land cover class was recorded according to the criteria in White (1983).

More details about the variables and how they were measured are given in **InfoBox 1**:

InfoBox 1. The measured variables.

Tree species. Tree species is crucial information for estimating stem volume and above ground biomass (AGB). General allometric models for biomass typically include wood density, which depends on species. Wood density can be measured in the field (e.g. Castaneda et al., 2013) but is usually derived from the literature or online databases (e.g. Kettering et al., 2001). Information on species is also used for species diversity measurement. Tree species is recorded for each measured tree having DBH > 10 cm. The dominant species of the trees having DBH 4–10 cm is also recorded for each subplot with a list of species found in the subplot. Tree species is identified by a taxonomist or local forester. Tree species is written in full (genus and species) on the field recording sheet or using codes given for each species and listed separately. The common or local names should be recorded when the scientific names are unknown. If the species is unknown, it is recorded as 'unknown' and possibly sampled for later identification. Trees on the border of the sample plot are included if the centre of the trunk is inside the sample plot**.** If trees are exactly on the border of the sample plot, every second tree is included and every second excluded. The trees that are hanging above the plot are excluded. The trees that have their trunks inside the sample plot but crowns outside the plot are included. (Figure 7)

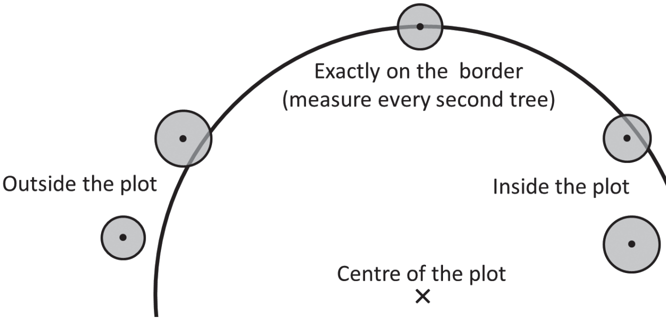


Figure 7. A tree is inside the sample plot if the centre of the trunk is inside the sample plot.

Tree diameter. Diameter at breast height (DBH) is the most commonly used tree parameter in the volume and biomass equations. Often it is the only field-measured tree parameter to estimate AGB in tropical forests. Breast height refers to the height of 1.3 m above ground level. DBH is measured for every tree having DBH > 10 cm in the 0.1 ha sample plot with 1 cm precision. In the 0.01 ha subplots, all the trees having DBH 4–10 cm are counted and DBH is measured for the median tree. As DBH is not measured for all the trees, the median tree is selected subjectively. Median is the middle value when trees are ordered from the smallest to the largest according to DBH. When measuring DBH and tree height, it is important to determine the level where the breast height and tree height are measured correctly (Figure 8). On level ground, height is measured from the ground level (Figure 8a). On slopes or uneven ground, height is measured from the uphill side of the tree (Figures 8b and 8c). If the trunk is bent or inclined, the heights are measured following the stem axis from the downhill side of the tree (Figure 8d). Furthermore, the following rules apply to the DBH measurements. If the tree has a limb, bulge or other abnormality at the height of 1.3 m, DBH is measured above it (Figure 8e). If the tree has buttresses that reach a height greater than 1 m, DBH is measured 60 cm above the buttresses (Figure 8f). If the tree forks exactly at breast height, DBH is measured below the enlargement caused by the fork (Figure 8g). If the tree forks below breast height, DBH is measured separately for each stem (Figure 8h). In order to indicate that stems belong to the same tree, they are numbered by adding a letter suffix to the tree ID (1a, 1b, etc.).

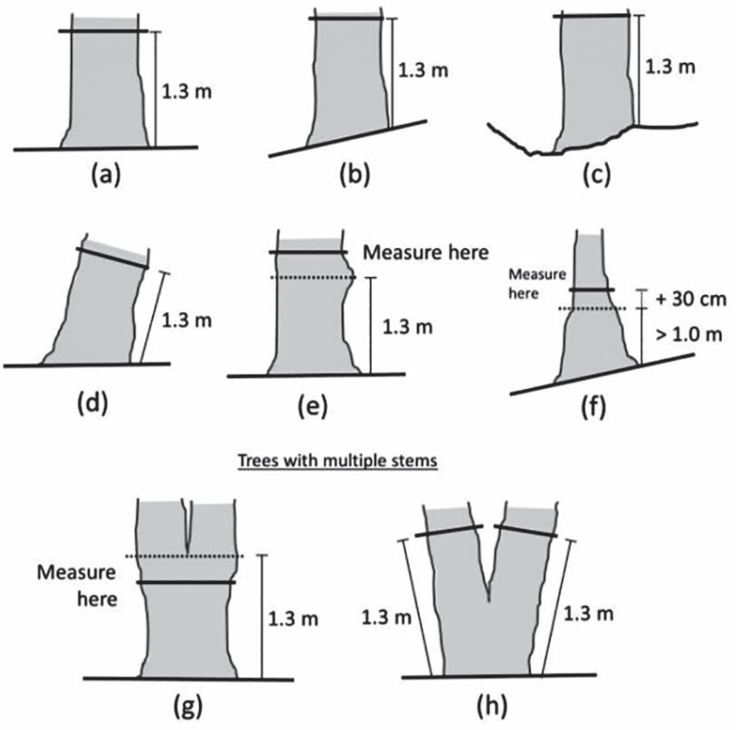


Figure 8. Measurement of DBH in different situations: (a) level ground; (b) slope; (c) uneven ground; (d) if the trunk is bent or inclined; (e) if the tree has a limb, bulge or other abnormality; (f) if the tree has buttresses; (g) if the tree forks exactly at breast height; (h) if the tree has multiple stems (adapted from Husch et al., 2003). See text for more detailed explanation. DBH is measured using calipers (Figure 4) or diameter tape (Figure 5). Calipers are used for measuring diameters up to 30–40 cm and diameter tape is used for larger diameters. The breast height is located by using a 1.3 m stick. When making the measurements, one must make sure that the measurement height is correct, calipers/tape are held in a plane perpendicular to the axis of the stem and calipers/tape are firmly around the trunk. If the stem is covered by lianas or vines, try first to move them and measure DBH below them. If this is not possible, estimate DBH visually using the backside of the measurement tape (i.e. standard measurement tape).

Tree height. Tree height (H) is another tree parameter typically included in the volume and biomass equations. Although it is possible to estimate biomass based on DBH only, it is highly recommended to use models including tree height (e.g. Feldpausch et al., 2012). Tree height can be measured for all the trees but it is often measured only for a sample of trees, because it is more time consuming to measure than DBH. Some trees are also very difficult to measure for height. The sample trees are then used for modelling the tree height for all the trees in the plot. Because DBH–height ratio varies from site to site, it is important to collect tree heights from all the sample plots. In volume and biomass estimation, tree height corresponds to the stem length, which is the distance between the ground level and tip of the tree along the stem axis (see Figure 9a–c for correct determination of the ground level). Usually the tree height and the stem length are equal, but if the tree is inclined or bent, the difference can be large. If all the trees are not measured for height, sample trees for height measurements need to be selected using some criteria.

When DBH > 10 cm, the height is measured for the smallest tree, the median tree and the largest tree based on DBH inside the 0.1 ha plot. In other words, DBH is first measured for all the trees and height is then measured for the sample trees. Median is the middle value when trees are ordered from the smallest to the largest according to the DBH. If there are many trees and measurements are recorded on the field recording sheets (i.e. not electronically), it can be difficult to determine the exact median tree. However, as sample trees are used only for modelling diameter–height relationships, some error in selecting median tree is acceptable and it can be selected subjectively. In the subplots, tree height is measured for the same tree that was measured for DBH (i.e. median diameter tree in the DBH range of 4–10 cm).

Height is measured using a hypsometer or a measurement pole. The measurement pole is the most accurate means to measure the height of low vegetation. However, the hypsometer is usually the most convenient method for measuring the tree height. A Suunto hypsometer (PM-5/1520) is an inexpensive handheld instrument for measuring tree height. The tree height is typically measured from a distance of either 15 m or 20 m when height can be read straight off the instrument scales. As the instrument does not provide distance measurement, the basic distance (15 m or 20 m) has to be established by measuring tape. However, using the third scale (angle in %) it is possible to calculate tree height for any measured distance. The details on the use of the Suunto hypsometer should be read from the user's guide.

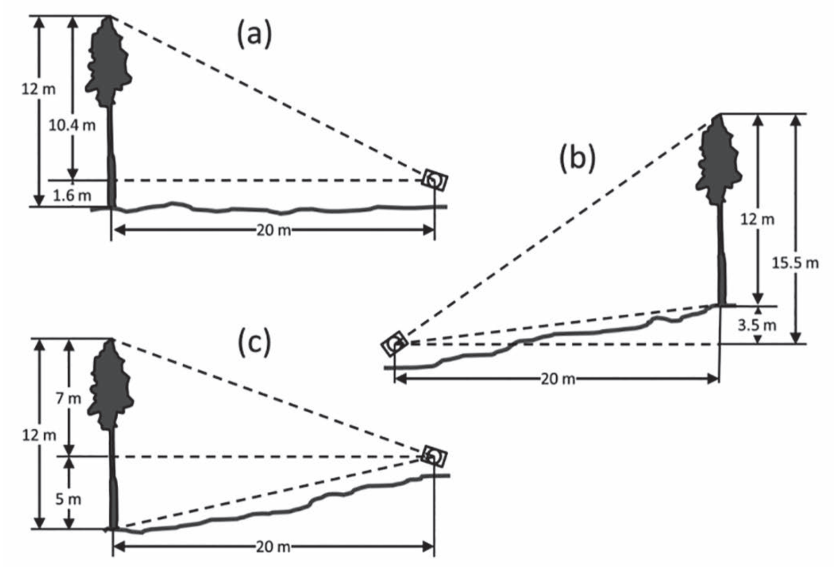


Figure 9. Calculation of tree height. (a) If the ground is horizontal, the height is calculated as a sum of the instrument height from the ground (e.g. 1.6 m) and the height above the horizontal line. (b) If the measurement is made upslope, the distance between the base of the tree and the horizontal line is subtracted from the total height. (c) If the measurement is made downslope, the height is calculated as a sum of the heights above and under the horizontal line.

Other instruments for tree height measurements include electronic hypsometers (e.g. Vertex) and laser rangefinders (e.g. TruPulse). These instruments also provide distance measurement. However, the price of these instruments is considerably higher than the price of the simple hypsometers. When measuring tree height, care must be taken to focus the hypsometer on the tip of the trees. This can be difficult for large trees with flat crowns.

Crown diameter. Crown diameter (CD) and crown area are commonly used for predicting tree volume and biomass in sparsely wooded areas (e.g. savanna, agroforestry), but also for estimating canopy cover. Crown area can be estimated from fine resolution remote sensing imagery and used for estimating DBH and AGB of the individual trees outside forest areas (e.g. Castaneda et al., 2013b). Here, the crown diameter measurements are made in order to estimate canopy cover and to calibrate regression models for estimating AGB from the crown area derived from fine resolution remote sensing imagery. In order to calculate crown area, the CD is measured crosswise in two directions (the largest diameter and the diameter perpendicular to it) (Figure 10). The crown diameter is measured for the same trees, which are measured for tree height in the main sample plot and in the subplots (see 4.4 above). CD is measured by measuring tape with one-metre precision.

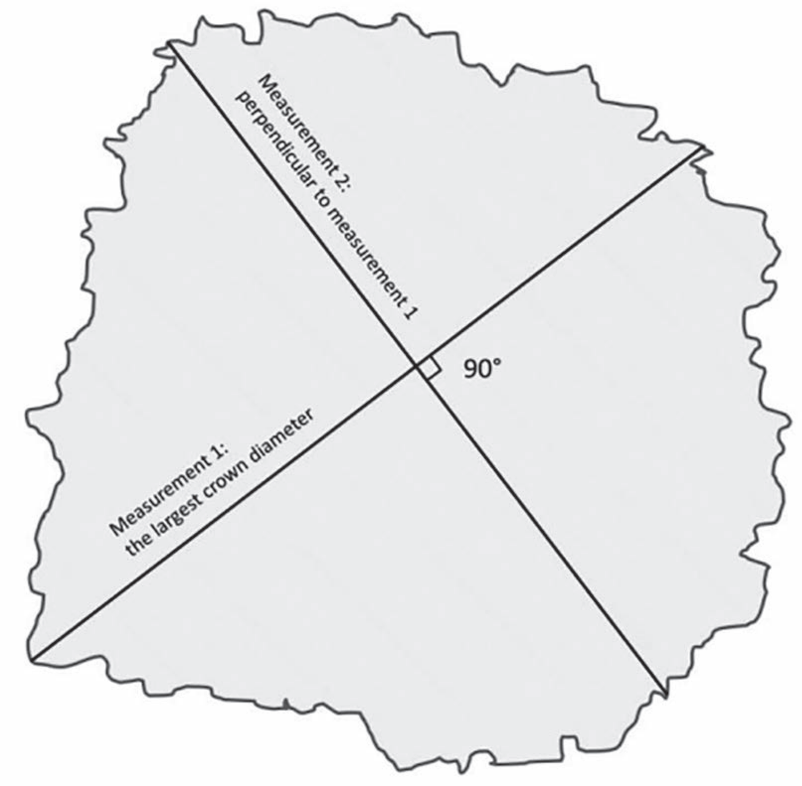


Figure 10. Measurement of crown diameter.

The measurement of CD can be difficult. For example, a clinometer can be used to ensure vertical upward sighting when positioning the crown edge. The determination of the largest diameter is based on the visual assessment.

Unusual trees. Allometric models to estimate AGB are not necessarily applicable to trees that are of unusual shape, typically because of a steep slope or some type of disturbance. This includes trees that are inclined, bent or heavily coppiced. For example, a tree can be thick but relatively short because of heavy copping. If this is the case, a mark should be made on the field recording sheet. The type and reason for the unusual shape should be also described briefly in the comment field.

Palms. Palms can make a large contribution to woody AGB. If palms are an important component of the AGB in the landscape under study, they should be measured. Biomass models for palms are usually based on height (Brown, 1997) and hence both DBH and H are measured for all the palms. Here, all the palms having DBH > 10 cm are measured in the 0.1 ha sample plot.

Dead wood. Dead wood is the non-living woody biomass that is too big to be included in the litter carbon pool. The dead wood includes both standing dead wood and wood lying on the ground. Standing dead trees are measured using the same diameter classes as used for living trees. DBH is measured for every dead tree having DBH > 10 cm in the 0.1 ha sample plot with 1-cm precision. Dead trees are measured at the same time with living trees and simply denoted dead on the field recording sheet. In the 0.01 ha subplots, all the dead trees having DBH 4–10 cm are counted and DBH is measured for the median tree among the dead trees.

Downed dead wood (dead wood lying on the ground) is measured in the subplots. Two attributes are measured from every piece having a minimum diameter of 4 cm: mean diameter and length. The diameter is measured from the middle point of the piece located inside a plot. Correspondingly, the length of the piece located inside a plot is recorded. Furthermore, decay class is given using the following classification: sound (recently fallen), intermediate (partly rotten) or rotten. If the tree is completely rotten and covered by litter, it is not measured. Diameters are measured using either calipers or diameter tape and length is measured using measurement tape.

Figure 11 shows the field teams in action:

Figure 11. Field crew measuring and writing down tree diameters in Burkina Faso (left). A field crew member measuring tree height with a Suunto hypsometer in Sierra Leone (right). Photographs by Janne Heiskanen (left) and Markus Melin (right).

As the measurements were detailed and time-consuming, the teams followed a practical workflow of how to do the measurements. In practice, the operation in the field plot followed the pattern shown in **InfoBox 2:**

InfoBox 2. Operating on the field plot.

1. Set up the sample plot.
- Measure plot centre coordinates using GPS
- Measure slope using clinometer (or hypsometer)
- Determine subplot centres using compass and measurement tape
- Calculate the correct sample plot radius if the slope is > 10° (see Appendix 2 from Heiskanen et al., 2013)

2. Measure trees with a DBH > 10 cm
- Record species and measure DBH for every tree inside the sample plot radius. Make a note if the tree is dead or has an unusual shape. Keep measurement tape as straight as possible when testing if the tree is inside the sample plot or not.
- Measure first a tree located north of the centre of a sample plot and mark it e.g. using marking tape. Then measure the rest of the trees in clockwise order. This makes it easier to find a tree from which the height needs to be measured later.
- If the density of trees is high, mark all the measured trees so that you do not measure the same tree twice.
- Estimate height and crown diameter for the smallest, median and the largest tree. Median is the middle value when trees are ordered from the smallest to the largest according to DBH.

3. Measure palms with a DBH > 10 cm
- Record species and measure DBH and H for every palm inside the sample plot radius.

4. Measure trees of DBH 4–10 cm in the subplots
- Count all the small trees inside the subplots.
- Determine the median tree and measure its diameter, height and crown diameter.
- Record the dominant (most common) species and make a list of all the other species.

5. Measure downed dead wood in the subplots
- Measure mean diameter and length for every piece of dead wood having a diameter ≥ 4 cm. Note that only a piece located inside the plot is considered.
- Determine the decay class for the piece (sound, intermediate, rotten).

In BIODEV, the field data was stored in a portable GPS device as well as on paper sheets. It was then transferred to Excel sheets and .csv files to allow for future calculations where the measured variables were converted to tell more about the forest structure on a wider scale.

2.3 Modelling of volume and biomass

As the tree top heights (H, m) were estimated only for the smallest, median and largest tree (in relation to DBH), the heights needed to be modelled for the remaining trees. Heights, in turn, are needed to estimate volume and biomass.

In BIODEV, this was done using mixed-effects H-DBH modelling (Valbuena et al., 2016). The use of the min, max and median sample trees then made the models more locally adjusted. These local height measurements from the sample trees were used to calibrate a multi-level mixed-effects model that predicted the H of each tree (i) based on Curtis's (1969) function:

$$\widehat{H}_{ijk} = 1.3 + \frac{\alpha_0 DBH_{ijk}}{\left(1 + DBH_{ijk}\right)^{\left(\beta_0 + \beta_{sp} sp_{ijk} + b_{jk} + b'_k\right)}}$$

where, as detailed in Valbuena et al. (2016), the fixed part (α_0,β_0,β_{sp}) was considered with respect to DBH and sp, and the random part (b_{jk},b'_k) was considered as nested effects of between-plot (j) differences within the between-cluster (k) differences.

Next, the described measurements and predictions were employed to calculate tree volumes (V, m^3) and biomass (AGB). Volumes, in the absence of local species-specific volume models, were approximated using geometric relationships (Magnussen & Reed, 2004):

$$V_i = F \cdot G_i \cdot \widehat{H}_i$$

where the volume of a cylinder was defined by the basal area of a tree $G = \pi \cdot DBH^2/40000$ times its $\widehat{H}$. These volumes of a cylinder were modified according to a form factor (F), which adjusts the formula to better approximate the real form of a tree trunk. We used the value of $F = 0.42$ suggested by Magnussen and Reed (2004) in the absence of local equations for volume. The same cylinder model was employed for calculating volumes of downed dead wood (V_{ddw}, m^3), just substituting with the length of the log, and with log diameter, but this time without using form factor correction ($F = 1$), because these diameters were measured from the central part of the log.

With the case of AGB, there are alternative options depending on the available data. If H is available, the best-fit pan-tropical model for tree AGB (kg) is (Eq. 4 in Chave et al. (2014) :

$$AGB = 0.06773\ (\rho \cdot D^2 \cdot H)^{0.976}$$

which includes the effect of species-specific wood densities (ρ;gcm^{-1}) In the case where H is not available, a recommended alternative model is Equation 7 (Chave et al. (2014):

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

where E is a dimensionless measure of environmental stress based on temperature seasonality (TS), climatic water deficit (CWD) and precipitation seasonality (PS). Valbuena et al. (2016) calculated AGB for each tree in the 0.1-ha plots (figure 6) using Eq 13 and different H predictions. They also calculated AGB for median diameter trees in the 0.01-ha subplots using the measured H.

Their study showed that AGB estimations are sensitive to height-diameter modelling. That is, how H was obtained for the AGB models. It has been suggested that AGB inventories should include tree height (H), in addition to diameter (D). Height is, however, a variable that takes time to measure and is prone to measurement error. Therefore, a common way is to measure height only for a sample of trees and then develop a H-D model to estimate the height for the rest. Valbuena et al. (2016) tested a number of approaches for H-D modelling and observed that AGB predictions without H were very sensitive to the chosen E, (the environmental stress parameter of a given site). They suggested that E may be systematically underestimated in forest areas with human intervention, although that extreme was untestable with the given experimental design. The factors most affecting the final AGB estimates were, in order of decreasing influence: the choice of E (when using no H-D models), species variation, and plot-level variation (differences between plots). Cluster-level variation had lower influence, which may be a sign of homogeneity within the given study area. Consequently, Valbuena et al. (2016) concluded that alternatives rank in this order from the most desirable to the least accurate: (1) using mixed-effects H-D models accounting for species and plot-level variation; (2) using local fixed-effects H-D models; and (3) obtaining the AGB from D data only.

2.4 Forest structure in Burkina Faso study site

For analysing the results, we identified the field plots that fell inside and outside of the CAF borders. Presently, two views exist on what are the accurate borders of the Cassou CAF areas. These two datasets have differences that range from ten metres up to 1000 metres regarding the location of the CAF borders. Therefore, we continued the work only with plots that were outside or inside of the CAF areas according to both datasets. The data consisted of 46 plots located inside the CAF and 87 plots outside the CAFs (noCAF). These were further divided into sub-classes according to the land cover classification (Table 1).

Table 1. The plots classified into land cover classes according to White (1983).

Zone	Class	Plots
noCAF	Cropland	50
noCAF	Shrubland	11
noCAF	Woodland	10
noCAF	Forest	16
CAF	Shrubland	6
CAF	Woodland	17
CAF	Forest	23

Next, we compared the forest structure between all the different classes, but especially between the forested areas of the CAF and noCAF lands. In practice, the actual forests between the two zones (CAF, noCAF) did not differ at all. Major differences were only found among other land cover classes (Table 2).

Table 2. Forest structure according to different land cover classes. V indicates volume and *V_ddw* indicates the volume of downed deadwood (m3/ha). Its minimum was zero in all classes.

Zone/Class	V (m^3/ha)			Stems / ha			DBH (cm)		
	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
noCAF/Cropland	0.00	5.6	22.8	0	40	280	0	21.9	40
noCAF/Forest	20.1	28.5	56.3	510	753	1425	8.6	10.9	14.1
CAF/Forest	8.8	28.4	54.	490	764	1125	7.8	10.5	14.8
noCAF/Shrubalnd	1.1	7.6	17.4	30	399	1195	6.4	12.	31.5
CAF/Shrubland	3.2	14.6	25.	155	568	970	8.	9.3	12.7
noCAF/Woodland	14.8	22.4	36.9	100	650	1935	7.7	12.8	25.4
CAF/Woodland	6	18.5	40.9	260	599	1145	7.6	9.8	12.6

Zone/Class	Height (m)			V_ddw (m^3/ha)	
	Min	Avg	Max	Avg	Max
noCAF/Cropland	0	6.7	11.7	0.3	5.4
noCAF/Forest	5.2	6.	6.8	0.3	1.8
CAF/Forest	4.8	6.3	8.5	0.9	17.5
noCAF/Shrubalnd	3.3	5.1	8.8	0.4	2.8
CAF/Shrubland	3.5	4.9	6.5	0.1	0.5
noCAF/Woodland	5.4	6.1	9.4	0.1	0.7
CAF/Woodland	4.9	5.8	8.4	0.3	1.9

The biggest difference in the class *forest* was in the amount of deadwood, which was almost absent outside the CAFs. In general, the areas classified as *forests* (CAF or noCAF) did not differ much between one another and were not very different from the areas classified as *woodlands* either. The CAF *shrublands* had higher stem counts and consequently volumes than the noCAF ones. In *woodlands*, the trend was the opposite with noCAF *woodlands* showing higher average volumes and more trees than the CAF ones. *Croplands* were present only outside the CAF zone and, as seen, some trees were also present in this class. The *croplands* were characterised by having the minimum amount of trees, but those with the highest diameters. The height of the forest was almost the same for all the classes.

The amounts and abundance of different tree species showed also some variation between the classes, but not as much as the forest structure. Altogether, 60 species were discovered from the study area. The first notation was that there were species inside the CAF zones that were not occurring in the noCAF zones and vice versa (regardless of the land cover class), although these species (that were present in only one of the areas) were occurring only in very low numbers. A list of all the documented species in the study area is given in Figure 12; a list of the species that were present only in one of the zones is given in Table 3. Finally, Table 4 shows the most common species in each of the land cover classes.

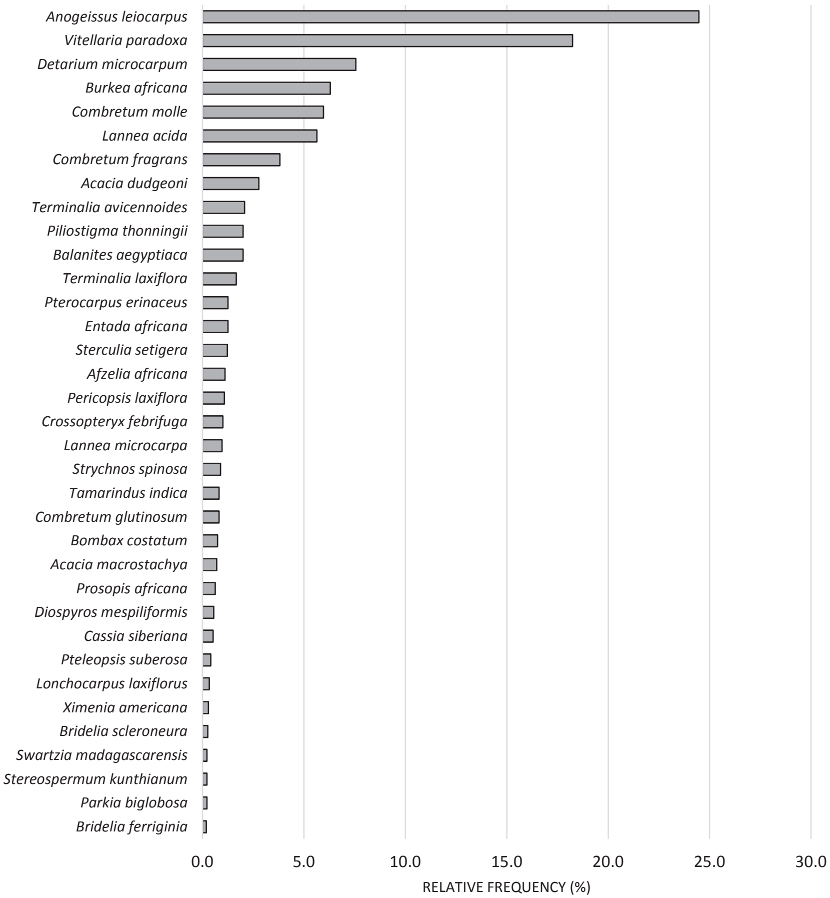


Figure 12. Documented* tree species in Burkina Faso study area and their relative frequencies

*Additional species documented in minority:
Acacia gourmaensis, Acacia pennata, Acacia seyal, Albizia chevalieri, Albizia malacophylla, Annona senegalensis, Cassia singueana, Combretum micranthum, Combretum nigricans, Daniellia oliveri, Dicrostachys cinerea, Feretia apodanthera, Gliricidia sepium, Grewia bicolor, Guiera senegalensis, Hannoa undulata, Khaya senegalensis, Margaritaria discoidea, Maytenus senegalensis, Ozoroa insignis, Pseudocedrela kotschyi, Securidaca longepedunculata, Terminalia macroptera, Vitex doniana, Xeroderris stuhlmannii

Table 3. Species found from only one of the areas (present only in minor numbers)

Present only inside CAF	Present only outside CAF areas
Acacia_pennata	*Acacia_gourmaensis*
Albizia_chevalieri	*Acacia_seyal*
Cassia_singueana	*Bridelia_scleroneura*
Combretum_nigricans	*Feretia_apodanthera*
Daniellia_oliveri	*Hannoa_undulata*
Dicrostachys_cinerea	*Khaya_senegalensis*
Gliricidia_sepium	*Lonchocarpus_laxiflorus*
Grewia_bicolor	*Maytenus_senegalensis*
Guiera_senegalensis	*Ozoroa_insignis*
Pteleopsis_suberosa	
Securidaca_longepedunculata	
11 species	9 species

Table 4. The seven most common tree species in each land cover class.

Rank	CAF Forest	noCAF Forest	CAF Woodland	noCAF Woodland	CAF Shrubland	noCAF Shrubland	Cropland (noCAF)
1	*A. leiocarpus*	*A. leiocarpus*	*A. leiocarpus*	*V. paradoxa*	*P. thonningii*	*V. paradoxa*	*V. paradoxa*
2	*V. paradoxa*	*V. paradoxa*	*V. paradoxa*	*B. africana*	*V. paradoxa*	*A. dudgeoni*	*B. africana*
3	*D. microcarpum*	*B. africana*	*D. microcarpum*	*C. molle*	*C. molle*	*C. fragnans*	*D. mespiliformis*
4	*C. molle*	*L. acida*	*B. africana*	*A. leiocarpus*	*D. microcarpum*	*D. microcarpum*	*L. acida*
5	*B. africana*	*D. microcarpum*	*C. fragnans*	*C. fragnans*	*L. acida*	*A. leiocarpus*	*A. dudgeoni*
6	*C. fragnans*	*C. molle*	*C. molle*	*D. microcarpum*	*B. africana*	*E. africana*	*D. microcarpum*
7	*L. acida*	*C. fragnans*	*L. acida*	*L. acida*	*A. macrostachya*	*P. thonningii*	*E. africana*

The two most common species were *Anogeissus leiocarpus* and *Vitellaria paradoxa*. The next group of common species included *Burkea africana, Combretum fragnans, Detarium microcarpum*, *Combretum molle* and *Lannea acida*. Forest areas, whether noCAF or CAF, shared the same seven most common species and the two dominant ones were also the same. In woodlands, the dominance of *A. leiocarpus* was found only inside CAFs; noCAF woodlands were dominated by *V. paradoxa* and *B. africana*. The woodlands and forests did not differ much from one another in relation to the species distribution. Shrublands, then, were clearly different with new species, such as *P. thonningii, A. dudgeouni* and *A. macrostachya* being introduced in the top seven. Croplands were neither totally without trees with *V. paradoxa* being the dominant one, followed by *B. africana* (Table 6).

In general, the interesting finding from the field measurements was that the forests and woodlands did not show major differences in and out of the CAF areas. The most noted differences were found in the amounts of deadwood, which were higher inside the CAFs most probably due to deadwood being used as firewood in the noCAF areas. The shrublands showed the only main differences with CAF shrublands having a better forest structure in terms of forest productivity (Table 3). The croplands had also some trees in them, the most common one being *V. paradoxa*, which can be linked to the fact that big *V. paradoxa* trees are not cut in order to produce Shea butter, a source of income. According to interviews in Puentes-Rodriguez et al. (2016), the most favoured tree species for private firewood were *D. microcarpum, Crossopteryx febrifuga* and *A. leiocarpus*. Interestingly, in both forests and woodlands (noCAF and CAF) *C. febrifuga* was not abundant and, in general, its abundance was very low (Tables 3 and 5) in the whole study area, indicating that it is, indeed, a preferred species. For trade and market, then, the most sold tree according to Puentes-Rodriguez et al. (2016) was *A. leicarpus* and *D. microcarpum* while *V. paradoxa* was widely sold, but less preferred than the former two, for which the demand was higher than could be supplied. This finding was supported by our results. These three species were very abundant in both areas, which explains why they would also be the most common ones being sold by trade and market; the most preferred ones (like *C. febrifuga*) have been over harvested.

2.5 Forest structure in Sierra Leone study site

In Sierra Leone, the field plots fell also in two different areas: the non-managed rural lands with all the human-induced effects, and intact forests located in the remote and hard-to-approach Kuru Hills Forest Reserve (Figure 2). Kuru Hills have very steep slopes that are hard to move on. Therefore, the forests there are relatively intact when compared to the lowland areas. The forests do suffer from occasional bushfires lit by Guinean cattle ranchers. Still, the setting allowed us to compare the structure of forests between forests disturbed and not disturbed by humans. As expected, the differences were very clear in regard to both species distribution (Figure 13 and Table 6) and forest structure (Table 7).

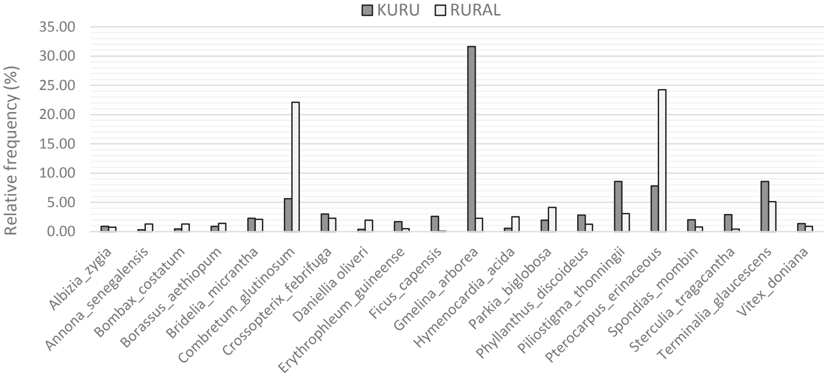


Figure 13. Tree species distributions in plots classified as forests – a figure showing the 20 most common species inside the forest reserve (KURU) and outside of it (RURAL).

As seen, the key difference is in the amounts of three species: *Combretum glutinosum, Gmelina arborea* and *Pterocarpus erinaceus*. These are related directly to human impact: The indigenous *G. arborea* is a species very much favoured by humans as firewood. Consequently, it is almost totally wiped out from the rural areas, whereas in the remote forests of Kuru Hills it is the dominant species. Then again, *C. glutinosum* and *P. erinaceus* are abundant in the rural areas. *C. glutinosum* is a very hard tree species (tough to make firewood). It is sometimes used for charcoal, but charcoal production in that area was not very intense very probably due to bad road conditions, which makes the transportation of charcoal hard. *C. glutinosum*, then, has other uses as well (non-timber related ones) such as dyeing and medicinal purposes. *P. erinaceus* is a species of savanna or shrublands and due to this probably not that abundant in the forest reserve. Its abundance in the rural areas can be explained also by other uses (gum, edible seeds and leaves, fodder for cattle) and lack of interest in burning it as firewood (Orwa et al., 2009). Altogether, the study area featured 91 different tree species, which clearly highlights the fact that Sierra Leonean forests are very diverse (Figure 14).

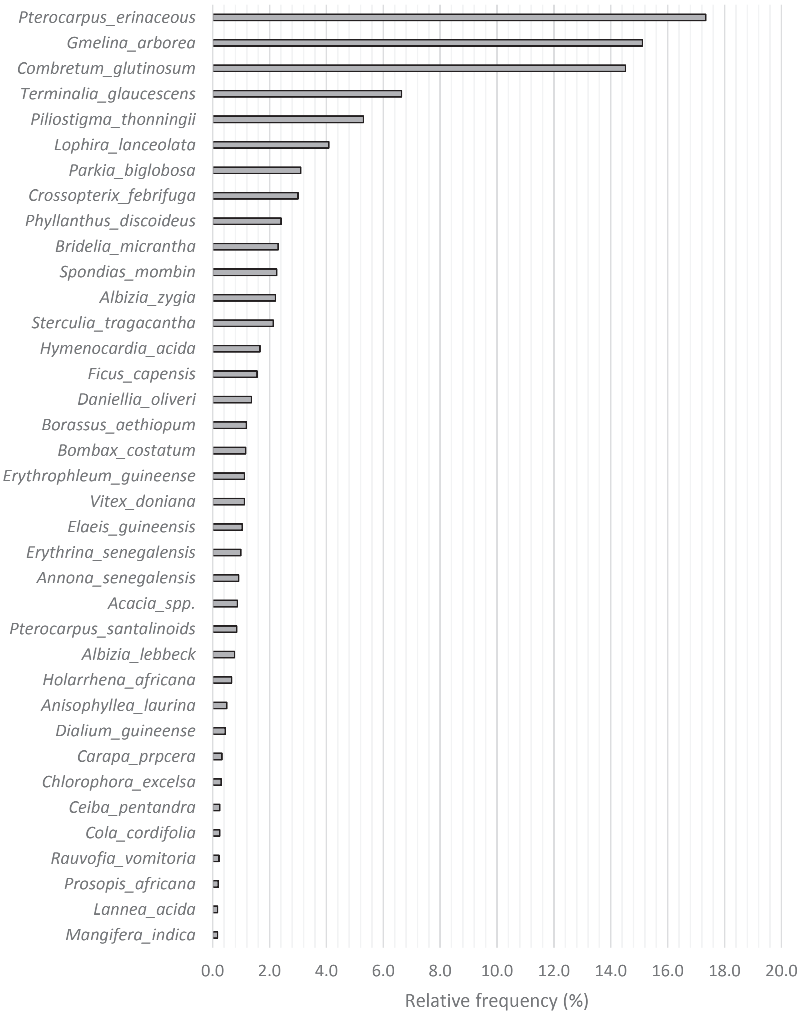


Figure 14. Documented tree species in the Sierra Leone study area and their relative frequencies

*Additional documented species were *Afzelia Africana, Alstonia boonei, Anacardium occidentale, Azadirachta indica, Bauhinia rufesoens, Brachystegia leonensis, Cleistopholis patens, Combretum molle, Detarium senegalense, Garcinia ovalifolia, Khaya senegalensis, Lannea kerstingii, Mitragyna stipulosa, Nauclea latifolia, Newbouldia laevis, Parinari excels, Parkia bicolor, Sarcocephalus diderrichii, Syzygium guineense, Tamarindus indica, Terminalia ivorensis, Uvaria chamae, Xylopia aethiopica* (+ 31 species with unknown Latin names).

Humans may have considerable effect on tree species distribution as seen from Table 7. For further information, Table 6 shows the species that were present only inside the Kuru Hills Forest Reserve.

Table 6. Species observed only in either of the zones (RURAL or KURU) and the species from which only the local names were known. These species were present only in minor numbers.

Present only in KURU	Present only in RURAL
Alstonia_boonei	*Combretum_molle*
Brachystegia_leonensis	*Khaya_senegalensis*
Cola_cordifolia	*Lannea_kerstingii*
Garcinia_ovalifolia	*Tamarindus_indica*
Mitragyna_stipulosa	*Xylopia_aethiopica*
Newbouldia_laevis	*Terminalia_ivorensis*
Parkia_bicolor	*Uvaria_chamae*
Sarcocephalus_diderrichii	Unknown_Boalokafini
Unknown_Felegae	Unknown_Bomboi
Unknown_Fofota	Unknown_Dabor
Unknown_Gbere	Unknown_Gbegbesena
Unknown_Gbomotinye	Unknown_Kolofika
Unknown_Kogolae	Unknown_Makia
Unknown_Kokonie	Unknown_Soconi
Unknown_Kubaboya	Unknown_Timoi
Unknown_Nyunyii	
Unknown_Suckidi	
Unknown_Sukui	
Unknown_Sukutah	
Unknown_Susui	
Unknown_Tanse	
Unknown_Telegae	
Unknown_Thabi	
Unknown_Tolifoi	
Unknown_Wobe	
Unknown_Yenthen	
Unknown_Younyee	
27 species	15 species

The human impact in the area was seen not only in the species distributions, but also in forest structure (Table 7).

Table 7. Key differences between the forest structure of rural plots and plots inside a forest reserve (KURU) displayed according to the land cover classification (White 1983). V indicates volume and *V_ddw* indicates the volume of downed deadwood (m3 ha^{-1}). Its minimum was zero in all classes.

Zone/Class	V (m^3/ha)			Stems / ha			DBH (cm)		
	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
RURAL/Cropland	5.2	15.2	33.9	40	140	430	7.8	22	35.2
KURU/Cropland	0	23.9	234.1	0	103	554	0	17.4	62
RURAL/Forest	1.7	66.7	160.8	110	634	2250	8.4	16.1	37.5
KURU/Forest	2.4	88.4	325	20	819	3466	8.2	14.6	25
RURAL/Shrubland	9.6	33.2	64.8	50	470	1445	8.8	16.6	31
KURU/Shrubland	0.4	34.5	131.7	70	955	3554	4.4	10.1	21.5

Zone/Class	H (m)			V_ddw	
	Min	Avg	Max	Avg	Max
RURAL/Cropland	5.3	9.6	11.3	1	5.7
KURU/Cropland	0	7.1	15.8	8.3	16.8
RURAL/Forest	5.2	8.4	11.8	0.9	4.5
KURU/Forest	5.8	8.7	12.1	1.2	12.6
RURAL/Shrubland	5.5	8.1	10.9	0.5	1.1
KURU/Shrubland	3.2	6.3	8.8	0.8	5.1

Note that Cropland in Kuru has high volumes, which is due to the classification of an area as cropland if there are traces of agricultural activities even though there may be a dense forest cover. Otherwise, the biggest differences are in the average stem count and maximum volume, the latter of which is over twice as high in the forest reserve as in the rural area. This gives views on the productivity of the forests, which, according to Millington (1994), can reach as high levels as 30 m^3 ha^{-1} year^{-1}. If these kinds of forests were not over exploited, their productivity would, indeed, be high enough to meet with the demand while also ensuring sustainability. The forests grow fast and can reach remarkably high stand volumes, but only if they are not exploited too soon. A clear key finding here – the take-home message – is that Sierra Leonean forests do produce wood at a growth rate that is far higher than that of local consumption alone.

The field measurements in both countries represented only a fraction of the total forest area. One key issue in practice is to expand the results in a way that, via some proxy variables, allows us to estimate the same structural attributes in other areas too. Remote sensing has been typically used for these kinds of tasks.

2.6 Integrating the field data with satellite remote sensing

Integration of remote sensing data into forest inventories is a common practice nowadays in many countries. The idea behind this link is to cover areas that are outside of the field campaigns, but also to gain additional information such as the spectral properties of the target forest and its species. For instance, a Landsat image covers an area of ~180 km x 180 km and so, if you can quantify a relationship between your field-measured variables and the Landsat pixel values, it becomes possible to extrapolate the abundance of the desired variables (e.g. canopy cover) across the area of the entire satellite image.

For less developed countries, an obstacle that often stands in the way of natural resource management and planning of land management in general is the lack of spatial information. A connection of field-measured data with freely available remote sensing data, such as Landsat satellite images, would provide one option for this. Within the BIODEV project, this kind of case was tested in Burkina Faso by Liu et al. (2016) and Heiskanen et al. (2016), the latter of which suits well for the purposes of this study book and chapter in particular.

Earlier studies in the region have used remote sensing mainly to assess changes in vegetation while the mapping of tree attributes has not been very much tested (Karlson & Ostwald, 2015) except mapping of canopy cover (CC) AGB (Karlson et al., 2015; Halperin et al., 2016). CC is an important parameter of forest structure especially when trying to define what is counted as a forest (Chazdon et al., 2016), which links it with REDD+ (Romijn et al., 2013). AGB, then, has gained more attention, because of growing needs to quantify the global carbon (C) pools, their abundance and any changes in them (Avitabile et al., 2016). In areas like Burkina Faso, biomass is also related to biodiversity, hydrological cycle, soil erosion and land degradation (Eisenfelder et al., 2012). Heiskanen et al. (2016) had their objectives in developing predictive models for various tree, soil and tree species diversity attributes by combining measured data from the BIODEV field inventory sample plots and optical remote sensing data from Landsat and RapidEye sensors.

The group purchased the RapidEye data that best matched the timing of the field inventory and downloaded all available Landsat Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager (OLI) Surface Reflectance Climate Data Record (CDR) images for the desired time period between November 2013 and October 2014. The remote sensing predictors from these datasets then included typical spectral and textural features used with RapidEye data, Landsat images, and seasonal features based on Landsat time series. For modelling and predictions, they used Random Forest regression.

As an example, the predicted map of CC based on RapidEye, Landsat image closest in time to RapidEye and Landsat time series is shown below:

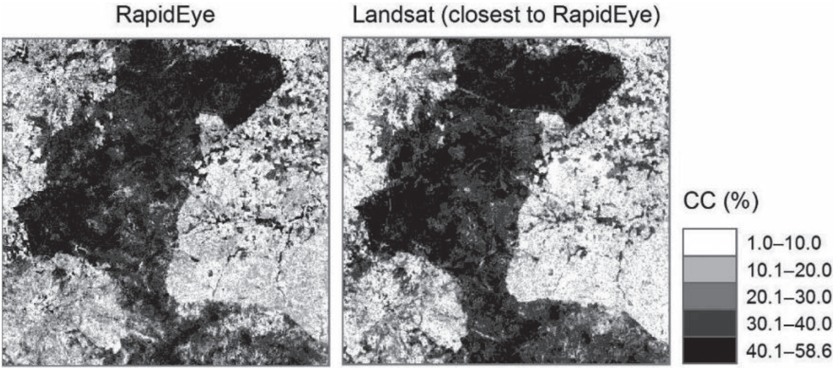


Figure 15. Maps of tree crown cover (CC) based on RapidEye image, Landsat image (closest to RapidEye) and Landsat time series.

As seen from Figure 12, the spatial patterns of canopy cover agree rather well between maps based on different data sets. The studied landscape consists of forest and woodlands surrounded by parklands and croplands of relatively high and low CC. The boundaries of the managed CAF forest areas are clearly visible in the maps of tree attributes (see Figure 1 for comparison).

Overall, the results of Heiskanen et al. (2016) demonstrated the feasibility of field inventory sample plots and free medium resolution satellite data for generating spatial information layers for planning purposes. Possible improvements are related to field data, additional predictor variables and alternative prediction methods. The study showed that tree crown cover and attributes correlated with it, such as basal area and tree species richness, could be most accurately predicted. Landscape analysis for natural resource management and planning of land management interventions, such as tree planting, could greatly benefit from suitable spatial information for informed decision making. The study showed how fixed area plots, typically collected in forest and carbon inventories, can be coupled with optical remote sensing data to generate a multitude of spatial information layers related to trees, soil and tree species diversity for such purposes. In the selected approach, the higher spatial resolution of the commercial RapidEye image provided only marginal improvement in comparison to free Landsat data, which also enable use of seasonal information from annual time series.

In general, the BIODEV case study proved the known usability of remote sensing for practical natural resource management.

2.7 Concluding remarks

The importance of proper field data cannot be highlighted enough. It was also vital for the articles produced in the context of BIODEV. This chapter gave an overview of the BIODEV inventory system, field measurements, calculations as well as results and applications. It must be noted that inventory schemes (e.g. plot size and sampling) and the measured variables vary according to the structure and complexity of the target forest as well as the purpose of the inventory itself. This was only one example, but it can be applied in similar environments as stated or it can be modified to a desired direction. The key is in designing the proper type of inventory and to measure the variables in an objective and accurate manner. This results in data from which reliable inferences can be drawn that are then useful in guiding planning and management.

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CHAPTER 3

Methods and techniques for efficient charcoal production 67

Methods and techniques for efficient charcoal production

Teemu Vilppo, Sari Pitkänen, Markus Melin and Kirsi Mononen

3.1 Current methods and issues in charcoal production

Charcoal is one of the most important sources of energy in many developing countries. In West Africa, charcoal is an urban fuel, which is produced in rural areas and consumed in the cities. In recent years, the rates of charcoal production have increased on a constant basis. For example, in 2014 Sierra Leone produced 420,000 t of charcoal, which was 2.5% more than in the previous year. At the same time, the production rate of charcoal in Burkina Faso exceeded 600,000 t. The trend has led to increasing amounts of wood being harvested. Thus, it is no wonder that charcoal production – along with firewood, agriculture, and expanding infrastructure – is also rated as one of the key drivers of deforestation in West African countries.

In West Africa, traditional methods are applied widely to produce charcoal in earth kilns by pyrolysis in the absence of oxygen. The two dominant kiln types are an earth pit kiln and an earth mound kiln. In an earth pit kiln, wood is stacked into a pit and sealed above usually with grass and soil (Figure 1). The pyrolysis is then started by lighting the pile of wood from one end of the pit. Figures 2 and 3 represent an earth mound kiln, in which instead of digging a hole into the ground, wood is stacked above the ground. Before lighting, the wood pile is sealed with soil (Fontodji et al., 2013). Basically, to build traditional kilns no additional building material is needed.

Figure 1. A traditional earth pit kiln open (left) and sealed with steel plate with wood inside (right). Small air-channels are made on top to allow outflow of emissions. Photographs adopted from http://biochar.bioenergylists.org/taxonomy/term/334

Figure 2. A traditional earth mound kiln shown with wood stacked (front left), covered (right) and lit (back). Photograph adopted from http://www.bbc.co.uk/news/world-middle-east-16598389

Figure 3. An improved model of an earth pit kiln in Southern Burkina Faso with improved control of airflow. Photograph by Markus Melin.

However, both traditional methods are considered unsustainable and characterised by low energy efficiency and a long processing time. Typically, the traditional process requires vast amounts of wood to produce low amounts of charcoal, thus resulting in marked energy loss. For example, using a traditional pyrolysis method, even 5 to 12 kg of wood may be required to produce 1 kg of charcoal. The process may take up to two weeks for complete conversion, and not much can be done to control the pyrolysis process. Some developments have been made on earth pit kilns to adjust, e.g., gas flow during pyrolysis (Figure 4). However, these improvements are not widely known. A low flow of information regarding efficient pyrolysis techniques has been probably due to low appreciation of the fuelwood industry. Generally, charcoal production is not considered as a real business in rural areas. Therefore, there has so far been no interest in research, dissemination of practical information or investments for better pyrolysis techniques (GIZ HERA 2010, NL Agency 2010).

Figure 4. A farmer is producing charcoal in Taiama, Moyamba District. Photograph by Javier Arevalo.

Recent studies indicate that with simple improvements in pyrolysis techniques it is possible to produce charcoal in a sustainable way. Such techniques to optimise currently used methods are discussed in the following section. In addition, a small-scale reactor for efficient charcoal production is introduced. In the end of this chapter, a simple camp stove called MIDGE by Arthur Noll to improve cooking with biomass is introduced.

3.2 Improving the efficiency of charcoal production

The thermal process by which wood is carbonised is called pyrolysis. In pyrolysis, organic material is heated resulting in chemical decomposition of biomass. The aim of the carbonisation process is to turn biomass (here, wood) into charcoal with minimal loss of utilisable energy to yield a non-degrading and clean-burning fuel with a high energy content per mass unit.

Generally, drying, with any preferable and available drying method – outdoors loose stack (covered under rain), kiln, solar application – and using it as fuel will not result in marked loss of energy. With carbonisation, undesired qualities of wood, e.g. formation of smoke when burnt, are removed from fuel with acceptable loss of energy. With pyrolysis, temperature plays a major role. However, with traditional methods, temperature cannot be controlled during pyrolysis. For example, with carbonisation at temperatures below 300 °C, the process yields fuelwood with improved stability during storage, but undesired wood-like characteristics are retained, too. Currently, this type of fuelwood will be classified as wood in the West African market (Antal et al., 1990), which makes processing pointless as energy is lost, but no quality, marketability or utilisation benefits are gained.

A key factor to improving charcoal quality obtained by using traditional methods is having a better control over the process. Surprisingly, better control over the process can be achieved by simple and easy methods and no expensive electronic systems are required. Those might even turn cost-ineffective since they require maintenance, skills and infrastructure. Instead, controlling the moisture content of the wood and wood dimensions as well as careful selection of wood material are general principles to improve charcoal yield and produce fuelwood in a sustainable way. In addition to general principles, using a steel kiln allows better conduction of the process.

3.2.1 Moisture content

Moisture content of fresh wood may be up to 50 weight-% (w-%). During carbonisation, a lot of energy is consumed to evaporate excess water from the wood during the process. To avoid energy loss and mass loss due to excess moisture, raw material should be air dried to moisture content below 30 w-%. The optimal moisture content is 10 w-%. Even a short drying time, e.g. one week, will be useful. Of course, optimal air-drying time should always be assessed depending on local weather conditions, e.g. air humidity or rain (Jahkonen et al., 2012).

To improve fuelwood quality
- Wood should be air-dried before carbonisation
- Using fresh wood is not recommended

3.2.2 Wood dimensions

For the traditional earthen mound method, especially for large mounds, the physical dimensions of the wood need to be revised. In the current practice, all the wood is stacked in the same mound without pretreatment, in the dimension with which it has been felled. To improve the process, the wood dimensions need to be controlled. Especially large logs need to be split to a more homogenous size.

The importance of wood dimension is because if the dimensions vary greatly, wood with smaller diameter has excessive residence time while the largest logs may not (especially if wet!) pyrolyse completely, yielding poor quality brown char. Therefore, the quality and yield of such a batch of biochar will decrease.

Pyrolysis propagates both through the wood stack and solid wood material with limited speed. The amount of reactive surface in wood material defines front propagation through a pile. Wood material properties play a major role in defining how pyrolysis will propagate through and along solid wood material (Ryu et al., 2006, Thunman & Leckner 2002, Thunman & Leckner 2005).

To improve fuelwood quality
- The simple method to control wood size is using a two-hand thumb-forefinger circumference as a rule
- If you can’t get both fingers together around the wood then split it (Figure 5)

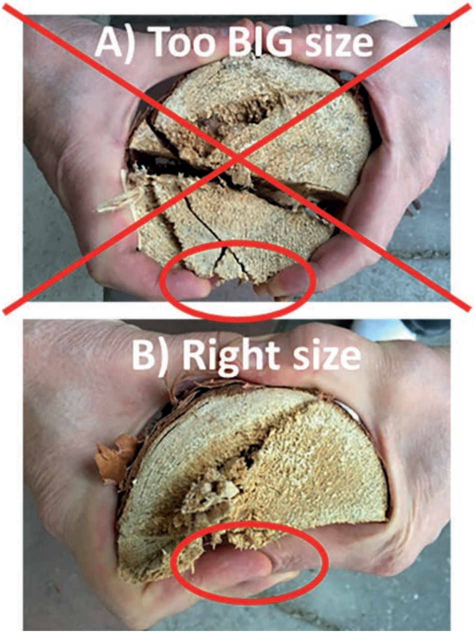

Figure 5. Right dimensions for charcoal production (finger rule). If your fingers do not touch (A, above) then split the wood (B, below).

3.2.3 Raw material selection and stacking

To further improve the conventional earth mound process, raw material selection and stacking can be improved. Stacking will be improved by dimension control itself, but also specific utilisation of wood species properties can improve yield and decrease processing time.

The majority of material in a stack should preferably be similar to *Acacia Mangium*, with low exothermic properties during pyrolysis, but within the stack there should be also *pyrolytic leads* present, that is wood pieces with high exothermic properties. A suitable wood species to be used as a pyrolytic lead is, for example, *Afzelia Africana*. When these leads of wood pieces form an interconnected web throughout the stack, pyrolysis will start and propagate quicker. Therefore, there will not be too short or too long residence times for each piece of wood.

To improve fuelwood quality

- Use a mixture of wood pieces containing species with lower and higher exothermic properties

3.2.4 Barrel pyrolyser

A barrel pyrolyser is a steel kiln that can be utilised to improve fuelwood quality, too. A barrel pyrolyser is presented in Figures 6 and 7. It allows additional control over the process after initial setup.

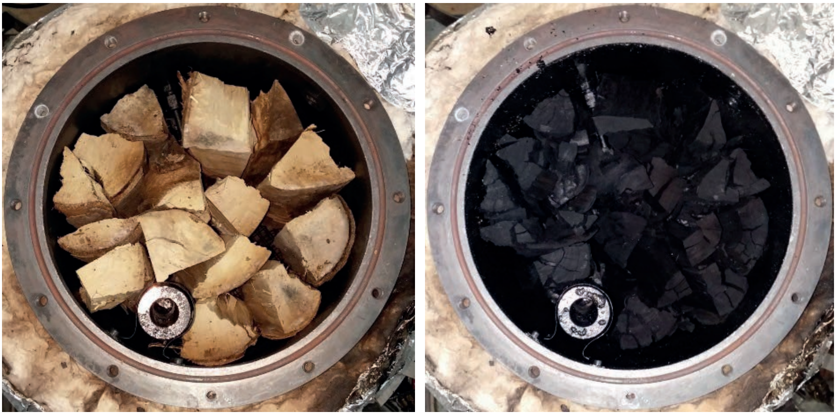

Figure 6. The input (left) and output (right) of charcoal processed in a steel kiln (barrel pyrolyser). Photograph by Teemu Vilppo.

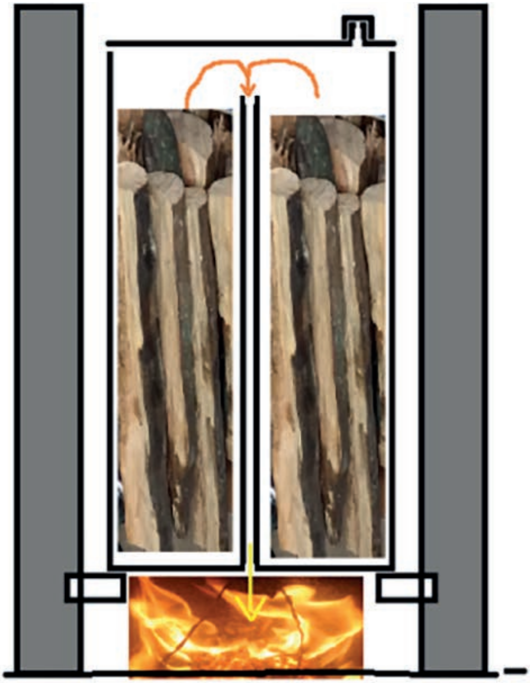

Figure 7. Schematic representation of a barrel pyrolyser.

A barrel pyrolyser is composed of a standard portable steel barrel and a kiln. The barrel should be equipped with a lid that can be closed tightly and a safety vent on the lid. A simple construction for a safety vent is a short tube, with a heavy cap freely sitting on it to prevent evolving of pressure and explosion. If the safety valve vents, the barrel should be removed from the kiln. In the bottom of the barrel a tube is welded leading the fumes from the top of the barrel back down onto the fire. Circulating fumes from top down will provide additional energy for the process. Another part of the system is a kiln where the barrel can be fitted, fired at the bottom and smoke led up around the barrel. For selection of wood material for pyrolysis, the same rules and treatments apply as discussed in the previous section for traditional methods.

Benefits from barrel pyrolyser compared to the conventional method, are

- shorter processing time estimated to be from 6 to 12 hours residence time
- more options to control pyrolysis such as intensity of fire
- possibility to cool the reactor by taking it out of the kiln and spraying with water

If more capacity is needed, instead of increasing the dimensions of the reactor, which decrease the control of the process and possibly increase expenses, the system is relatively simple to multiply. The kilns can be in continuous use and loaded in turns.

One load for a barrel pyrolyser is about 70 kg of wood for a 200 L sized barrel. Optimally, one load will yield about 30 kg of biochar. However, biochar yield is strongly dependent on how well the process is managed. The optimal is dry wood with less than 10% moisture content with a processing temperature of 300 °C with minimum residence time. Wet wood with low density and with a poorly managed process may yield less than 15 kg of biochar from 100 kg wet weight (50 kg dry weight) of wood.

3.3 Simple methods to calculate moisture, ash content, mass yield and energy yield to estimate efficiency of the carbonisation process

In this section, simple methods for estimation of moisture content, ash content, mass yield and energy content are introduced to improve charcoal yields. These methods are loosely based on SFS EN bioenergy standard methods.

InfoBox 1. Moisture content measurement

Moisture is one of the most important issues affecting the quality of the charcoal and it determines also how much energy is needed in the process. Here, a simple method for measuring wood moisture is presented.

To measure moisture content of wood, the following equipment is needed:
- a large oven
- a pan that fits inside the oven
- a scale
- (optional: a thermometer)

Heat the oven to over the boiling point of water to 105 °C (minimum temperature)–160 °C (maximum temperature). After heating, if possible use a thermometer to read the exact temperature inside the oven. Note that the temperature of the oven cannot exceed 160 °C. In case there is no thermometer available, the following tests can be made to estimate if the temperature of the oven is appropriate.

- Water droplet test: Drop a water droplet onto a flat surface inside the oven. The droplet will hiss and boil, but it may not jump and skittle around on the surface (*Leidenfrost effect*). If the water droplet jumps and skittles on a hot surface, the oven is overheated. If it doesn't hiss and boil quickly away, the oven is too cold.
- Cooking oil droplet test: Drop a droplet of cooking oil onto a surface inside the oven. The oil must not smoke. If it smokes, the oven is too hot (cooking oil smoke point).

Performing a moisture content measurement

- Measure the weight of the available pan or use the earlier measured known weight of it to obtain m_{pan}
- Spread a raw wood sample onto the pan. Measure the weight of the pan and the sample to obtain m_{raw}
- Put the pan inside oven. Let it warm up for 1 hour.
- Take the pan out and measure the weight to obtain m_{dried}
- Put the pan back in oven. Let it heat for another hour and measure weight m_{dried} Repeat until two consecutive weights m_{dried} are the same:
  - If the weight is the same as in the previous measurement, the measurement can be stopped and moisture content using m_{dried} can be calculated.
  - If not, put the pan back into the oven and let it heat for another hour and measure the weight again until the result is same as the previous one

Using the values obtained, calculate moisture content as follows

$$Moisture\ (\%) = \frac{(m_{raw} - m_{pan}) - (m_{dried} - m_{pan})}{(m_{raw} - m_{pan})} * 100\%$$

Example:

The weight of the pan was m_{pan} = 0.21 kg. The raw sample + the pan weighed m_{raw} = 0.55 kg. After drying at 105 °C, the dried sample + pan weighed m_{dried} = 0.50 kg (after drying of 1 h, two consecutive results were obtained for m_{dried} = 0.50 kg)

$$Moisture\ (\%) = \frac{(m_{raw} - m_{pan}) - (m_{dried} - m_{pan})}{(m_{raw} - m_{pan})} * 100\%$$

Typical values for moisture content are from 5% (dry straws) to 50% (fresh wood).

InfoBox 2. Ash content measurement.

To measure ash content, the following equipment is needed:
- a combustion stove
- a sample container
- an ash container
- a scale

Ash content measurement:
- Measure the weight of a sample container to obtain m_{cont1} as well as the weight of an ash container to obtain m_{cont2}
- Place the sample into the sample container and measure the weight of the sample and sample container to obtain m_{test}. You can make multiple batches, if necessary.
- Move the sample to the stove and combust the sample(s) until completely fine white or grey ash without any bits of coal.
- Let the ash cool. After cooling, transfer all the ash to an ash container.
- Measure the weight of ash + ash container to obtain m_{ash}

Ash content is calculated using the following formula

$$Ash\ content\ \% = \frac{(m_{ash} - m_{cont2})}{(m_{test} - m_{cont1})} * 100\%$$

Example:
Measurement of the weight of the sample container resulted in $m_{cont1} = 0.21$kg and the weight of the ash container was $m_{cont2} = 0.05$ kg. The sample + the sample container weighed $m_{test} = 0.53$ kg. After combustion, the ash was transferred into the ash container and weighed to obtain $m_{ash} = 0.09$ kg.

$$Ash\ content\ \% = \frac{(0.09\ kg - 0.05\ kg)}{(0.53\ kg - 0.21\ kg)} * 100\% = 12.5\%$$

During performance of the measurement, attention should be paid to the following factors that affect the accuracy of the measurement. These are
- how representative the sample is
- dryness of the sample
- accuracy of the scale
- rate of combustion (complete or not)
- complete transfer of ash from the stove to the ash container
- to which accuracy you can calculate the results

The typical range of ash content is from less than 0.5% (stem wood without bark) to over 10% (wood bark or low quality charcoal) ash content.

InfoBox 3. Mass yield estimation.

Mass yield can be estimated from the ash content. You'll need
- a raw material sample (obtained before carbonisation)
- a biochar sample (obtained after carbonisation)

It is critical that samples are obtained from similar spots and they are of the same wood species, i.e. both samples, before and after carbonisation, should be either from branch or trunk of the same wood species.

Measure ash content (%) as described above from both raw material to obtain AC_{raw} and processed (carbonised) material to obtain AC_{proc}.

The mass yield % can then be calculated as follows

$$Mass\ yield\ \% = \frac{AC_{raw}\%}{AC_{proc}\%} * 100\%$$

Example:
Ash content of the raw material was 1.5% while ash content of the biochar was 4.5%.

$$Mass\ yield\ \% = \frac{1.5\%}{4.5\%} * 100\% = 33.3\%$$

In this example, mass yield was 33.3% indicating that 66.7% of the mass of the sample was lost during carbonisation.

InfoBox 4. Estimation of the energy content.

There is slight systematic bias between results calculated from ash content and results from actual energy content measurement and the formula is valid only between 300 °C and 500 °C. At higher temperatures, energy content begin to level off, and at lower temperatures, pyrolysis reactions cause quick changes in mass-energy balance at narrow temperature range.

Energy content of biochar can be calculated from mass and energy yields using the following formula

$$Energy\ yield\ \% = Mass\ yield(\%) * 1.1 + 10\%$$

Example:
Mass yield of the biochar was 33.3%. Calculate the energy content.

$$Energy\ yield\ \% = (33.3\% * 1.1) + 10\% = 46.6\%$$

In this example, energy yield was 46.6% indicating that 53.4% of energy was lost during carbonisation.

It is worth noting that this formula includes the following assumption: materials are measured and processed ‘bone dry’, e.g., the moisture content is below 5% and the gross calorific value for wood is 18 MJ/kg. However, if there is any significant amount of moisture present in the samples this formula will no longer be valid. If the moisture content of the material is known, dry matter amounts can be used. Figure 8 shows experimental results for energy content estimation.

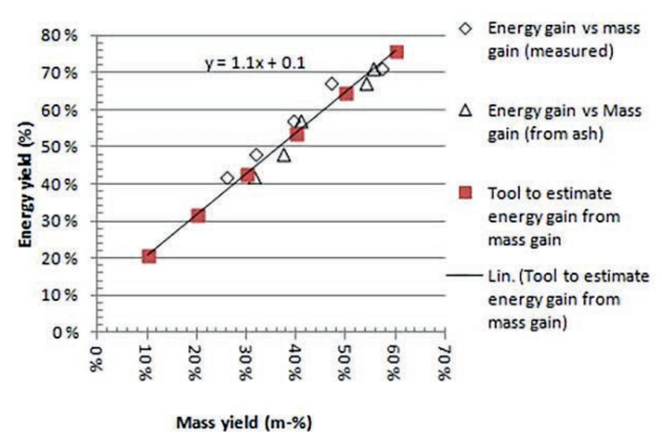

Figure 8. Experimental results for energy content estimation.

3.4 A case study from Sierra Leone

In this section, a case study (manuscript Vilppo et al., 2016), in which five tree species were processed in Sierra Leone, is represented. The aims of the study were to assess and improve energy value of biochar produced in West African countries for domestic use. Increased total energy yield and improved utilisation in biochar production increases energy efficiency and reduces pressure on forests. As raw material, wood samples from Sierra Leone were used (selected by John M. Koroma Njala University SL) with a criterion being preferred wood species by biochar producers. Species *Afzelia Africana*, *Acacia Mangium*, *Dialum Guineensis*, *Gmelina Arborea*, *Lophira Lanceolata*. *Gmelina Arborea* and *Acacia Mangium* are foreign species with fast growth rates, while *Afzelia Africana*, *Dialium Guineensis* and *Lophira Lanceolata* are native, slower growing species. Each sample contained 20 kg of wood species, but their moisture content varied from 20% to 50% and, respectively, the amount of dry matter varied from 15 to 9 kg after cutting and splitting.

The pyrolysis tests were carried out with a pyrolysis reactor of a 10 L stainless steel container followed with a series of condensers for condensing pyrolysis liquids from pyrolysis exhaust gas. CO_2 was used as a carrier gas to maintain continuous flow through the reactor. A pyrolysis reactor is heavily insulated and heated from the bottom. Temperature is controlled by automation based on a single measurement point. There are additional temperature measurements inside the reactor for data gathering purposes.

Wood samples were pyrolysed at 5 different temperatures (250 °C, 275 °C, 300 °C, 350 °C and 400 °C). Charcoals are shown in Figure 9.

Figure 9. Solid residues from different processing temperatures of *Lophira Lanceolata.*

The residual chars were analysed to obtain:

- Gross and net calorific value
- Mass and energy yields from dry raw material
- Moisture and ash content
- infrared (IR) spectra to characterise chemical composition of charcoal

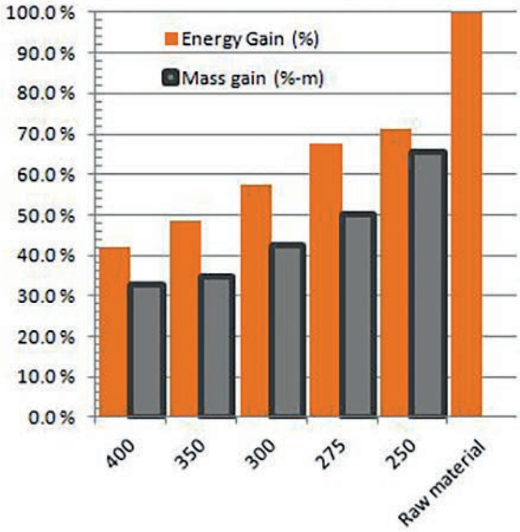

Figure 10. Energy and mass yields from *Lophira Lanceolata* processed at five different temperatures.

Process and process products are analysed by change of mass (secondary control is ash content), energy content and to some degree process exhaust to assess optimal energy balance for the process. The changes in chemical compositions are characterised by diamond-ATR FTIR spectroscopy. After analysis, the two best choices of process temperatures for further study were made: 275 °C for ideal and 350 °C for realistic energy content yield target.

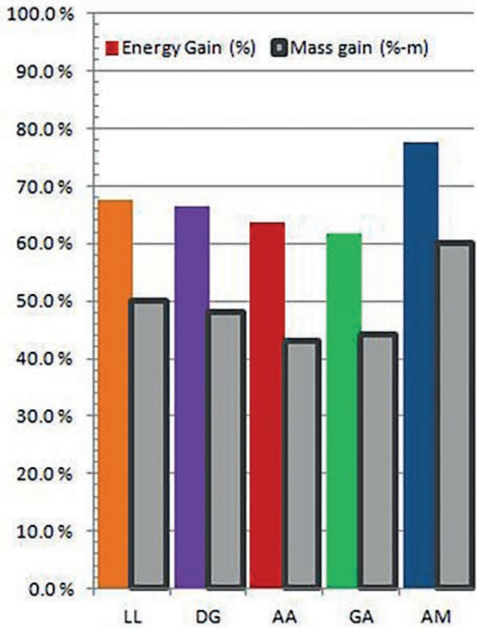

Figure 11. Energy and mass yields of different wood species at 275 °C processing temperature. *Lophira Lanceolata* (LL), *Dialium Guineensis* (DG), *Afzelia Africana* (AA), *Gmelina Arborea* (GA), *Acacia Mangium* (AM).

The results of the pyrolysis study show that mass and energy yields decrease as process temperature increases (Figure 10). The material used must be very dry and in this study the drying of the samples was carried out overnight at 130 °C and chemically unbound water was released. The yield of water from drying was very close to the amount of moisture measured from raw material. Yields, if calculated from raw material, will change when raw material moisture changes.

In the first stage of study, the first pyrolysis, of the five consecutive processes, was made with raw material at moisture content of 21.6%, “as recieved”. The last process was conducted when raw material was dried during storage down to 6.2% moisture content. The amount of moisture content in the sample affects net calorific value. Therefore, energy content comparisons are done on a dry basis.

In the study, the energy yield is simply calculated by multiplying gross calorific value by mass yield from dry matter in raw material. From this follows that biochar energy yield follows, to a degree, the mass yield.

Mass yield can be directly measured if the weight of raw material and biochar after process is measured. An alternative method (Figure 8) is to measure the ash content of raw material and biochar, with the assumption that inorganic ash content and composition does not change during the process. Then mass yield can be calculated by dividing raw material ash content with biochar ash content.

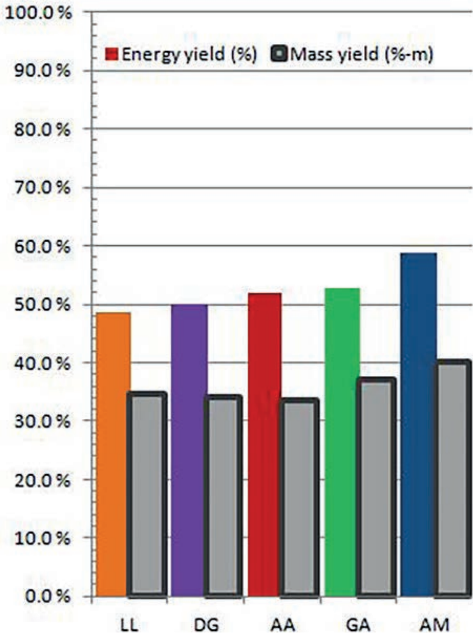

Figure 12. Energy and mass yields of different wood species *Lophira Lanceolata* (LL), *Dialium Guineensis* (DG), *Afzelia Africana* (AA), *Gmelina Arborea* (GA), *Acacia Mangium* (AM*)* at 350 °C processing temperature.

At the ideal temperature of 275 °C, the process is a mild heating regime; after the initial heat pulse the temperature was raised roughly every 45 minutes by 10 degrees. At the temperature of 350 °C, the process heating regime was much more intense; heat pulses were several tens of degrees about once an hour. *Afzelia Africana* had a clear, strong exothermic stage starting around 250 °C, which made achieving the target temperature more challenging than it was with two previous wood species. The *Acacia Mangium* process was the mildest observed. There were no significant exothermal peaks at either temperature. *Dialium Guineensis* processed much like *Lophira Lanceolota*. A notable property of the liquid by-product was an unusual purplish brown colour (in 275 °C processing). *Gmelia Arborea* processed again in an almost identical manner to *Lophira Lanceolata*; an even slightly less volatile manner.

When compared within the process temperatures (Figures 11 and 12), *Acacia Mangium* showed the greatest mass (and energy) yield in each process temperature. This is at least partially due to a lack of tendency to exothermal pyrolytic propagation. The tendency to generate heat shows clearly in *Afzelia Africana* when initial heating during the pyrolysis stage of the process heats up in an uncontrolled manner due to energy produced by exothermic reactions in raw material and the process's maximum temperature was almost 50 °C above the nominal target. *Dialium Guineensis* show similar behaviour to a slightly lesser degree, while *Lophira Lanceolata* and *Gmelia Arborea* stay close to the target temperature in a mild, nominal target 275 °C process and do not exceed the nominal target temperature in the more intense heating regime of a 350 °C nominal target temperature process.

Elemental yields are compared to raw material (100%). The amount of oxygen decreases fastest, as mass is lost as water and small oxygen containing organic molecules, while solid residue, i.e. biochar, is reduced. As temperature increases, hydrogen is lost and the proportional content of carbon increases.

FTIR assay can be used to track changes in the chemical composition of wood with carbonisation. By analysing signals due to the structural components of wood, a maximum residence temperature for heat-treated biomass can be estimated (Keiluweit et al., 2010). In Figure 13, FTIR spectra of native *Lophira Lanceolata* and those exposed to elevated temperatures are shown.

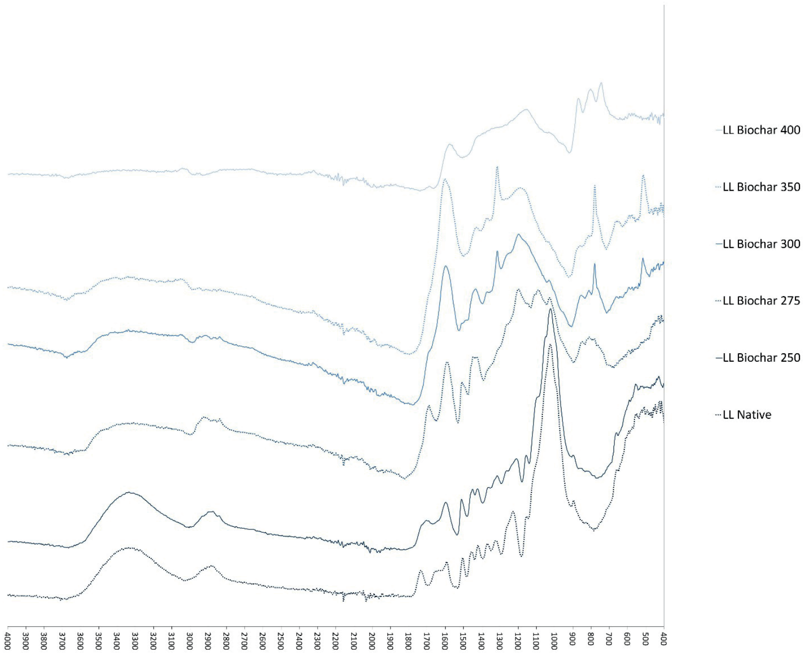

Figure 13. FTIR spectra of native *Lophira Lanceolata* and pyrolysed at 250 °C, 275 °C, 300 °C, 350 °C and 400 °C.

According to FTIR spectra, there are some chemical changes in samples processed at 250 °C and in samples processed at 275 °C compared to native wood. With treatments at temperatures of 250 °C and 275 °C, a broad peak in the region at 3500–3200 cm^{-1} characteristic for hydroxyl groups decreased, indicating loss of water and decomposition of structures containing hydroxyl groups. Similarly, peaks characteristic for aliphatic hydrocarbon structures around 3000 cm^{-1} have changed, indicating changes in aliphatic chains of wood constituents in treated samples. However, a peak characteristic for unconjugated and conjugated carbonyl structures at 1600 cm^{-1} (aromatic) at 1700 cm^{-1} (polysaccharides) occurred in native and treated samples. Similarly, a clear signal characteristic for cellulose structures at around 1000 cm^{-1} is clearly visible, indicating presence of cellulose structures in native and treated samples.

Marked spectral changes occurred in samples treated at higher temperatures of 300 °C, 350 °C and 400 °C compared with that of native wood or wood treated at lower temperatures. A peak in the region at 3500–3200 cm^{-1}, characteristic of hydroxyl groups, did not occur indicating dehydration of wood. Similarly, at temperatures of 300 °C, 350 °C and 400 °C, a relative increase of a broad peak occurring at 1600 cm^{-1} compared with the intensity of the peak occurring at 1700 cm^{-1} indicated decomposition of structural wood components. At elevated temperatures of 300 °C, 350 °C and 400 °C, an absorption maximum at 1000 cm^{-1} was shifted to 1300 cm^{-1} indicating decomposition of polysaccharides with relative increase of aromatic structures in biochar. In summary, with treatments at elevated temperatures, signals characteristic for structural constituents of wood decreased indicating decomposition of structural wood components into elemental carbon (Keiluweit et al., 2010; Williams & Besler 1996).

One of the most interesting results was the impact of wood species on pyrolysis yields. From a process control standpoint, *Acacia Mangium* was shown to be the best of the tested species as it provided the highest energy yield in a biochar production process. Also, it had the lowest tendency to go to runaway pyrolysis, which led to energy and mass loss. Mass (and energy) yields were the best in both nominal temperatures for *Acacia Mangium*. *Afzelia Africana* and *Dialium Guineensis* had the greatest tendencies to go to runaway pyrolysis, but if included in a small portion in the batch they acted as a heat source, initiator or pyrolytic lead for the process.

When the results of this charcoal experiment in modern laboratory circumstances are compared to biochar from Sierra Leone, the following can be stated. The most important result the comparison to biochars produced in the Sierra Leonean framework is the quality of charcoal in terms of what is sold in the market, i.e., the type of charcoal the end user prefers. It is represented in Table 1.

Table 1. Commercial quality assessment of produced charcoal (assessed by John M. Koroma).

Biochar	Nominal Temp °C	Quality
Lophira Lanceolata	400	Average, people will prefer better biochars if those are available
Lophira Lanceolata	250	Bad, people will not buy. Produces smoke
Lophira Lanceolata	350	Poor, people will buy but prefer better if available, 1 log residue used in 2 pieces
Lophira Lanceolata	300	Preferred on market, 1 log residue is used in 2 pieces
Lophira Lanceolata	275	Average, people will prefer better biochars if those are available
Dialium Guineensis	275	Bad, people will not buy. Produces smoke
Dialium Guineensis	350	Preferred on market, 1 log residue is used in 2 pieces
Afzelia Africana	275	Bad, people will not buy. Produces smoke
Afzelia Africana	350	Preferred on market, 1 log residue is used in 2 pieces
Gmelina Arborea	275	Average, people will prefer better biochars if those are available
Gmelina Arborea	200	Wood, not biochar
Acacia Mangium	275	Poor, people will buy but prefer better if available, 1 log residue used in 2 pieces
Acacia Mangium	350	Preferred on market, 1 log residue is used in 2 pieces
Gmelina Arborea	350	Preferred on market, 1 log residue is used in 2 pieces
Afzelia Africana	350	Preferred on market, 1 log residue is used in 2 pieces

Lophira Lanceolata had a general brownish sheen in the char, which reduced its market value in a sort of intrinsic way. *Gmelina Arborea*'s low density of wood led to a poor mechanical characteristic (easily crumbling), which reduced the quality but did not make it unsellable as coal. Increased temperature improved mechanical properties; material ending up harder.

For *Dialium Guineensis* and *Afzelia Africana*, low temperature referred to poor quality due to wood colour and it was considered as wood. Quality was excellent at higher temperatures. These heated significantly during process without external heating when reaching the exothermal pyrolysis stage, the point where carbonisation occurs.

Acacia Mangium assessment is similar to *Dialium Guineensis* and *Afzelia Africana*, but the pyrolytic property is non-exothermic, which means a constant supply of external energy was required, consequently meaning the process was easy to keep in control.

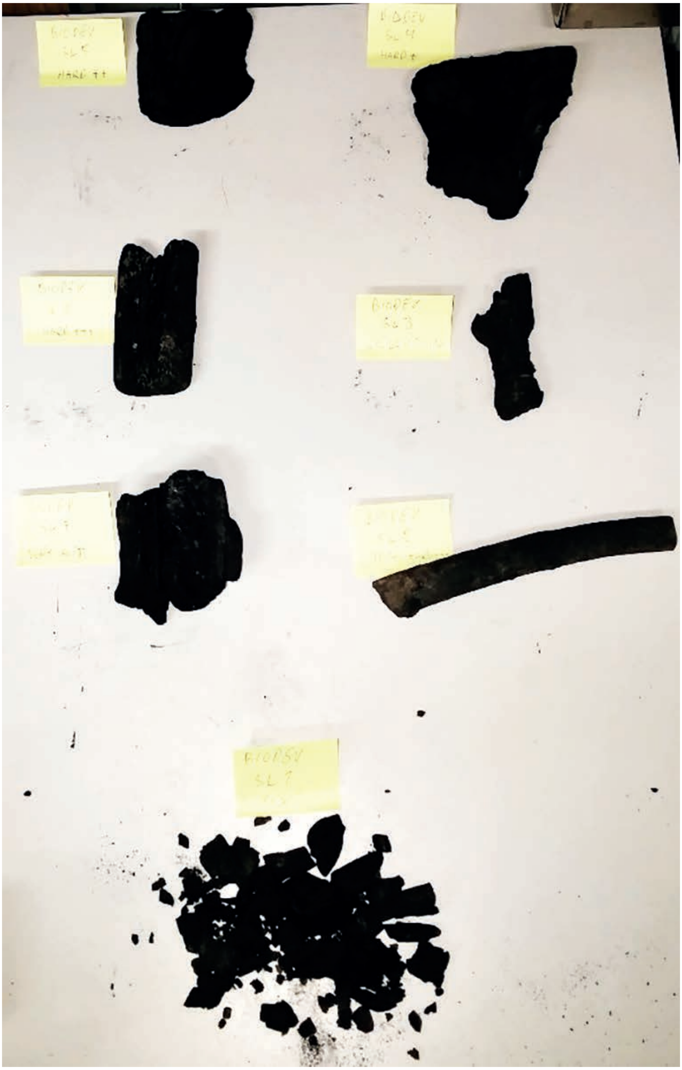

Figure 14. Examples of different kinds of biochars from a local producer in Sierra Leone.

When Sierra Leonean biochars are compared with samples produced in the study, it is clear that process temperatures for Sierra Leonean samples are at least 400 °C. The two clearest parameters are carbon content (m-%, Figure 15) and gross calorific value (MJ kg^{-1}, Figure 16). Gross calorific value increases as process temperature increases, but total mass yield decreases. Sierra Leonean samples all have values greater than the sample processed at 350 °C. With the same clear trend in carbon content, Sierra Leonean biochar carbon content indicates a process temperature of at least 400 °C. This also means that a huge energy loss has occurred in the process.

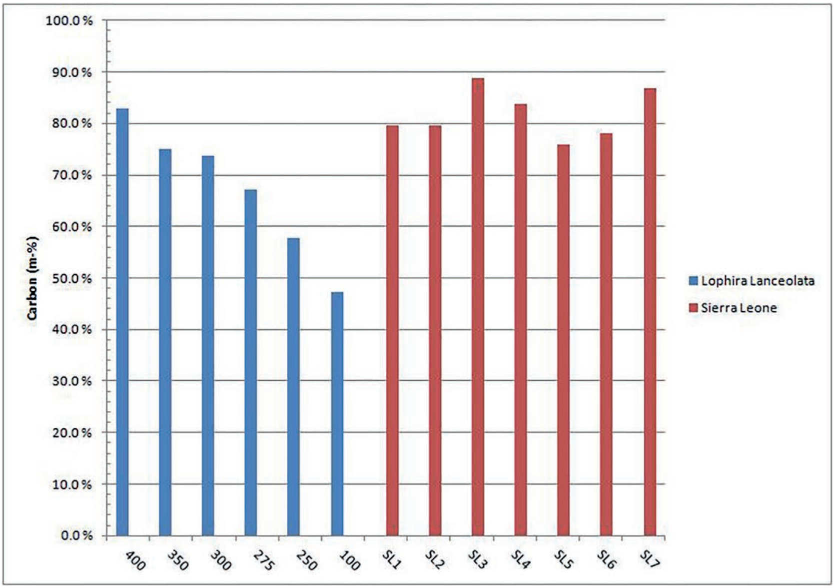

Figure 15. Carbon mass-% for *Lophira Lanceolata,* native and processing temperatures (blue) and for Sierra Leonean biochars (red).

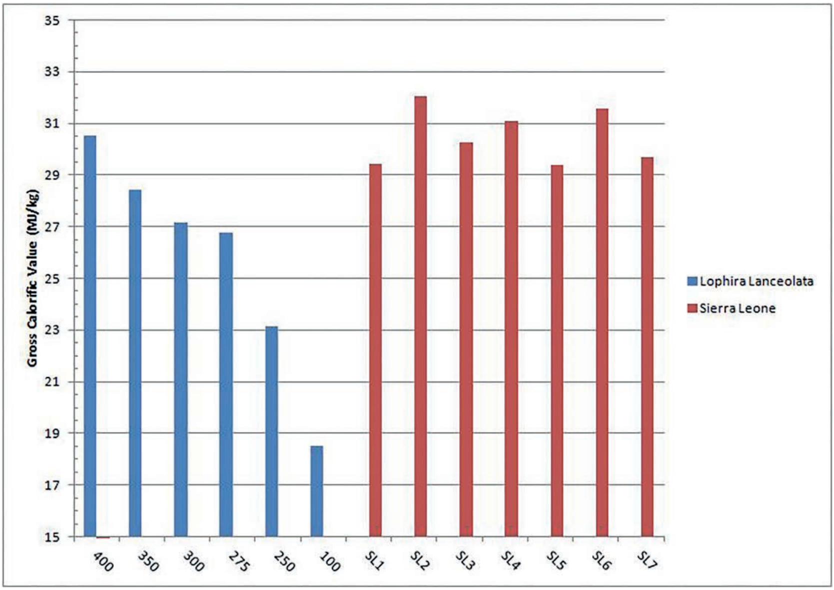

Figure 16. Carbon q_{gross} (MJ kg^{-1}) for *Lophira Lanceolata,* native and processing temperatures (blue) and for Sierra Leonean biochars (red).

3.5 Simple method to improve cooking with biomass – The MIDGE

Developed in a modified inverted downdraft gasifier experiment by Arthur Noll, MIDGE is a camp stove based on the inverted downdraft gasifier principle. This stove will combust biomass cleanly and without producing significant amounts of smoke. The amount of wood needed to boil water is minimal and the amount of fuel used can be easily optimised. In MIDGE, any combustible biomass, especially tiny fragments otherwise with little utility, can be used as fuel.

MIDGE is developed and reported by Arthur Noll (arthurnoll@onedomain.com) as a freely available pdf document (http://www.instructables.com/id/MIDGE-gasifier-campstove/). To build a MIDGE, one will need the following building materials and tools

- 4 cans of different sizes
- piece of metal wire
- hammer
- punches with flat, pointed and round hole heads
- (optional: 5 to 10 screws or nails)
- (optional: cutting and/or flat pliers)

Building the MIDGE took about 1 hour with all above (also optional) tools included.

In the study of Vilppo (2015), the MIDGE was tested with pine chips and biochar from mixed conifer wood (pine and spruce). The MIDGE was loaded with 61 g of wood chips and in the second test with 54 g of biochar and ignited using birch bark as an ignition bit. Combustion time was measured from the point when the water container was added on to the fire. The combustion time of biochar was much longer, but also with a much lower temperature and heating potential than wood chips (Figure 17).

Wood chips had a lot of volatile organic compounds, which are already removed from biochar (Williams & Bessler 1996). The wood chips burnt with a bright yellow and tall flame and high combustion temperature, which was enough to bring 500 ml water to 95 °C in 10 minutes with only 61 g of fuel. The biochar combusted with a glow and the gas temperature under the water container was only 200 °C to 300 °C. The water reached a temperature of only 60 °C, but combustion time was about 2 hours, as opposed to the fuelwood's 45 minutes. The biochar flame temperature could be brought to over 600 °C with additional fanning, which naturally increases fuel consumption and decreases combustion time.

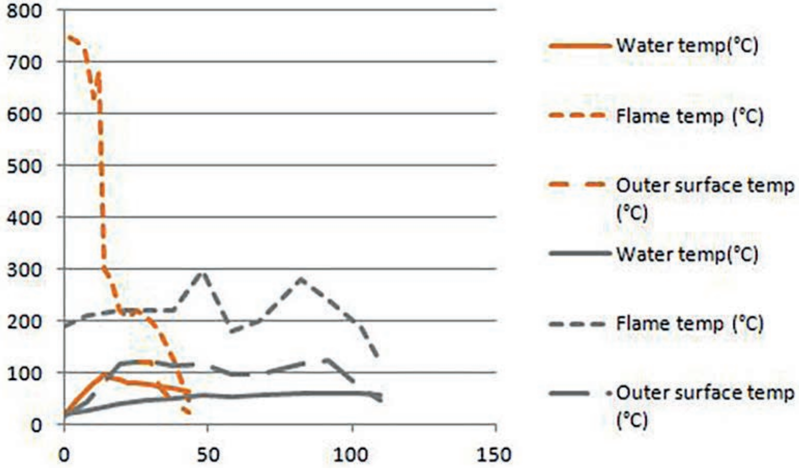

Figure 17. Temperature of water and flame under container; grey line represents biochar and the brown line represents wood chips.

According to the tests, the MIDGE works fine with biomass as constructed, but minor improvements may make it more feasible in home use. A longer combustion time requires larger fuel capacity, meaning either a taller or broader gasifier. These changes will increase combustion time, even if the flame outlet dimensions should not be increased, regarding user safety. Complete combustion of gasifier gas is mandatory, because producer gas contains tens of per cent of toxic carbon monoxide, which *must* be completely combusted.

A larger outer can or ceramic construction would decrease the outer can surface temperature, which was in the tests hot enough to cause burns. A larger dimension would also reduce resistance to airflow improving draft and increasing flame intensity. To improve fire safety, an air space between the outer can and ash container would be feasible. Without a predetermined material shape (i.e. cans), an opening for fanning could be included in the structure. Ceramic construction with the MIDGE principle could be better for fuel wood than current stove designs.

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CHAPTER 4

Bioeconomy aspects: value chain analysis for fuelwood 99

Bioeconomy aspects: value chain analysis for fuelwood

Yohama Puentes Rodriguez, Sabaheta Ramcilovic-Suominen, Piritta Torssonen, Sari Pitkänen and Jouni Pykäläinen

4.1 Introduction

The number of people relying on fuelwood in African countries is high and is expected to increase in the future. In most of the countries, including Burkina Faso, deforestation is partly caused by the overexploitation of forest resources for fuelwood and is strongly influenced by the lack of forest regeneration measures, unclear tenure and access rights, and lack of good resource governance. The increasing pressure on forest resources and its side effects (i.e. climate change, desertification, etc.) is of great concern and therefore some measures are urgently required for maintaining and enhancing the forest values (i.e. economic, social and environmental values), for the benefit of present and future generations. Thus, following the UN concept of Sustainable Forest Management (SFM) (FAO 2006) and in line with sustainable bioeconomy strategy, the different phases and actors from fuelwood production to consumption should be addressed for further improvement, e.g. with a value chain analysis (VCA). VCA is a common tool used to differentiate the various stages in the production and utilisation of certain products (i.e. fuelwood) to understand the economic flows between actors, among other things. To do so, FAO (2008 cited in Ndegwa 2010) recommends analysing the social and economic dimensions of fuelwood value chain (VC) processes.

In this context, the purpose of this chapter is to show how VCA can be utilised as a tool for assessing the sustainability of fuelwood production and consumption. Firstly, general information regarding VC, VCA and the tools commonly used for the analysis is presented. Then, some examples of fuelwood VCA carried out in Africa are described, and finally some outputs from the fuelwood VCA in Burkina Faso, carried out as part of the BIODEV project, are summarised here.

4.2 What are value chain and value chain analysis?

4.2.1 Value chain

A value chain involves a set of agents, with related activities and markets, which contribute directly to the production, transformation and distribution to final markets of a single product (Bellù & Guilbert 2009). The term has been known since the 1960s and 1970s; however it became widely used in 1985 as an influence from Michael Porter's best-seller *Competitive Advantage: Creating and Sustaining Superior Performance* (Kaplinsky 2000). Considering the wood energy sector, VC contributes to understanding the economic flows between the actors and also to recognising the importance of fuelwood in regional and national economy (Ndegwa 2010).

A typical VC starts with the production of a primary commodity and ends with the consumption of the final product. It also includes a number of basic steps undertaken between production and consumption such as processing, transportation and trade, and distribution and retailing (Schure et al., 2014). A VC largely depends on the product itself. For instance, in the case of the fuelwood VC, the main processes include:

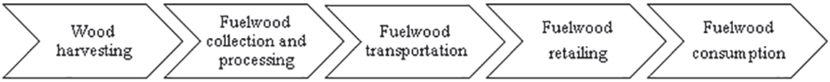


Figure 1. The general fuelwood VC.

Figure 1 is a simple representation of the key processes included in the fuelwood VC, while usually VCs are much more complex and often include more than one channel, which supply more than one final market (Hellin & Meijer 2006). This complexity is due to the need for a comprehensive mapping and analysis of the chain processes, the main actors, as well as the market dynamics and related governance issues (SNV 2012 as cited in Schure et al., 2014).

4.2.2 Value chain analysis

The VCA represents a tool to differentiate various stages in production and utilisation of a certain product. Bellù and Guilbert (2009) define it as a "*technique for assessing how public policies investments and institutions affect existing or public policies, planned chains for agricultural commodities*". While this definition focuses only on agricultural products, it is important to point out that VCA can be conducted for any other product, such as forest products and timber. VCA allows the analyst to identify bottlenecks, target groups, winners and losers of a policy measure; trace the effects of a policy along the chain of commodities; and understand changes for agents and the VC as a whole (Bellù 2013). According to Kaplinsky and Morris (2001), there are three main reasons justifying the importance of VCA in the rapid era of globalisation: i) the growing importance of systematic competitiveness, ii) efficiency in production, and iii) understanding dynamic factors within the VC. In terms of policy making, VCA implies looking at the different economic, ecological and social dimensions of the VC and assessing their likely impacts on the available policy options, as well as the identification of areas of potential improvement of the VC through public policy measures (Bellù 2013).

4.2.3. Tools utilised for VCA

VCA consists of qualitative and/or quantitative tools. Although there are no rules for this analysis, qualitative tools (i.e. semi-structured interviews and focus groups) are recommended to be carried out in the first place and then a quantitative study (e.g. household survey or a questionnaire), if time and resources are accessible. Information on prices and quantities can be obtained from qualitative research and from secondary sources like national statistics and from quantitative study (Hellin & Meijer 2006).

According to Hellin and Meijer (2006), the most common tools used for VCA are:

- **Participant observation**, which is a basic tool for collecting data about people, processes and cultures (Kawulich 2005). This is used in qualitative research, especially in anthropological research and it gives a greater understanding of the characteristics of the situation being researched (Hellin & Meijer 2006). For effective work, it is important to establish a good relationship between researchers and informants, and consider the last one as collaborators (Kawulich 2005).
- **Semi-structured interviews and focus group meetings:** these are two different kinds of interview techniques used to collect information in a dynamic and iterative way. They include guided conversations with predetermined topics and during which new questions and insights arise as a result of the discussion and visualised analyses (Hellin & Meijer 2006). Focus group meetings are basically dynamic group discussions for collecting information (Cohen & Crabtree 2006). Group interviews may be more instructive than those with individuals and cover a wider field than any single person (Hellin & Meijer 2006).
- **Questionnaires** are a data collection method constituted by a set of questions, which are usually associated with quantitative data. Questionnaires facilitate an assessment of larger-scale patterns, trends and relationships among different VC actors for a more objective assessment (Hellin & Meijer 2006). According to the same authors, questionnaires focus on what VC actors are doing while qualitative research gives answers into why actors are doing what they do and how they formulate their decisions.

The information provided by the above mentioned tools could be then used for analysing the VC of a certain product. Specific software has also been developed to facilitate the analysis. For instance, “FAO’s VCA-Tool software” was developed to analyse policies and their socio-economic impacts. It can also be used for the assessment of profitability of different activities, effect on different agents, etc. (Bellù 2013). With this software it is also possible to analyse and compare the effects of different policy options for agriculture and sustainable rural development, allowing analysts to create an accounting framework for VCA, as well as to compare different scenarios and to create and handle one’s own VC database (Bellù 2012). A number of VCAs have been carried out with this tool, including the evaluation of firewood in Burkina Faso (Bellù & Guilbert 2009).

4.3 How VCA can be utilised in research: case studies of fuelwood VCA

4.3.1 Examples of VCA used in research

VCA has been extensively used for analysing the VC of a variety of commodities such as coffee, medicinal plants, mushrooms, fuelwood, etc. (Fitter & Kaplinsky 2001, Hishe et al. 2016, Getachew et al. 2016, among others). In terms of fuelwood in Africa, a number of VC and VCA studies have been carried out addressing different issues. For instance, Bellù and Guilbert developed in 2009 a VCA for firewood in Burkina Faso; they utilised the FAO VCA as a tool for quantitative analysis of socio-economic policy impacts with data from Ouagadougou corresponding to 2006. The authors observed within the production situation two chains – the formal and informal one – with the latter being more numerous.

Formality issues within the VC have been of great concern and therefore an important research topic. In 2013, Schure et al. combined a VCA and livelihoods approach to assess the relations between the formalisation of charcoal VC and socio-economic outcomes in Central and West Africa. The authors observed that charcoal VCs in the studied regions are mostly lacking formal governance or incomplete implementation and there is also a predominance of informal rules.

In 2014, Netherlands Development Organisation (SNV) examined the fuelwood VC focused on the Democratic Republic of Congo and Burkina Faso (Schure et al., 2014). They developed an approach for contributing to a better understanding of the fuelwood VC and to introduce interventions for reducing forest degradation and livelihoods improvement. And more recently, Cerutti et al. 2015 utilised a systematic map to analyse the socio-economic and environmental impacts of wood energy VC in Sub-Saharan Africa.

4.3.2 Fuelwood VCA in Burkina Faso: A case study

Fuelwood production is defined as one of the main drivers of deforestation in Burkina Faso (Arevalo 2016). Considering the high rate of population growth and the high dependency on fuelwood as the main energy source (i.e. cooking and heating), a sustainable fuelwood management is urgently needed for the country. To do so, it is necessary to have a proper understanding of all the processes taking place within the fuelwood VC along with the main actors involved and the challenges faced by them. Therefore, and as part of the BIO-DEV project, the WP 1.4 on sustainable fuelwood carried out a fuelwood VCA in Burkina Faso (Puentes Rodriguez et al., 2016). Here we present the most relevant outcomes obtained from the analysis.

4.3.2.1 Materials and methods

Study area

The fuelwood VCA was carried out in two important areas for energy production and consumption in Burkina Faso: Cassou village (Cassou commune in the Ziro province) and the capital city Ouagadougou, located in southern and central Burkina Faso, respectively (Figure 2).

Cassou forest covers approximately 29,515 ha within the Bakata, Gao and Cassou rural communes. It is administratively defined as the Protected and Managed Forest of Cassou and represents one of the last remaining dry forests in the country. Natural resources management is carried out by:
i) the land chief,
ii) the Village Development Committees (VDCs), and
iii) the Forest Management Groups (FMGs), together with
iv) the local forest services (Tondoh & Degrande 2015).

Forest management areas (CAF) have been established in the area since 1986 for fuelwood production (Schure et al., 2014) with large amounts of fuelwoods

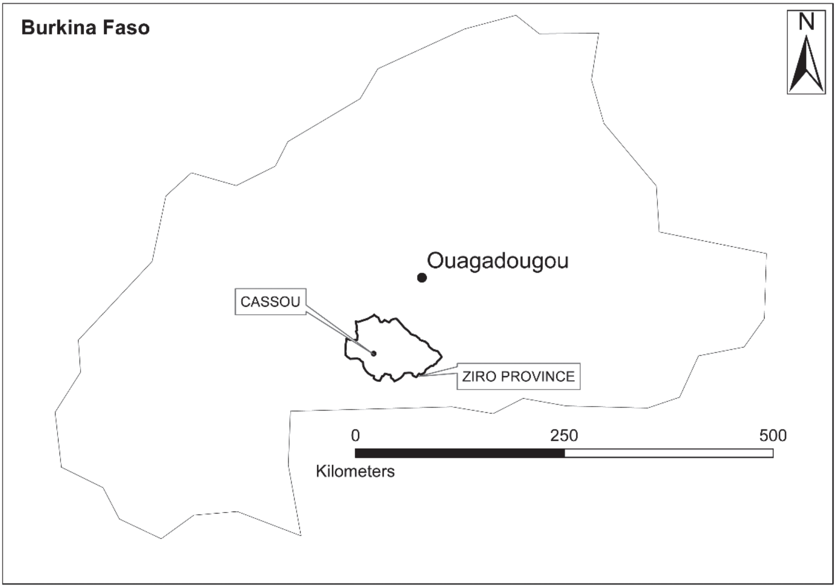


Figure 2. Cassou commune in the Ziro province and capital city Ouagadougou, Burkina Faso (Puentes Rodriguez et al., 2016).

Data collection and analysis

In order to collect the data for the fuelwood VCA, a questionnaire survey was implemented during June–October 2015 among the main stakeholders within the five identified processes (Figure 1). "Snowball", a non-probability sampling method (for more information see Voicu & Babonea 2011), was used for selecting the respondents. Harvesters and collectors were interviewed in Cassou village, transporters and traders in Ouagadougou, and consumers in both locations. The questionnaire consisted mainly of closed questions to obtain quantitative and qualitative information such as:

(i) type and number of species used for fuelwood,
(ii) quantity and price of fuelwood in each process,
(iii) formality of activities, and
(iv) self-consumption and commercial trading of fuelwood.

In addition, the main issues and challenges faced by the actors along the chain were also included in the survey. The analysis was carried out with descriptive statistics (IBM SPSS and Microsoft Excel Spreadsheet), considering economic (i.e. fuelwood prices), environmental (i.e. tree species for fuelwood) and social (i.e. gender) aspects as well as the formality of the processes, among other things.

4.3.2.2 Main results from fuelwood VCA

The most relevant information obtained from the fuelwood VCA is summarised in Figure 3 (modified from Puentes Rodriguez et al., 2016). The main observation was the presence of an informal chain (except for harvesting process). According to the analysis, the formality level decreases from the initial processes (harvesting) towards the final one (i.e. trade). It was also observed that most of the fuelwood processing activities (i.e. harvesting and collection) appeared to be mainly carried out by men. On the other hand, women play an important role in the transportation and trade processes, especially in the informal chain.

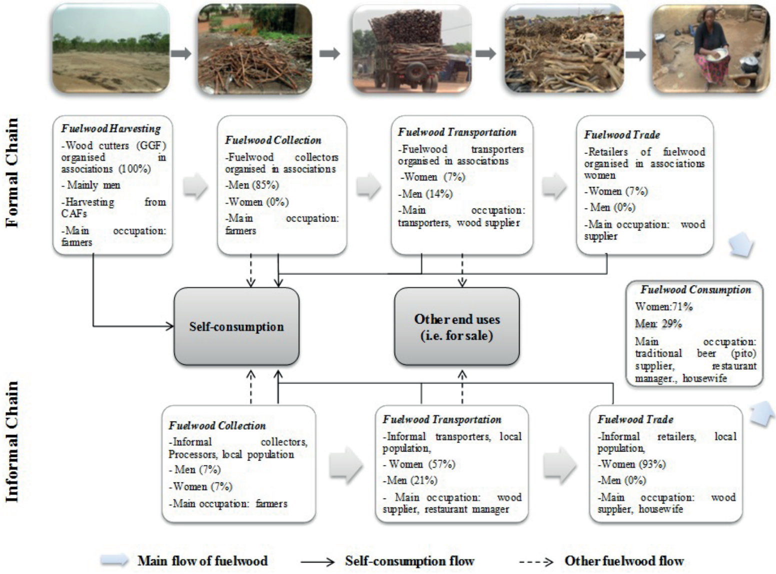


Figure 3. Fuelwood value chain graph (modified from Puentes Rodriguez et al., 2016).

In economical terms, the fluctuation in fuelwood prices was clearly identified along the chain (Figure 4); in fact, this was defined as one of the economical challenges faced by the main VC actors (Puentes Rodriguez et al., 2016). The informal nature of some of the processes together with the outdated official prices (established since 1998) may explain this variation. Nevertheless, this varies depending on the process; for instance collectors considered wood prices to be low (selling price), while for traders the fuelwood price was high (buying price).

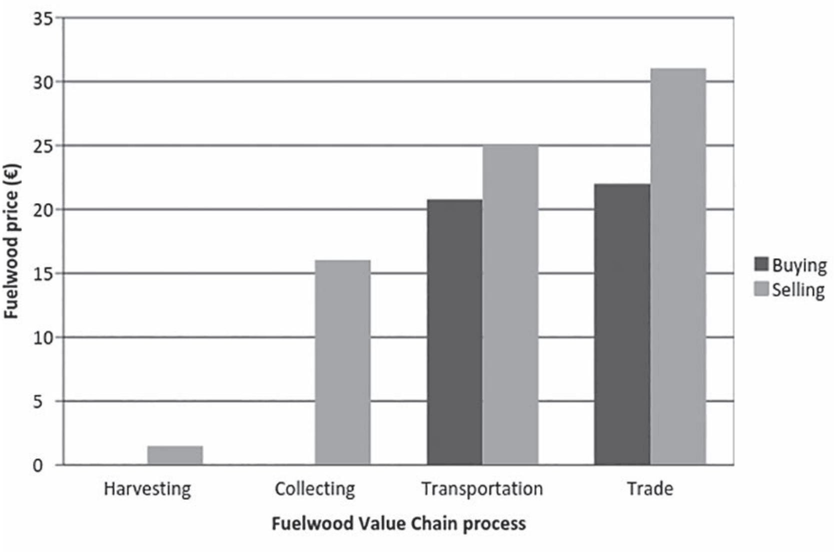


Figure 4. Trading prices (€) of fuelwood within the VCA in Cassou and Ouagadougou.

The analysis also showed the most preferred tree species for fuelwood according to the interviewees. As shown in Figure 5, *Detarium microcarpum*, *Crossopteryx febrifuga* and *Anogeissus leiocarpus* were identified as the most preferred ones. *A. leiocarpa* and *D. microcarpum* were also identified as the most sold according to the fuelwood traders together with *Vitellaria paradoxa*. According to the study carried out by Melin et al. (2016) in the Cassou area, *A. leiocarpus* was the most common species found in the study. *V. paradoxa* and *D. microcarpum* were also included in the second group of the most common species in their study (Melin et al., 2016). Although the forest area is rich in wood species, anthropogenic pressure, livestock and forestry have driven the scarcity or even disappearance of some of the wood species (Tondoh & Degrande 2015). In fact, the scarcity of natural resources was identified by most of the interviewees as the only ecological problem within the fuelwood VC (Puentes Rodriguez et al., 2016).

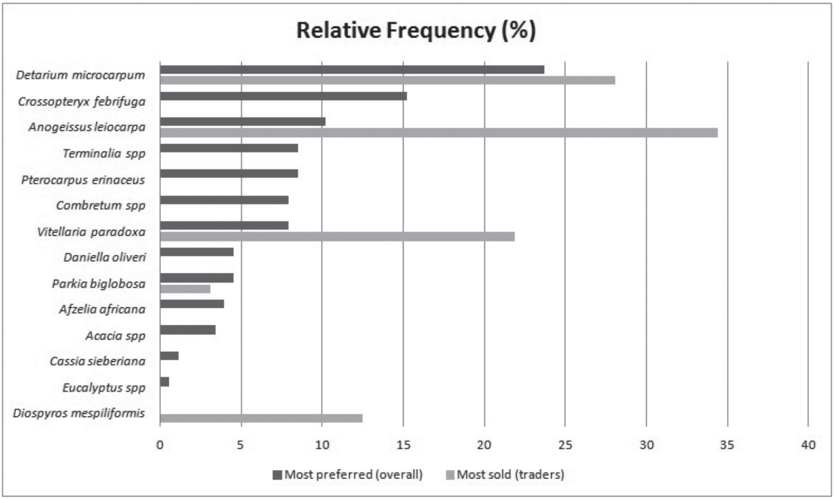


Figure 5. Most preferred and sold tree species for fuelwood (relative frequency %).

4.4 What can be concluded from the fuelwood VCA in Burkina Faso?

This analysis of fuelwood VC in Cassou and Ouagadougou represents an overview of the current situation in the whole country. According to the main findings, it is clear that there are many issues that need to be addressed to achieve a more sustainable fuelwood management. One of the crucial points is related to the formality of the process, which should be extensively considered together with all the actors, processes and flows.

In terms of social impact, it is clear that women are playing a key role in the fuelwood VC; however, formality of the processes may change the situation. For instance, women are collecting fuelwood for personal use, which is not completely reflected in this study since men were the main collectors. Formality may also have an impact on the economical side of the VC, since it is not possible to get a real picture of the situation when many activities are not controlled and price fluctuations may be a result of such phenomenon. And lastly but not of least importance, the environmental impact due to informal activities should also be considered since there is no control over fuelwood exploitation within the informal chain and subsequently there is no proper management plan to be followed.

In the above context, the main recommendation for a sustainable, eco-efficient fuelwood production and consumption in Burkina Faso, in line with the bioeconomy concept, is to develop and implement new strategies, action plans and practices to be fully able to create a sustainable wood energy management plan addressing also proper land use management and land tenure policies. It is necessary also to create a fuelwood market policy (i.e. update the current fuelwood prices) and create awareness among local people (i.e. through education) of the forest resources management and also of the business opportunities in the field. In this way, they should understand and consider the effect of their actions on the environment, their livelihoods and welfare.

4.5 Strategic forest planning as a tool for promoting sustainable use of forests

4.5.1 Need for participatory strategic level planning

Forest energy cannot be separated from other uses of forests. For example, collecting energy wood might affect forest biodiversity, establishing wood energy plantations always has effects on land use, and thus, on other uses of forests, and producing charcoal has its effects on deforestation and the environment in general. From the viewpoint of regional economy and people living in the region, use of forests should be understood as a combination of all forest uses, which are important for the stakeholders in the region. More generally, social sustainability of forest use requires that different forest uses are taken into account in a way accepted and preferred by stakeholders. Otherwise, implementation and controlling of forestry actions is a very challenging task. Without achieving the requirement of social sustainability, no goals related to other dimensions of sustainability – i.e. economic and ecological sustainability – can be met.

Many forest energy projects carried out throughout the world are very local and short-term by their nature. However, decisions considering the use of forests have long-term effects over wide geographic areas and they impact significantly on local communities. That is why considering the sustainable use of forests requires larger scales and longer time periods in planning, i.e. *strategic planning*. Furthermore, forest management decisions on the utilisation of forest resources often have significant impacts on different forest-user groups, i.e., local communities, local people's livelihoods, and many others (e.g. Martin et al., 2000 and Hytönen et al., 2002). That is why *participatory strategic-level planning* has become an important tool for promoting sustainable forest management particularly in publicly (state-) owned forests (e.g. Buchy & Hoverman, 2000 and Sheppard, 2005).

Enhancing social sustainability has been often strived for by participatory planning, and social sustainability has been often interpreted to include the employment of local people, the status and living conditions of indigenous people, as well as wide participation possibilities in the planning process, and the broad acceptance of its results. Participatory planning may also be used in mapping out the risks of conflicts between the different participants and avoiding unnecessary conflicts, sharing information between participants, and promoting good relationships in the operational environment of the planning organisation (e.g. Hellström, 2001 and Kangas & Store, 2003).

4.5.2 General steps of participatory strategic level planning

The general level planning steps (planning process as whole) consist of (e.g. Keeney 1982):

(i) structuring the decision problem,
(ii) defining decision alternatives,
(iii) assessing the possible impacts of each alternative, and
(iv) determining the preferences of the decision maker(s) and other participants and comparing and evaluating the decision alternatives.

The actual decision is made separately, based on the decision support produced in the planning process.

Planning methods for carrying out the planning process can be divided to *aggregative* and *dis-aggregative* planning. The main differences among these approaches are related to rationality assumptions, primary aim of the process and approach for supporting comparison of alternatives (Table 1).

Table 1. Characteristics of aggregative and dis-aggregative planning.

Rationality assumption	Human scientific ideal and on the communicative rationality	Natural scientific ideal and on the instrumental rationality
Primary aim of the process	Describing decision situation in a versatile and illustrative manner	Showing the best possible option
• supporting comparison of alternatives	• describing impacts with a measure typical to each of them. Monetary impacts only one possible dimension of impacts • creating a common knowledge base for decision making • encouraging stake-holders to consider alternatives on the basis of their own values • supporting a discussion in order to find a course of action that is agreeable to all stake-holders	• measuring all possible consequences with single measure (money, points etc.) • integrating different impacts having different measures • integrating impacts irrespective of time with discounting calculations • integrating impacts to different stake-holders

Aggregative planning calls for using methods like cost-benefit analysis or value/utility function definition, which, in turn, requires profound education for use of the method. As such, aggregative methods are technically more efficient for supporting decision making, but adopting them for actual use calls for profound education and also better educational background of the participants. In dis-aggregative planning, there is no need to estimate monetary values for different forest uses nor constructing technical decision analysis models. Hence, in many actual planning cases adopting a dis-aggregative planning approach is much easier than using aggregative decision support systems. In this chapter we introduce an example of implementing a participatory strategic level planning process by using a dis-aggregative planning process and corresponding methodology in Finnish Lapland (Hiltunen et al., 2009). In our example, we focus on the most important steps of participation, i.e. determining the preferences of the decision maker(s) and other participants and comparing and evaluating the decision alternatives.

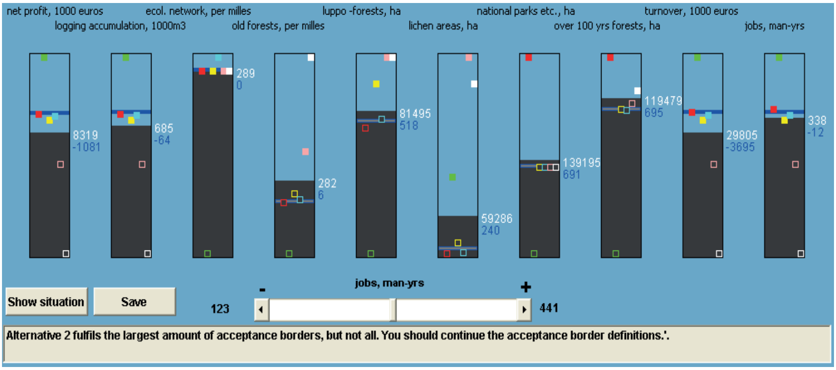
4.5.3 Planning example

Selection among alternatives can be seen as the core of planning. In our planning case, the alternatives were produced by first discussing about goals for forest management in the area and then producing discrete alternatives where the realisation of these goals was varied. The alternatives were produced by using forest inventory data, GIS systems and simulation-optimisation systems. A total of seven alternatives were finally included in the analysis (Table 2).

Table 2. The outcomes of the strategy alternatives in terms of the selected evaluation indicators.

	Basic	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7
Total net income, € million year^{-1}	9.4	9.4	12.2	9.1	9.3	6.9	2.4
Sustainable allowable cut, 1000 m^3 year^{-1}	749	747	944	721	741	535	156
Ecological network, % of productive forest area	28.9	28.9	24.6	28.9	29.2	28.9	28.9
Forests clearly older than their regeneration age, % of forest area	27.6	27.6	25.9	27.9	27.7	29.3	32.4
Forests characterised by beard lichen, ha	80,977	80,572	72,094	83,522	81,131	85,279	85,279
Lichen areas, ha	59,046	59,007	59,633	59,097	59,022	60,593	60,382
Scenic areas and recreation forests and national parks, ha	138,504	158,995	122,213	138,506	138,508	138,509	138,510
Forests older than 100 years included in above forests, ha	118,784	122,768	107,977	118,916	118,825	119,309	120,297
Gross turnover of Metsähallitus, € million year^{-1}	33.5	33.7	42.7	32.4	33.2	25.0	10.1
Employment opportunities offered by Metsähallitus, man-years	350	357	440	339	347	269	124

In our planning case, we used an application of parallel coordinates called MESTA for dis-aggregative and interactive evaluation of the strategy alternatives. The MESTA system helps the participants to directly and holistically evaluate the decision alternative without any mathematical aggregation. Planning participants define so-called *acceptance borders* that divide the alternatives into acceptable and not acceptable with respect to each decision criterion and, after that, they adjust the acceptance borders as long as at least one alternative has been accepted with respect to all criteria. The planning participants may also use the intermediate values between the original alternatives as their acceptance borders. In our case, the participants first defined their own acceptance borders independently, and after that the participants worked as a group for finding out *a solution accepted by all the participants.* The result of the negotiation and the acceptance border definition process was that alternatives 2, 4 and 5 and the basic alternative could be accepted (see Figure 6). This result satisfied the group and, in further discussion, the group ended up recommending the implementation of alternative 5.



Alternative 2 fulfils the largest amount of acceptance borders, but not all. You should continue the acceptance border definitions.'.

Figure 6. User interface of the MESTA system.

As a whole, the method proved to work well in actual participatory strategic level planning. It was easy to use and understand, and it can be used over the Internet. It supports learning the connections between the criteria values in different alternatives and it works as a good tool for supporting negotiation. The same benefits of the MESTA method might be realised in the context of Western-African strategic level planning cases. However, evaluating the real applicability of the MESTA method in West-Africa would require testing of the method in actual planning cases.

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CHAPTER 5

Views on sustainability

Sari Pitkänen, Piritta Torssonen, Antti Kilpeläinen and Markus Melin

5.1 Introduction

Sustainable forest management and use of forest resources balances environmental, socio-cultural and economic objectives of management according to the "Forest Principles" adopted at the United Nations Conference on Environment and Development (UNCED) in 1992. Sustainable forest management increases benefits both for people and environment, but also considers forest degradation and deforestation. Socio-culturally and economically sustainable forest management contributes to livelihoods, income generation and employment. Environmentally sustainable management contributes to important ecosystem services that are e.g. related to carbon and water cycles, soil and air condition and biodiversity (http://www.fao.org/docrep/015/i2763e/I2763E04.pdf).

In Africa, the vast majority of the population, especially in rural areas, is dependent on traditional biomass harvested directly from the forests for cooking and heating. In the poorest countries, more than 80% of energy comes from traditional sources such as crop residue and wood (UNDP 2003). The overuse of forests leads to deforestation and environmental degradation (Janssen et al., 2009, Mangoyana 2009). As there exist complex links between poverty and the environment, improvements in bioenergy systems based on wood energy are therefore generally of importance in Africa. The development of bioenergy systems may offer opportunities for investment and infrastructure to promote socio-economic development and to improve sustainable forest management and climate change mitigation. To achieve lasting results in sustainable development, it is of crucial importance that policies and development plans related to wood-based energy are implemented in African countries to ensure environmentally, economically and socially sustainable bioenergy.

Also in the Nordic countries, forests are the most important renewable resource but they also act as carbon sinks. For example, in Finland forest cover is more extensive than in any other European country, i.e. 86% of land area is covered by forests. In Finland, the annual increment of growing stock has been higher than the annual drain for many decades (Finnish Statistical Yearbook of Forestry 2013). In the Nordic countries, because forest management is generally done at stand level, forests constitute mosaics of single stands of varying site fertility, tree species composition, age structure and volume of growing stock. To obtain a long-term sustainable flow of timber from the forest region, an even aged stand management in forests has been a long-term target in forest policy. In Finland, forest management practices are guided by Recommendations for forest management done by Forestry Development Center Tapio. Recommendations are specific for different tree species, site fertility types and regions of Finland. Recommendations consider all three criteria of sustainability (economic, environmental and social) and are in line with Finnish law of forests, conservation, wild areas, and land use and construction.

In the BIODEV project, the sustainability of wood-based energy was assessed in the working group of WP1.4 by conducting case studies in the West African countries of Sierra Leone and Burkina Faso. These studies integrated information on the inventory of biomass and forest resources, charcoal production and questionnaires for the local people. In the following chapters, views on sustainability are elaborated on by giving some example calculations on important factors affecting the production and use of fuelwood in Sierra Leone and Burkina Faso and setting possible strategies to improve the sustainability of wood-based energy not only in these countries but also in the whole of West Africa.

5.2 Sustainability assessment of wood-based energy in West Africa

5.2.1 Method development for calculations of fuelwood sustainability

The vision is to develop sustainable fuelwood management in West Africa to help rural people meet challenges of deforestation and climate change. The key part in here is to assess the current situation of fuelwood use, the whole value chain, and to understand what the weakest links in the chain are. Thereafter, this can be contrasted with how the situation could be; what is the best-case scenario and what would the benefits be if the current methods are made better and adjusted towards sustainability (Figure 1)?

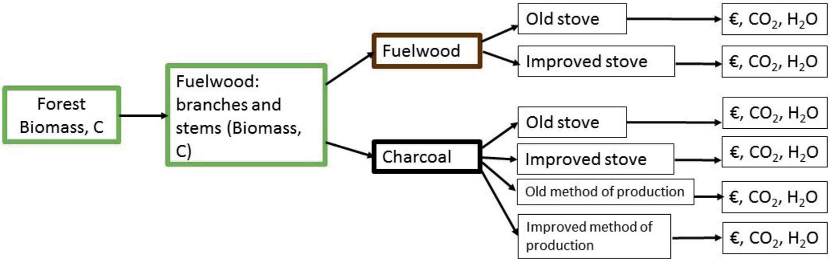

Figure 1. The chain beginning from the forests and ending in the final use of fuelwood as either fuelwood or charcoal. The chain shows the two routes (current and more efficient one) that, based on the BIODEV research, can now be analysed and contrasted with one another.

The two main uses of wood for energy in both countries are fuelwood and charcoal. In numbers, fuelwood is the dominating one and it is commonly the fuel for rural areas while charcoal is used in cities. Yet, charcoal production takes place also in rural areas. That is, the wood for charcoal is being harvested from the rural areas, which are also the sites where deforestation occurs. The questions that can be raised from the chain in Figure 1 can now be formulated. If both fuelwood and charcoal processes are made more efficient:

1.) How much more energy can be produced with the more efficient methods? What is the value of this energy in terms of income for the producers?
2.) How much forest can be saved when the processes are more efficient? What is the outcome of this in relation to CO_2 emissions or to the levels of deforestation?

And to tackle the main vision outlined in the beginning:

3.) What if both countries would establish designated forest areas for sustainable and well-managed production of wood energy? What would be their impacts on the issues mentioned above?
4.) What would be the impact of this on the countries' CO_2 emissions?

Questions 1 and 2 – More energy, more forests.

The BIODEV project addressed these issues with studies conducted on the use of improved stoves and improved charcoal production methods. And, as we know the numbers of Question 1, we can link this to the forests. If energy production is more efficient, then fewer trees are needed to produce the same amount of energy. In this way, how many hectares of forest does this save?

The studies on the use of improved stoves have reported as high as 29–43% decreases in the amount of wood consumed (Arevalo 2016, Bensch et al., 2013). Here, we will continue with an assumed decrease of 30%. For consuming charcoal, the improved stoves have been reported to decrease charcoal consumption by up to 15% when compared to the usual stove used for charcoal burning (Bensch et al., 2013). We will continue with an assumed decrease of 10%. The BIODEV studies on the effects of improved charcoal production were conducted in laboratory with designated pyrolysis device that outputted all the figures (temperature, gas content, end product contents) in numbers. This allowed estimating the effects of the raw-material and its quality on the end-product (charcoal) and its quality (energy content). The factors that contribute to the end-product (charcoal) and that can be easily controlled are moisture of the wood and particle size; the size of the wood chunks that are to be charcoaled. The BIODEV study found that by properly drying the material and by using wood chunks of uniform size, the gain of charcoal can be easily increased by over 10% (Vilppo 2016). The figures of more efficient methods are now:

- Use of firewood can be decreased by 30% with improved stoves (at least)
- Use of charcoal can be decreased by 10% with improved stoves (at least)
- Charcoal yield can be increased by 10% with better production methods (at least)

When these numbers are related to the fuelwood use, the figures start to look promising.

According to past studies, the average fuelwood consumption in an average rural household can vary between 14–25 m^3 $year^{-1}$ (Arevalo 2016, Degrande 2016, Puentes-Rodriguez et al., 2016). With proper use of the improved stoves, these figures could be decreased to 9.8 and 17.5 m^3 $year^{-1}$. In the future, we will keep the consumption figures of 14 and 9.8 m^3 $year^{-1}$as a baseline for the comparisons.

Question 3 – Sustainable forest management. As stated, improved production processes do not mean anything if the forest production itself is not efficient. An ideal chain would be one where either Sierra Leoneans or Burkinabe would manage their forests from nursery production to planting, to harvesting and back to regenerating them; all in a sustainable manner and, more importantly, in a manner that would boost the productivity of the forest lands into new levels (Figure 2). The locality of the chain would bring jobs, income and development to the rural areas.

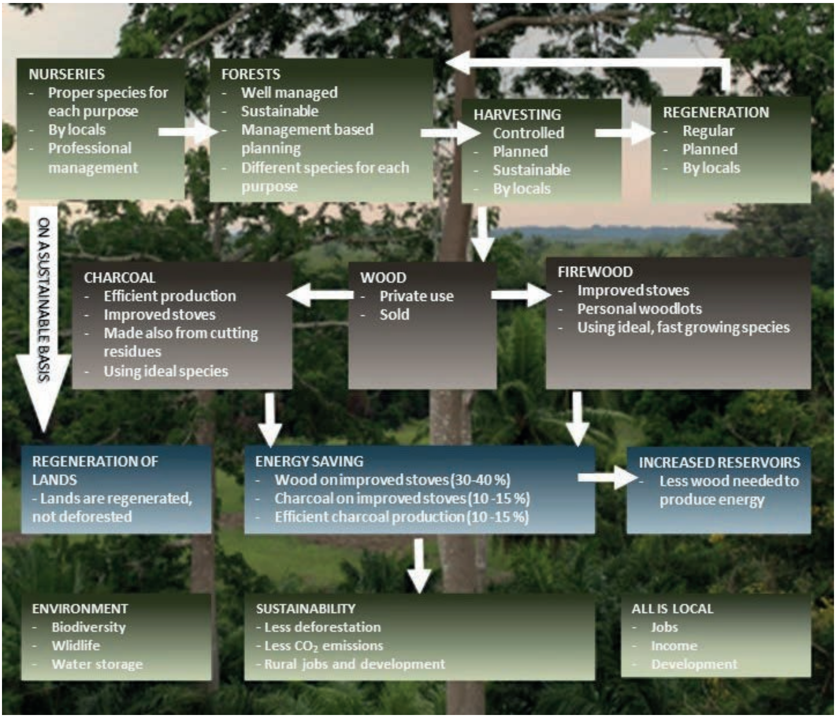

Figure 2. A flowchart depicting the ideal way of managing the forests and producing income, products and development on a sustainable basis.

Based on the conducted trainings and interviews, the keys to achieving this would be more efficient agriculture (to decrease the % of agricultural land) and land use policy and obviously further training and capacity development on the actions within the whole chain of sustainable forest management.

Question 4 – CO_2
If **Question 3** would be a success, the consequences would be not only local, but global. When forestlands are regenerated on a regular and sustainable basis, they naturally do not deforest and become degraded. This decreases the CO_2 emissions that result from deforestation. Current (1990–2010, mongabay.com) levels of deforestation in Burkina Faso are estimated at 59,000 or 14,000 (2001–2014, globalforestwatch.com) ha year^{-1}. In Sierra Leone, deforestation has been accelerating at an alarming pace. The estimates vary, but current ones suggest that the country loses forests at a pace from 19,000 (1990–2010, mongabay.com) up to 36,000 ha year^{-1} (2001–2014, globalforestwatch.com).

5.2.2 Example calculations on fuelwood sustainability in target countries

In the BIODEV project, the target countries were Burkina Faso to represent arid forest areas and Sierra Leone to represent more fertile tropical forests. The BIODEV field measurements were conducted in the Ziro province (Burkina Faso) and Bombali district (Sierra Leone). Ziro province has a population of 207,079 (2011) and a land area of 513,900 ha. Bombali district has a land area of 798,000 ha and a population of 606,183 (2015). Studies on the use of fuelwoods suggest that only a few per cent of the population are using charcoal while a clear majority is using fuelwood (Arevalo 2016, Deakin et al. 2016, Degrande 2016, MEF 2006, UNDP 2012). We will now work with figures of 95% for fuelwood and 3% for charcoal. It is important to consider the above-mentioned Questions in the context of the target countries concerning energy and the effect on CO_2 emissions.

5.2.2.1 More energy, more forests

Burkina Faso. The managed CAF forests are established to secure higher stem count and volume when compared to the noCAF forests. This kind of a forest (the CAF forest) can be assumed to produce about 2 m^3 ha^{-1} of wood, which can now be regarded as the sustainable harvest level (Arevalo 2016, Nygård 2003, Renes 1991, MASA 2013). Now, the province (Ziro) has 207,079 inhabitants, distributed into approximately 29,000 households. Of these households, 95% use fuelwood, which means that the annual fuelwood consumption in the province is around 385,000 m^3 of wood year^{-1}, which could be decreased to 270,000 m^3 with as simple method as using improved stoves. To sustainably harvest 385,000 m^3 annually would require approximately 190,000 ha of managed CAF forests, which with the improved stoves could be decreased to 135,000 ha (22% of the Ziro province land area). It must be noted that the current CAF area is around 30,000 ha and most fuelwood from the area goes to the capital city Ouagadougou, where it is turned also into charcoal. The improved charcoal methods and improved stoves could thus further decrease the area of forests needed to provide the amount of wood sold to the capital. It is clear that the unmanaged lands do not produce the same amount of wood as the CAF lands, which in turn clearly explains the current rate of deforestation in the area: forests are being harvested for private fuelwood needs, but they are not re-generated. Due to the huge over use (fuelwood cuttings) of the noCAF forests, the productivity of these lands is nowhere near to what it could be. Improved stoves or improved charcoal production methods cannot help here.

Sierra Leone. In the Sierra Leone site, the forests inside the reserve area showed just how high volumes of wood the forest can produce if not disturbed. This is a similar finding to Burkina Faso: the forest productivity could be significantly higher, which would be key when battling deforestation and aiming at sustainable use of the forests. The Bombali district had a population of ~600,000 inhabitants distributed into ~85,000 households. Based on the Degrande (2016) interviews, this means that the annual consumption of fuelwood in the district is around 1,100,000 m^3 of wood $year^{-1}$, which with the improved stoves could be decreased easily to 790,000 m^3. The forests that grow on Kuru Hills can be expected to reach annual productivities easily as high as 15 m^3 ha^{-1} (even 35 m^3 ha^{-1} has been reported from Eastern Sierra Leone) (Millington 1994). With the productivity of 15 m^3 ha^{-1}, it means that the district would need ~53,000 ha of sustainably managed forests, which is only 8% of the district's land area.

In sum, improved stoves and improved charcoal production methods are good steps towards sustainability. However, their effect is absolute zero if the forest areas are not managed on a sustainable basis. It does not make the situation better to say that “with the improved stoves we can halt deforestation by 0.1%”. It would be better to say that with sustainable forest management we could stop deforestation and introduce reforestation.

5.2.2.2 Sustainable forest management

When considering the workflow in Figure 2 and the figures outlined in Questions 1 and 2, sustainable forest management should be realistic in the target countries: in Sierra Leone the Bombali district would have to designate a mere 10% of the land area to sustainably manage forest production and the same figure for Ziro in Burkina Faso is about 30% (it must be higher than the 22%

mentioned, because the area also produces fuelwood for the capital). These percentages are a fraction when compared to the forest cover of e.g. Finland or Sweden.

5.2.2.3 CO_2

Burkina Faso. In Burkina Faso, the managed CAF forests had an average volume of ~22 m^3 ha^{-1}, which (with their tree densities) gives an estimate of ca. 15 t ha^{-1} of woody biomass, which, in turn, equals to 7.5 t ha^{-1} of carbon. This number equates to ~27.5 t of CO_2. With an area of 100,000 ha, it would mean that the forests would sequester 2,750,000 t of CO_2 in them. Naturally the forests would be used as well for fuelwood burning, but through forest growth about 250,000 t more of CO_2 would be sequestered into forests each year (growth is around 2 m^3 ha^{-1} (total of 200,000 m^3)). In points 1 and 2, the calculations showed that managed forests could produce enough wood to meet the demand, but also that there are potentials to make the balance positive so that the growth of forest area and the forests is higher than the harvest.

Sierra Leone. In Sierra Leone, the situation is even better due to high growth of the forests. The deforestation is high, but it also could be stopped and turned into reforestation very promptly due to high productivity of the forests. In a forest with an area of 100,000 ha, the mentioned annual growth of 15 m^3 ha^{-1} would equal an annual sequestration of almost 2,000,000 t of CO_2 in the trees. In addition, the balance would be highly positive since the growth of Sierra Leonean managed forests exceeds the demand easily. Furthermore, in the best regions of the country the annual growth of forest can even reach 35 m^3 ha^{-1}. In sum, both of the countries have good possibilities for shifting the balance of their CO_2 emissions.

5.3 Views on sustainability from the locals

Both target countries had rather similar problems when it comes to planning and management of forest resources. It was therefore no wonder that the local views on what could and should be done better did not differ that much either. Within the BIODEV WP 1.4, trainings were organised around the theme of sustainable forest management. These trainings were held at Njala University (Sierra Leone), Makeni (Sierra Leone) and the University of Ouagadougou (Burkina Faso). The target audience ranged from field technicians to students and professors. Discussions and exchanges of opinions proved to be a by-default component of the trainings and these discussions provided valuable insights into what the participants perceived as halting the development of their forest sector. This chapter summarises the views of the locals, who were either working in the field of natural resources/forestry/environmental sciences or studying the subjects.

Lack of reliable data – National Forest Inventories. The target countries do currently suffer from deforestation. That is a fact. Yet, just at what rates the forest is being lost and how does the land cover change from thereafter are questions that are without an objective answer. They could be answered through national forest inventories. Burkina Faso has launched national forest inventories, but the results are yet to be announced. Sierra Leone has no on-going forest inventories. The views were simple here: proper and objective data about the status of the forests would form the base stone above which to build forest policies and management plans. This was seen as a concrete development, which could be easily attainable in practice given the required resources.

Education. Education at all levels, from the field workers and elementary schools to universities, was seen of decisive importance. Since forests and wood in particular is highly important for the rural people, they and their children should be educated in properly using these resources and in managing them in a sustainable way. The education, however, should also reach the current leaders and politicians so that they would be able to see and understand the problems, which would provide the base knowledge for making the decisions that can aid in solving the problems. Here, a recommendation was also that there should be an organisation that can provide local aid in their own area for practical issues such as tree planting, forest management etc. – “practical education”.

Land and forest ownership – Motivation for the private people. This was identified as a very current and practical problem. If the private people would be allowed to more easily own and manage their lands, they would have the motivation to manage them on a sustainable basis simply because they would be the ones who benefit from the resources they manage: growing the wood, selling the wood etc. Figure 3 shows an example of abandoned land where currently there is no farming, but no active re-planting of forestry either.

Figure 3. Land in Southern Province of Sierra Leone that was once cultivated is now left out of all activities for most parts. There were no clear signs of large-scale agriculture nor forestry.

Forest policy and law – governance. Both of the countries have published official papers on both forest policy and law. However, the locals felt that these are literally just words on paper that have not been turned into practice, or at least not as efficiently as expected. Also, even if the policy and law would be adequately spelled out, there would be no effect unless they are governed properly. Here, the participants had their views on a system where the *local* forest authorities would know what is going on in their own area: forest owners (private, community or company) would report all activities such as planting, thinning, harvesting etc. to this authority (how much, where, when, by whom). When discussing these matters, a common view was that there was no serious commitment among the country leaders to these issues. As one of the participants in Sierra Leone put it: "In Sierra Leone, we seem to know all the solutions and everything that should be done, but for some reason nothings ever gets done."

This view, in fact, summarised the points presented here very efficiently. The professionals in the countries know what needs to be done, but they have neither the means nor the resources to do it. Also more political support would be needed.

5.4 Means to improve the sustainability of the wood-based energy in Sierra Leone and Burkina Faso and in West Africa

The following issues concerning West Africa can be concluded:

1. There is a huge need for development of forest policy and forest law. Basically these countries are lacking the monitoring of nature and forest related laws. In addition, clear decisions on how to improve the position of the poorest people are needed since the situation is not going to be changed until each family has proper conditions and possibilities for living. The questions on land use play an important role in this: the rural/local people must be able to trust that the resources (money, work in tree planting etc.) they put to the surrounding area are able to benefit their own everyday life in the near future. There is a need for an agency to provide help to the forest- or landowners who have the desire to manage forests, but not the knowledge to do so. The lack of knowledge at the moment is a big obstacle preventing the development of forest management in the rural areas. The help should be done at the practical level, while the professionals providing this help

would have ideally gained their experience and skills at a higher education institute providing teaching and training in forest sciences.

2. A systematic national forest inventory must be started to be able to follow the changes in woody biomass and a more public system, especially in the sharing of the inventory information (e.g. for researchers), to assess the situation and to provide teaching and decision making with the latest data.
3. Training at all levels is a key factor; there is a huge need to increase capacity and knowledge of village people, farmers, forest managers, wood sellers, researchers, teachers, businessmen, politicians and decision makers to fully understand and acknowledge the reasons to the forestry and energy problems in their countries as well as to accept and adopt the methods and knowledge of how to improve the situation. The capacity-building via training should be practical and it should include all the mentioned aspects so that the future generation would then have the right knowledge and the skills to continue the teaching to the next students and future foresters and managers.
4. Improved and modernised teaching at all levels of education from primary schools to universities concerning climate issues, biodiversity, forests and forestry etc. In this BIODEV project the working group of WP1.4 took the first step by training the staff of Njala and Ougadougou Universities in sustainable fuelwood management and also by publishing a study book for universities.
5. Need to build up a strategic plan for sustainable fuelwood management; in this paper this work is started and the recommendations of the WP1.4 working group are presented.
6. Need to improve charcoal production to more effective to reduce the energy loss in the process. The suggestions made in the BIODEV project should be studied further and be modified to answer each local situation.
7. Need to combine agroforestry and fuelwood production to increase easy access fuelwood plantations and income for farmers (producing and selling fuelwood in the area).

For Sierra Leone, the need for basic research is urgent: research on the usability, management, growth and properties of different tree species: what species suits for which soil and site type etc. What is best for timber, what for fuelwood, how to grow and manage them, how to develop growth models etc. The country's vast species diversity in trees makes this task difficult, but all the more interesting and worthy of pursuing at the same time. For Burkina Faso, the situation regarding the skills on managing forests is somewhat (based on the views gained) better, but as the country is closer to Sahara, the forests do not do as well as in Sierra Leone. The situation is here somewhat flipped since Sierra Leone's forests grow at a rapid rate and would produce huge amounts of wood if they were only managed even a fraction better than now. In Burkina Faso, the forests grow very slowly when compared to Sierra Leone even though they would be managed according to best practices. Here, the need for developing management is crucial to cut the desertification chain.

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The Biocarbon and Rural Development project (BIODEV) is an initiative to achieve developmental and environmental benefits accrued from natural carbon through improved agroforestry and forestry management and tree planting. This is referred to as “high-value biocarbon development”. Launched in Bamako in 2012, BIODEV represents an innovative approach aimed at improving integrative land management models for improved livelihoods in arid and humid zones of West Africa. The four-year project, funded by the Government of Finland, aims to generate information that is critical for linking climate change mitigation with efforts aimed at helping people adapt to climate change in Burkina Faso, Mali and Sierra Leone.

Large data sets have been collected in Burkina Faso and partly in Sierra Leone to support significant progress in understanding drivers of land degradation, impacts of climate change as well as changes in social and economic contexts. This knowledge guided the interventions in agroforestry, forest management and improved energy systems to promote biocarbon and many related ecosystem services. Thus BIODEV has created transdisciplinary work at multiple scales that lead to development of good practices and replicable tools for biocarbon interventions. BIODEV is implemented by the World Agroforestry Centre (ICRAF), the Center for International Forestry Research (CIFOR), the University of Eastern Finland (UEF) and the University of Helsinki (UH) in collaboration with national organisations and government ministries at national and local levels in the three countries in which BIODEV works (Burkina Faso, Sierra Leone, and Mali).